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**SVC Partners with International Conferences in 2010**



# Bulletin

Spring 2010  
[www.svc.org](http://www.svc.org)

A Publication for the Vacuum Coating Industry

## TechCon Orlando

### *Session Highlights from the 2010 TAC Chairs*

*Plus! A New Technology Review Session,  
Business Topics Program and Unique  
Networking Opportunities*

## *Original Contributed Articles*

- *Oblique Incidence and Dielectric-coated Metals*
- *Advanced Pulsed DC Technology for Material Processing Applications (Part 4)*
- *Update on the Solar Photovoltaic Industry*

### *From the 2009 Proceedings*

*Mass/Energy Analysis of a Modulated Pulse Power Plasma  
Compared to a DC Plasma*

*In Situ Spectroscopic Ellipsometry for Atomic Layer Deposition*



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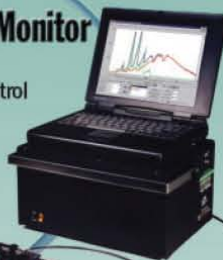


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## Bulletin

Spring 2010  
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### About This Publication

Deadlines for advertisement space reservations: Spring: January 5  
Summer: June 1, Fall: September 1

### On the Cover: Chiral Sculptured Thin Films

Sculptured thin films are composed of three-dimensional nanostructures, which grow in a self-organized process using an oblique angle for the particle flux accompanied by a synchronized substrate movement. The material properties can be designed by control over size, shape and nanostructure arrangement. For more information, contact Eva Schubert, University of Nebraska – Lincoln (402/472-1697; [evaschub@engr.unl.edu](mailto:evaschub@engr.unl.edu))

Photo: Daniel Schmidt, University of Nebraska – Lincoln

## Letter | from the President

Most of you know that I was born and brought up in Scotland. The Scots, and particularly the highlanders, are cautious folk. My grandfather, for example, would never state an intention to do something significant without qualifying it with "If I'm spared." This Scottish caution extended to the New Year celebrations. Calendars for the coming year would never be displayed until the year had actually begun. It was considered bad luck to wish anyone a Happy New Year before the first of January. If you wanted to wish someone well beforehand, you would use a form like "A Happy New Year when it comes." So, now that the New Year is well and truly here, let me safely wish all of you a Happy, Healthy and Prosperous New Year.

2009 was a difficult year for all of us. Making it immensely more difficult was the loss of two very good friends, John Reading and David Cushing, both strong and long-term supporters of the Society of Vacuum Coaters.

John, who was Director of Special Products at Tico Titanium, in Michigan, for many years, was born and educated in Britain. He had



*Drawing from his extensive background in thin films, David Cushing had collaborated with local Tucson artists creating colorful aluminum sheeting art using a multilayer thin film deposit technique. The brilliant colors are achieved by varying the coating thickness using an industrial vacuum coating machine.*

the most incredible knowledge of Scotch Whiskey, quite eclipsing that of anyone else I have ever known. He delighted in sharing this knowledge, and in arranging tastings where he would explain the mysteries. I learned a great deal from him.

Dave was one of that select group who began their careers with Edgar Barr. He was the first to set up a truly successful production unit for DWDM filters. When he retired to Tucson, AZ, he installed a machine in the College of Optical Sciences and went back to

work, reporting his efforts on decorative coatings at the 2009 Santa Clara SVC Technical Conference.

We shall miss them so much.

Angus Macleod, Thin Film Center, Inc.  
(520/322-6171; [angus@thinfilmcenter.com](mailto:angus@thinfilmcenter.com)) is the SVC President.

To read more about John Reading and Dave Cushing, see page 62 or visit the In Memoriam section of the website at [www.svc.org/about/SVC/in-memoriam.cfm](http://www.svc.org/about/SVC/in-memoriam.cfm)

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## Editorial: Fraud and Misconduct in Science

Somewhere in my mind I have a definition of science as “Exact and classified knowledge” – I must have received that tenet from my high school biology class. Of course it is inaccurate – science is never exact – our knowledge is always changing. Even our so-called constants are not fundamentally correct. For example, the speed of light may differ depending on the frame of reference. I think that the mathematicians say that only the value of  $\pi$  (ratio of the circumference to the diameter of a circle) is unchanged with frame of reference. Back to the subject: Science to me is the accumulation of knowledge and organizing it in such a way as to be able to explain observations and to propose hypotheses and theories that can be tested. There is no such thing as “accepted science” or “consensus science.” The recent revelation (hacked or leaked) of e-mails between climate “scientists” seems to reveal that there was at least misconduct by having a small number of “scientists” control scientific discussion on climatology by controlling the peer-review and publication processes. This has been termed “climategate” by some (e.g. [www.masterresource.org/2009/12/sarcastic-responses-to-climategate-misconstrue-the-real-debate/](http://www.masterresource.org/2009/12/sarcastic-responses-to-climategate-misconstrue-the-real-debate/)) and does seem to throw doubt on some claims about past climate change. Fraud may be involved in that the climate data (which was gathered at public expense) that has been published has had a “value-added” effect and then the raw data was destroyed or denied to other investigators. Fraud is nothing new in science. A recent example is that of Jan Hendrik Schön who gained such prominence that he received the “Outstanding Young Investigator” award by the Materials Research Society (2002). His work (which had been peer-reviewed) was later shown to be fraudulent (Eugenie Samuel Reich, “The rise and fall of a physics fraudster”, *Physics World*, May 1, 2009).

Modeling to my mind is not science. In modeling, parameters and variables are organized in such a way that if proper values and extremes are introduced and weighted correctly, a conclusion can be reached. Modeling is used all the time to design optical stacks, vacuum systems, gas manifolds, etc. with great success. To use a model to predict (e.g. an economic forecast) may be useful as a guideline. However it must be suspect and should be able to reproduce known events. The important point is that a predictive model is only as good as the inputs and assumptions being made. At this point a quote seems appropriate:

“Sometimes we know what we don’t know and sometimes we don’t know what we don’t know.”  
(paraphrased from Donald Rumsfeld)

Modeling of climate change, particularly if it leads to “alarmist” results, is especially worrisome because I don’t really think that we understand the energy balance of the earth. For example, it has only been recently (1997) that H. Svensmark proposed that galactic cosmic rays, which are modulated by the sun’s magnetic field, significantly affect the earth’s cloud cover (hence its albedo). We don’t know much about the history of the sun’s magnetic field directly but it seems to directly correlate with sunspot activity, which is at present at a very low level historically. Presently the solar geomagnetic strength is also at a record low (Space Weather Prediction Center - [www.swpc.noaa.gov/ftpd/weekly/RecentIndices.txt](http://www.swpc.noaa.gov/ftpd/weekly/RecentIndices.txt)). How will this affect the climate? I certainly don’t know, but perhaps it should be a variable in the predictive models of climate change.

The effects of CO<sub>2</sub> may be overblown in computer modeling of climate change as shown in the article “Falsification of The Atmospheric CO<sub>2</sub> Greenhouse Effects Within The Frame of Physics” (G. Gerlich and R. D. Tscheuschner: *International Journal of Modern Physics B*, Vol. 23, No. 3 pp. 275-364 (2009)) where they state “The derivation of statements on the CO<sub>2</sub> induced anthropogenic global warming out of the computer simulations lies outside any science.”

The “mainstream media” does not help the overall situation by the vagrancies and bias in their reporting (e.g. [www.businessandmedia.org/specialreports/2006/fireandice/fireandice.asp](http://www.businessandmedia.org/specialreports/2006/fireandice/fireandice.asp)) and (e.g. [www.washingtontimes.com/news/2009/dec/28/biased-reporting-on-climategate/](http://www.washingtontimes.com/news/2009/dec/28/biased-reporting-on-climategate/)).

## General Reference

“On Being a Scientist,” third edition, National Academies Press (2009)

Donald M. Mattox ([donmattox@mpinm.com](mailto:donmattox@mpinm.com)) is the SVC *Bulletin* Editor. Contact him with your views on this Editorial and the *Bulletin*.



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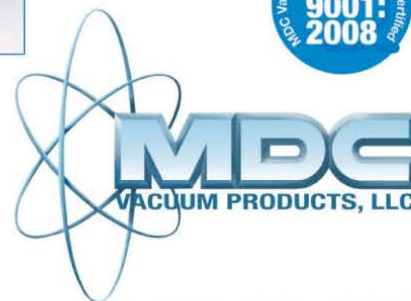


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## 2010 TechCon | Network and Learn with New Programs

Why do you attend a conference and exhibit? Our attendee surveys consistently show that one of the most important reasons is to network with friends and colleagues, and to make important new professional contacts.

SVC has always understood the value of networking and has strived to facilitate opportunities for attendees and exhibitors to come away from this important annual event with increased technical knowledge and a desire to pursue innovation in this new decade. This applies to both industry and academia, for each is complimented by the existence of the other.



### What's New in Orlando

#### Business Topics Program

The SVC introduces a new **Business Topics Program** in Orlando. The goal of this program is to help the companies who represent our vacuum coating industry and who strongly support our society gain a better understanding of where our complicated and diverse business is headed, put forth from a business-to-business (B2B) perspective. This session will be held on Tuesday, April 20 from 10:30 a.m. to 11:45 a.m.

Organizers are pleased to announce the first speaker in this new program: **Richard Sager with Williams Advanced Materials**. Sager's talk is titled "SVC 2010 and Beyond - What's in Store for Us in the Next Decade?" Stay tuned! The second speaker in this session will be announced in the Final Program and on the Web Site.

### Technology Review Session

Three 40 minute presentations on Monday morning will explore the current status of research and development in three different technological areas; Clark Bright (3M Company) will address Emerging Technologies, Hana Baránková (Uppsala University, Sweden) will discuss Atmospheric Plasma Technologies, and David Glocker (Isoflux Incorporated) will discuss Vacuum Processes and Coatings for Healthcare Applications.

Each presentation will offer attendees a roadmap through the SVC TechCon Program to gain a better understanding of the technology. This session will be of special interest to first time SVC TechCon registrants, students and participants in our Young Member's Group.

### Young Members Group Mentors Program

If it's networking that you want, the SVC TechCon has got it! For our younger members (under 31 years of age), we're offering a new **Young Members Group Mentors Program** on Sunday afternoon, April 18, from 2:00 p.m. – 4:00 p.m. This mentoring program will provide a "bridge" between Young Members, students and mentors within the Society, and will provide a venue for connecting with those working in specific areas of vacuum coating before the conference begins, thus enhancing their overall TechCon experience. For a list of Mentors, visit the Web Site at [www.svc.org](http://www.svc.org).

### "Meet the Experts" Corner

Each year we have experts available to answer questions on every aspect of vacuum coating. Join our experts on Monday, Tuesday and Wednesday for a productive exchange of ideas and solutions to your vacuum coating challenges. See page 11 for details on the experts and topics for each day.

### Technology Forum Breakfasts

Facilitator-led round-table discussions provide an opportunity for informal conversation and interaction on different topics. These popular discussion groups are offered on Monday and Tuesday mornings, from 7:00 a.m. – 8:15 a.m. See page 16 for topics and facilitators.

### Register Now!

Register for the TechCon and book your hotel room at [www.svc.org](http://www.svc.org). When registering it is important for the success of the event that you book your stay at the Orlando World Center Marriott. The conference rate of \$185/night single or double is outstanding for a hotel of this caliber. Staying at the conference hotel also allows for effective networking with other registrants, and offers more opportunities to participate in the events that start early and continue throughout the evening. We look forward to seeing you at the TechCon in April.

### Get Outside in Orlando!

#### Participate in the SVC Foundation Golf Tournament and/or the Fifth Annual 5K Fun Run and Walk.

For outdoor fun and networking in a relaxed environment, join colleagues for the fifth annual **5K Fun Run and Walk** in Orlando on Tuesday morning, April 20. No matter what your ability, this early morning event is always a great experience for all runners and walkers who participate.



The Foundation is also organizing a **Golf and Give Tournament** on Sunday afternoon, April 18, at the Hawk's Landing Golf Club on the grounds of the Orlando World Center Marriott Resort. Both of these events will benefit the SVC Foundation Scholarship Fund. See page 58 for more information on these events.



## New Keynote Speaker Announced

Program Chairs for the Technical program in Orlando have announced a new Keynote Speaker to kick off the Technical sessions on Monday morning. Magnus Odén (Nano-structured Materials, IFM, Linköping University, Sweden) will be replacing Lars Hultman (Linköping University, Sweden) as Keynote Speaker on Monday morning.

### Nanostructured Hard Coatings Monday Morning, April 19 at 8:30 a.m.

Multifunctional carbides and nitrides processed by PVD methods are strategic materials in advanced surface engineering applications. Recent findings of nanostructuring by design and self-organizing in different compounds will be presented here.

Nanoscale multilayer coatings, such as TiN/NbN, exhibit superhardening compared to the constituent layer materials. This is explained by dislocation hindering at interfaces between layers of different shear modulus. Superhardening also occurs in TiN/Si<sub>3</sub>N<sub>4</sub> nanocomposites with monolayer-thick SiN<sub>x</sub> tissue phase. Here, we show that this tissue phase can be a cubic SiN<sub>x</sub> layer that is epitaxially stabilized to TiN.

The concept of age hardening is introduced for supersaturated cubic-phase transition metal nitride alloys systems. Spinodal decomposition of TiAlN into coherent nm-sized domains of TiN and AlN is demonstrated. The nature and impact of the elastic anisotropic nature

of the TiAlN alloy is addressed especially on the decomposition behavior and the hardening mechanism. Furthermore, the influence of temperature, composition, and pressure on the spinodal decomposition process is given and how it can be used to form different types of microstructures will be explained. The microstructures that may evolve at the cutting edge of a metal machining tool are discussed.

Finally, examples of how multilayer TiAlN/TiN can be used to combine superhardening and age hardening effect to enhance their mechanical properties and at the same time improve their thermal stability.

**Magnus Odén** is professor and head of the Nanostructured Materials Division at the Department of Physics, Chemistry and Biology (IFM), Linköping University, Sweden. He received his PhD in Engineering Materials in 1995 from Linköping. He was then a visiting scientist at Northwestern University for two years. From 2002-2006 he held a professor chair at Lulea University of Technology before returning to Linköping to start a new research division. In 2008 he received the Jacob Wallenberg Foundation Award for Materials Science. His research is aimed at materials design of nanostructured materials, both for fundamental-research purposes and applications. Other than hard transition metal nitride based thin films, he pursues research on, for example, mesoporous oxides and nanoparticles.

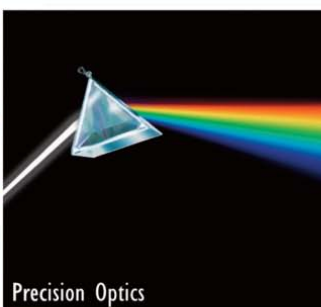


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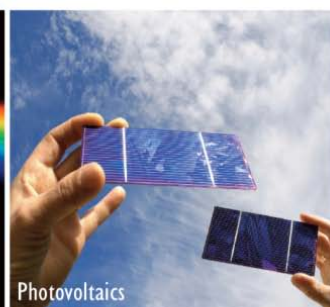
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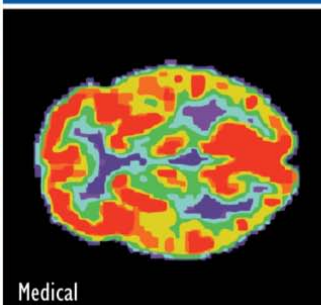


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## 2010 TechCon | Preview from the TAC Chairs



### Tribological and Decorative Coating

In the Tribological and Decorative Coating sessions, presenters from industry and academia will show applications and new developments in the area of coatings that improve the tribological performance of cutting and forming tools, automotive and aerospace components, and decorative coating applications.

Application oriented talks from representatives of automotive system manufacturers, as well as talks about the analysis of properties of carbon based coatings, will create an exciting program.

Carbon based low friction coatings play a major role in automotive systems. At present, the reduction of CO<sub>2</sub> emission by EU regulations, as imposed upon the car manufacturing industry, is one of the major drivers for the development of low friction coatings in automotive design. Yashar Musayev (Schaeffler KG, Germany) will start with an invited talk about the cam/bucket tappet system. Design and cost aspects, where the coating is to be regarded as an integrated design element, will be discussed.

Other presentations will be held on low friction coating systems, consisting of AlMg-boride and hydrogen free carbon coatings produced with laser-arc and with pulsed arc. Juliano Avelar Araujo (Mahle Metal Leve S.A., Brazil) will present a paper focused on Cr-based nitride coatings for piston ring systems.

An attractive talk will be held by Hiroyuki Kousaka (Nagoya University, Japan) about low friction coatings inside narrow tubes (aspect ratio 1:10) utilizing microwave activated plasma.

Adhesion and optical/electrical properties of Ag-films on flexible substrates are presented, showing the importance of the method of plasma pre-treatment. Another talk addresses carbon based coatings as adhesion promoter for platinum in catalysts.

In the field of tool coatings, plasma nitriding combined with coating on forging tools for diesel injection component manufacturing is shown to improve impact fatigue resistance. A presentation about cubic BN coatings on cutting tools will reveal that thicker coatings are now possible.

For decorative coatings in automotive

applications, combination technologies are also applied. It will be shown in the combination of sputtered color coatings with UV cured top and base coatings on plastic parts. Other interesting talks will be presented on red coatings, produced in one case by combining sputtering and interference, and in another case by Surface Plasma Resonance (SPR). Filtered arc for carbon-based coatings are used also for decorative applications (faucets).

Coatings for protection against mechanical wear, erosion and corrosion will be discussed by Marwan Azzi (École Polytechnique de Montréal, Canada). He will discuss tribocorrosion effects that play a role in for instance aero-engines. There will be other talks on aero-engine coatings: HIPIMS-based coatings to protect TiAl alloys for high temperature applications in aero engines against fretting wear; and erosion protection by nanolaminated coatings based on MAX\* phases.

\*MAX phases: these materials are nanolaminated hexagonal structure compounds, which consist of: a transition metal (M), an element from group IIIA or IVA (A) and carbon or nitrogen (X). Monocrystalline MAX phase is made of MX monolayers intertwined with monoatomic A layers.

Roel Tietema, Hauzer Techno Coating BV, The Netherlands (31/77-3559741; [rtietema@hauzer.nl](mailto:rtietema@hauzer.nl)) is the Tribological and Decorative Coating TAC Chair. Jolanta Klemberg-Sapieha, École Polytechnique de Montréal, Canada (514/340-5747; [jsapieha@polymtl.ca](mailto:jsapieha@polymtl.ca)) and Michael Drory, Timken Technology Center (330/471-2683; [Michael.drory@timken.com](mailto:Michael.drory@timken.com)) are the Assistant TAC Chairs.



### Process Modeling and Control

Today's vacuum processes require levels of control that were virtually unheard of only a few years ago. Enabling some of the most advanced control methods are modeling tools that have also evolved to meet the demands of leading edge process technologies.

The Process Modeling and Control Session plans to showcase some of today's most compelling technologies in the process control and simulation arena. This year we are fortunate to welcome two invited speakers covering both sides of the modeling and control theme.

Our invited speakers are Azer Yalin

(Colorado State University) and Michael Siemers (Fraunhofer Institute for Surface Engineering and Thin Films IST, Germany). Yalin will present on a newly developed system for high sensitivity differential sputter yield measurements using Quartz Crystal Microbalance (QCM). Siemers will speak on 3D simulation techniques for modeling gas flows and gas discharges in industrial magnetron sputtering and plasma enhanced CVD systems.

In addition to our invited speakers, there is a strong complement of other papers throughout the session touching on a broad range of control and modeling techniques that are sure to be relevant to virtually all vacuum processing applications.

Dan Carter, Advanced Energy Industries, Inc. (970/407-6699; [dan.carter@aei.com](mailto:dan.carter@aei.com)) and Colin Quinn, Veeco Instruments, Inc. (970/221-1807; [cquinn@veeco.com](mailto:cquinn@veeco.com)) are the Process Modeling and Control TAC Co-Chairs.



### Emerging Technologies

The Emerging Technologies Session at the 2010 SVC TechCon is the forum to highlight new technologies and future trends in surface processing and coating. Anchored by four invited talks, this year's program showcases a broad range of coating techniques and applications.

For the tribological as well as the semiconductor community, cubic boron nitride (cBN) has been a very promising but also notoriously challenging high-performance coating material. Two papers (including an invited paper by Wenjun Zhang (City University of Hong Kong, China) will present recent advances in material properties, processing and practical tool/device performance.

Among several process-related contributions, an invited paper by Robert Sargent (JDS Uniphase) will demonstrate how modern optical coating technology answers to the challenge of the commoditization of very demanding (but now ubiquitous) optical filters by improving economics but also conquering new markets. Other talks with a focus on process technology present latest results on Atomic Layer Deposition (ALD) for pragmatic, lower-cost packaging solutions and



to enhance functional coatings through nanolaminates, modern methods that efficiently manage arcing problems in sputter processes, and an invited paper by Viacheslav Zhurin (Colorado Advanced Technology LLC) will update the community on new perspectives on industrial ion sources.

Extending the view towards the emergence of flexible organic photovoltaic (OPV) devices, an invited talk from Peter Peumans (Stanford University) summarizes latest device- and process options that focus on simplified manufacturing, lower cost, and improved performance.

As a new introduction to the Monday afternoon session, TAC chair Clark Bright (3M Company) will summarize particular topics of interest and the high-level scope of the "Emerging Technologies" session as part of the Technology Review Session on Monday morning at 9:30 a.m.

Clark Bright, 3M Company (520/746-7061; [cibright@mmm.com](mailto:cibright@mmm.com)), Carlo Misiano, Romana Film Sottili S.r.l, Italy (39/064 423 0163; [carlo.misiano@libero.it](mailto:carlo.misiano@libero.it)), and Chris Stoessel, Southwall Technologies (707/525-8874; [stoessel@attglobal.net](mailto:stoessel@attglobal.net)) are the Emerging Technologies TAC Co-Chairs.

*continued on page 12*

## "Meet the Experts" Corner

This year we have a variety of experts available to answer questions on every aspect of vacuum coating. Join these experts for a productive exchange of ideas and solutions to your vacuum coating challenges.

### Monday – 1:30 p.m.-2:30 p.m.

David Glocker, Isoflux Inc. and Bill Sproul, Reactive Sputtering, Inc. will answer questions about sputter technology. Targets, substrates, power supplies and the different variants of sputtering, including reactive sputtering, high power impulse sputtering will be explored.

### Tuesday – 1:30 p.m.-2:30 p.m.

Smart materials such as adaptive coatings, smart windows and many others are the topic for Tuesday. Claes Göran Granqvist, Uppsala University, Sweden and Wolfgang Diehl, Fraunhofer Institute for Surface Engineering and Thin Films IST, Germany will be available for this session to respond to your questions.

### Wednesday – 10:15 a.m.-11:15 a.m.

Vacuum coating involves a number of different stages: From choice of substrate, to substrate preparation, to vacuum deposition, to coating characterization. Problems can occur anywhere along this process flow. Join Donald Mattox, Management Plus, Inc., who will address common problems posed by the attendees.



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## TechCon Preview

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### Cleantech Energy Symposium

Following the grand success of our Santa Clara Cleantech Energy Symposium last year, we are offering an expanded program in 2010. We have two coordinated programs on clean technology, including photovoltaics, as well as the main sessions of Cleantech and a focused session in the Large Area Coatings program.

On Monday afternoon we have a strong program on Large-area coating moderated by Michael Andreasen, AGC Flatglass North America, and Bernd Szyska (Fraunhofer Institute for Surface Engineering and Thin Films IST, Germany). Symposium organizers have been lucky to have James Papanu, the Senior Technology Manager of Applied Materials to present an invited talk on sputtered zinc oxide for silicon solar cell applications. Doped Zinc oxide is one of the replacements for the more expensive and resource dependent indium oxide. Several other presentations on zinc oxide and other transparent conductors are detailed in the Large Area Coating Program. Also, on late Monday afternoon we will hold the Cleantech Energy Forum. The Forum will endeavor to give the attendees an overview of the U.S. Energy Program and industry developments in photovoltaics and related topics. The speakers for this Forum will be announced in the SVC Final Program and on the SVC Web Site.

One of the main sessions on Wednesday is on thin film photovoltaics, headed by Wolfgang Diehl and Volker Sittinger (Fraunhofer Institute for Surface Engineering and Thin Film, IST, Germany). The invited talk is by the head of the European Photovoltaic Industry, Winfried Hoffmann (Applied Materials, Germany). Hoffmann will speak on the role of "Thin Films in Photovoltaic Products." This will be a significant talk since the European PV manufacturing industry is so strongly developed. Another invited talk will be given by Bernd Rech (Helmholtz-Zentrum, Berlin). Rech will speak on the "Challenges and Perspectives of Thin Film Photovoltaics." Thin film photovoltaics have been steadily gaining market share over silicon based multicrystalline wafer based PV. After the break, the session continues with another invited talk by the well known Yuzo Shigesato (Aoyama Gakuin University, Japan). Shigesato will speak on "High Rate Deposition for Transparent Conductive Al-doped ZnO Films by Reactive Sputtering". Zinc oxide films are a strong contender as a lower cost substitute for indium oxide based films. Shigesato is known for his organization of the TOES transparent con-



*Prototype of an electrochromic "smart" window with four panes, two of which are dark and the other two being fully transparent. The properties of the panes can be changed, gradually and reversibly, during the course of some tens of seconds. The "smart" functionality is obtained via a potentially low-cost foil that can serve as a lamination material and also provide mechanical ruggedness and acoustic damping.*

ductor conferences. Still another invited talk is on developments on a new flexible transparent electrode, presented by Hulya Demiryont (Eclipse Energy Systems). This is a non-indium oxide nanostructured materials system. Timothy A. Potts (Dark Field Technologies), will address on-line glass and film inspection for PV devices in his presentation. As we move forward with higher production rates of PV device, the detection of defects in manufacturing is becoming critical.

In the Wednesday afternoon Cleantech session, the presentations will focus on smart windows and films for energy control. This session is led by Claes Granqvist (Ångström Laboratory, Sweden) and Carl Lampert (Star Science). One of the invited talks is given by Australian Physics professor, Geoff Smith

(University of Technology, Sydney). Smith will speak on "Coatings Tuned for Atmospheric Infrared for High Performance Radiative Cooling". The ability to cool surfaces, especially in remote regions, is extremely important to the well-being of many people in the world. Another invited talk in this session will be presented by Ivan Parkin (University College of London, UK). Parkin will speak on "Optimization of Thermochromic Thin Films on Glass: Design of Intelligent Windows". The field of thermochromic materials is re-emerging as it is possible to better tailor transition temperatures and optical properties of these films. Another important presentation in this session will be given by Oleg Zabeida (École Polytechnique de Montréal, Canada). Zabeida will speak on the thermo-optical properties of LSMO manganite films. Claes Granqvist (Ångström Laboratory, Sweden) will wrap up this session with his presentation on new results on smart materials including thermochromic vanadium oxide and electrochromic nickel oxide films for energy control.

As part of the conference-wide Cleantech topics, there are also Technology Breakfast Forums on Monday on Thin Film Photovoltaics and on Tuesday on Cleantech Energy and Conversion and Storage. These are very popular interactive discussions and are open to all conference attendees. Come early with your questions.

Cleantech is also represented in the "Meet the Experts" Corner on Tuesday afternoon. In this popular networking program, participants talk with Claes Granqvist (Ångström Laboratory, Sweden) and Wolfgang Diehl, experts on smart materials, including adaptive coatings and smart windows.

#### CleanTech Symposium on Energy Conversion Storage and Related Processes Symposium

**Organizer:** Carl M. Lampert, Star Science, (707/794-0333; [cmlstar@sonic.net](mailto:cmlstar@sonic.net))

##### Session Organizers:

- **Thin Film Photovoltaics Co-Chairs:** Wolfgang Diehl, Fraunhofer Institute for Surface Engineering and Thin Films (IST), Germany (49/531 2155 515; [wolfgang.diehl@ist.fraunhofer.de](mailto:wolfgang.diehl@ist.fraunhofer.de)) and Volker Sittinger, Fraunhofer Institute for Surface Engineering and Thin Films IST, Germany (49/531 215 5512; [volker.sittinger@ist.fraunhofer.de](mailto:volker.sittinger@ist.fraunhofer.de))
- **Organic and Polymer Photovoltaics Co-Chairs:** Barry C. Thompson, University of Southern California (213/821-2656; [barry.thompson@usc.edu](mailto:barry.thompson@usc.edu))
- **Cleantech - Large Area Coating Co-Chairs:** Michael Andreasen, AGC Flat Glass North America (707/455-7321; [michael.andreasen@na.agc-flatglass.com](mailto:michael.andreasen@na.agc-flatglass.com)) and Bernd Szyska, Fraunhofer Institute for Surface Engineering and Thin Films IST, Germany (49/531-2155641; [bernd.szyska@ist.fraunhofer.de](mailto:bernd.szyska@ist.fraunhofer.de))
- **Smart Materials Co-Chairs:** Claes G. Granqvist, Uppsala University, Sweden (46/18-4713067; [claes-goran.granqvist@angstrom.uu.se](mailto:claes-goran.granqvist@angstrom.uu.se)) and Carl M. Lampert, Star Science (707/794-0333; [cmlstar@sonic.net](mailto:cmlstar@sonic.net))
- **Photochemistry Co-Chair:** Peter Martin, Columbia Basin Thin Film Solutions, LLC (509/783-5553; [totsmartin@aol.com](mailto:totsmartin@aol.com))
- **Defense Applications Co-Chair:** Ron Storm, Ricardo Inc. (734/394-4114; [ronald.storm@ricardo.com](mailto:ronald.storm@ricardo.com))
- **Cleantech Business Co-Chairs:** Carl M. Lampert, Star Science (707/794-0333; [cmlstar@sonic.net](mailto:cmlstar@sonic.net)) and Ric Shimshock MLD Technologies LLC (650/938-3705; [ricshimshock4mld@aol.com](mailto:ricshimshock4mld@aol.com))

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## TechCon Preview

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### Large Area Coating

Come see us in Orlando and learn the latest and greatest in Large Area Coating strategies for new technologies, new applications, cost reduction and quality improvement.

Large Area Coating will be sponsoring two sessions at the 2010 SVC TechCon: one focused on Cleantech Energy technologies and applications and one focused on the “bread and butter” areas of residential and commercial coatings, technologies and applications.

In the Cleantech session scheduled for Monday afternoon, Applied Materials will be presenting their progress in developing a sputtered ZnO based TCO for solar cell front contact application, including the critical post-deposition processes required to meet stringent performance requirements. Papers from Fraunhofer IST, Umicore and Gencoa will provide further details and insights into ZnO and ITO sputter targets and deposition strategies for photovoltaic TCO applications. In addition, Beneq Oy will present the results of their development of atomic layer deposition for depositing high performance moisture barrier coatings for PV and OLED applications.

In the Large Area session on Tuesday, Victor Veerasamy, of Guardian Industries, will present his leading edge development of TCO coatings from carbon nanotubes and

nanowire composites on glass. This is a very exciting area and the presenter will show how he has developed TCOs that have stable sheet resistance well below 100 ohm/sq at a visible transmittance level above 83.5%. He will discuss the technology and two near-term applications that are foreseen. In addition, there are a great mix of papers in this session including:

- General Plasma's Large Area CVD processes and applications presentation
- Academy Precision's presentation on silver sputtering targets for TCO and low-E applications
- Dark Field Technology's online haze measurement technology
- Fraunhofer's presentation on Cold Cathode sources for high rate PVD requirements
- Further presentations on ZnO TCO technology

*Michael Andreasen, AGC Flat Glass North America (707/365-7433; [michael.andreasen@na.agc-flatglass.com](mailto:michael.andreasen@na.agc-flatglass.com)) is the Large Area Coating TAC Chair, and Johannes Strümpfel, VON ARDENNE Anlagentechnik GmbH, Germany (49/351-2637350; [struempfel.johannes@vonardenne.biz](mailto:struempfel.johannes@vonardenne.biz)), is the Assistant TAC Chair.*



### Optical Coatings

This conference, like its predecessors, meets to survey and capture advancements in the broad area of optical coatings. The Optical Coatings sessions serve as a focal point for global technical interchange in the field of optical coatings. This 53rd Annual SVC

Conference will cover all recent trends in the optical coatings community, including interesting papers on new and novel applications in optics, optoelectronics and photonics, new processing methods and the latest in optical coating characterization.

The Optical Coating sessions are scheduled for both Tuesday and Thursday. The sessions are anchored by a trio of excellent invited talks. On Tuesday, Eva Franke-Schubert (University of Nebraska) will speak about art and promise of sculptured thin films. The fabrication of nanoscale structures with chiral or non-chiral properties promises exciting new possibilities as optical filter materials, sub-wavelength antireflection coatings, diffractive optics from nanogratings and active Terahertz materials.

The Thursday Optical Coating session will host two invited speakers. It is our great pleasure to have Angus Macleod from the Thin Film Center in Tucson discuss how coherence relates to a system involving optical coatings. Also on Thursday, Karin Scherer (Essilor International, France) will describe the optical sophistication employed in coatings for eyeglasses. Her talk will cover requirements, current products, and new and emerging technology being proposed and used for eyeglass coatings.

Many additional papers will help to make the 2010 Optical Coatings session a well-rounded and exciting venue.

*Ulrike Schulz, Fraunhofer Institut für Angewandte Optik und Feinmechanik IOF, Germany (49/3641 80 7344; [ulrike.schulz@iof.fraunhofer.de](mailto:ulrike.schulz@iof.fraunhofer.de)), Bryant Hichwa, Sonoma State University (retired) (707/785-1922); [bhichwa@earthlink.net](mailto:bhichwa@earthlink.net)), and James N. Hilfiker, J. A. Woollam Co., Inc. (402/477-7501; [jhilkfiker@jawool-lam.com](mailto:jhilkfiker@jawool-lam.com)) are the Optical Coating TAC Co-Chairs.*

## SVC Young Members Group/Mentors Program

A new mentoring program is being offered at the 2010 TechCon for Young Members and students, and is being designed to offer participants the opportunity to engage in one-on-one discussions with volunteer mentors from industry and academia within various sectors of the vacuum coating community.

The mentoring program will provide a “bridge” between Young Members, students and mentors within the Society, and will facilitate a venue for connecting with those working in specific areas of vacuum coating, thus enhancing their overall TechCon experience. The program will be the focus a special session on Sunday afternoon, April 18, 2010, from 2:00 p.m. to 4:00 p.m.

The Young Members Group is open to young people with an interest in vacuum coating and related technologies. Members of the group may be students or young staff in industry; the common feature is that they should meet the age requirement (under 31 years of age at any time in 2010) and have a keen interest in any of the topics that sit under the umbrella of the SVC. Young Members receive the following discounts:

- Discounted Membership Fee of \$40.00
- Discounted Registration Fee of \$225.00
- A 50% Discount for Tickets to the Tuesday evening Networking Event of \$23.00

*If you have questions regarding the Young Members Group and Mentors Program, please contact the Chair or a Board Mentor.*

### Young Members Committee

*James McShane, Chair*  
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## Plasma Processing

The Plasma Processing session will continue in its traditional role of presenting and discussing plasma applications which are integral to several aspects of the many topics covered by the SVC conference. Join us in Orlando to explore thin film deposition and surface modification/functionalization for textiles, along with transparent conductive oxides and graphene – just a few examples extracted from the session planned for Wednesday morning, April 21, 2010.

The Wednesday morning program will also host oral contributions aimed at presenting the most recent developments in the field of plasma sources. These presentations are guaranteed to be of interest to the broad and diverse industrial community visiting the SVC conference, where new designs and large area processing are actively discussed.

The Plasma Processing session also features the exploration of the fundamentals of plasma science, by welcoming an invited talk from Dirk Hegemann (EMPA, Switzerland) on plasma polymer growth (planned for the Wednesday morning session) and the development of a macroscopic approach aimed to allow a consistent comparison among several deposition processes and plasma technologies. An additional session is planned for Monday afternoon and is dedicated to plasma chemistry studies and plasma diagnostics. This session will feature a highly anticipated invited talk from Jan Benedikt (Ruhr University, Germany) on the application of threshold ionization mass spectrometry for radical detection in processing plasmas.

We invite you to attend the Plasma Processing sessions at the 2010 SVC Technical Conference to gain first-hand knowledge of the latest scientific findings and technological applications. You can also expect to experience the instructive and inspiring invited talks and participate in the networking activity and discussions that make this conference “a must attend” for anyone interested in the future of plasma processing and vacuum coating applications. See you in Orlando!

Mariadriana Creatore, Eindhoven University of Technology, The Netherlands (31/402 474 223; [m.creatore@tue.nl](mailto:m.creatore@tue.nl)) is the Plasma Processing TAC Chair. Scott Walton, U.S. Naval Research Laboratory (202/767-7531; [scott.walton@nrl.navy.mil](mailto:scott.walton@nrl.navy.mil)) and James Bradley, University of Liverpool, UK (44/151 794 4545; [j.w.bradley@liverpool.ac.uk](mailto:j.w.bradley@liverpool.ac.uk)) are the Assistant TAC Chairs.

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## Business Topics Program

Tuesday Morning, April 20, 2010  
10:30 a.m.-11:45 a.m.

Moderators: Carl Lampert, *Star Science* and  
Frank Zimone, *Angstrom Sciences*

New for the 2010 TechCon in Orlando, SVC will introduce a Business Topics Program. The goal of this program is to help the companies who represent our coating industry and who strongly support our society gain a better understanding of where our complicated and diverse business is headed, put forth from a business-to-business (B2B) perspective. The Business Topics Program is open to all exhibitors and attendees. This session will be held on Tuesday, April 20 from 10:30 a.m. to 11:45 a.m.





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## TechCon Preview

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### Vacuum Web Coating

The Web TAC has put together three strong sessions for the 2010 TechCon in Orlando. Presentations will cover a wide variety of topics with several main (and often related) themes emerging.

#### Barrier Films

Judging by the number of abstracts submitted, this is an area seeing a tremendous amount of development effort, related both to ultra high barrier films for OLED devices and solar cells and to packaging films. These presentations will be headlined by an invited talk from Senthil K. Ramadas (Tera-Barrier Films, Singapore) on “Nanoparticulate Barrier Stacks for Display and Solar Applications”.

#### Solar Cells

Flexible solar cells are attracting a great deal of interest and two invited presentations by key individuals talk about some of the challenges involved in their development and production. Karsten Otte (Solarion AG, Germany) will review “Web Coating of Flexible CIGS on Polyimide Substrate” and Ayodhya Tiwari (Swiss Federal Laboratories for Material

Testing and Research, Switzerland) discusses “Roll-to-Roll Manufacturing for Flexible CIGS and CdTe Solar Cells and Modules”.

#### Transparent Conductive Films

Many of the presentations in this area look at alternatives to ITO to improve performance or reduce cost – with doped zinc oxide attracting the attention of several authors. An invited paper by Kwang-Leong Choy (University of Nottingham, UK) titled “Transparent Conducting Oxide Films on Flexible and Glass Substrates by ALD and ESAVD” will evaluate ITO, doped zinc oxide and carbon nanotubes deposited by novel methods. John B. Fenn (Fennagain), Donald J. McClure (Acuity Consulting and Training) and Charles A. Bishop (C. A. Bishop Consulting Ltd., UK) in the presentation “If Not ITO, Then What” will take a broad look at the performance of ITO against newcomers as well as reviewing volume and growth potential.

There are also many other presentations on topics outside these themes. We believe that there will be presentations of interest to anyone involved in web coating and a great opportunity to network with others in the field from around the world. We look forward to seeing you in Orlando.

*Geoff Ringer, 3M Corporate Process Research Laboratory (520/746-7066; [gringer@mmm.com](mailto:gringer@mmm.com)) and James McShane, Avery Dennison (219/322-5030; [james.mcshane@averydennison.com](mailto:james.mcshane@averydennison.com)) are the Vacuum Web Coating TAC Co-Chairs.*



### The Marriott Spa Terrace Networking Event

Tuesday Evening, April 20, 2010  
7:00 p.m. – 10:00 p.m.

Cost per person: \$46.00  
(*\$23.00 for Students and Young Members Group registrants*)

Plan to join colleagues at the Tuesday evening Networking Event in Orlando! This year's event will take place by the lake at the Spa Terrace on the magnificent grounds of the Orlando World Center Marriott Resort. Enjoy a buffet dinner and live entertainment under the stars. Purchase your tickets for this unique networking event when registering for the Conference and Exhibit.



### Technology Forum Breakfast Topics and Speakers

#### Monday, April 19

7:00 a.m.-8:15 a.m.

- **Coatings for Thin Film Photovoltaics**  
Wolfgang Diehl, *Fraunhofer Institute for Surface Engineering and Thin Films IST, Germany*
- **High Power Impulse Magnetron Sputtering (HIPIMS)**  
Arutun P. Eghisarian, *Sheffield Hallam University, UK*
- **Transparent Conductive Oxides (TCO) and Electronics**  
Clark Bright, *3M Company*
- **Optical Coating Design**  
H. Angus Macleod, *Thin Film Center Inc.*
- **Process Modeling**  
Bernd Szyszka, *Fraunhofer Institute for Surface Engineering and Thin Films IST, Germany*
- **Tribological Coatings**  
Allan Matthews, *University of Sheffield, UK* and Bill Sproul, *Reactive Sputtering, Inc.*

#### Tuesday, April 20

7:00 a.m.-8:15 a.m.

- **Atmospheric Plasma Technologies**  
Hana Baránková and Ladislav Bárdos, *Uppsala University, Sweden*
- **Cleantech Energy Conversion and Storage**  
Carl Lampert, *Star Science* and Ric Shimshock, *MLD Technologies, LLC*
- **Diamond-Like Carbon (DLC) Coatings**  
Klaus Bewilogua, *Fraunhofer Institute for Surface Engineering and Thin Films IST, Germany*, Gerry van der Kolk, *IonBond Netherlands b.v., The Netherlands* and Thomas Schuelke, *Fraunhofer USA*
- **Fabrication and Performance of Optical Coatings**  
Ludvik Martinu, *École Polytechnique de Montréal, Canada* and Bryant Hichwa, *Sonoma State University (retired)*
- **Gas/Moisture Permeation Barrier Layers**  
Mariadriana Creatore, *Eindhoven University of Technology, The Netherlands*
- **Magnetron Sputtering**  
David Glocker, *Isoflux Incorporated*
- **Plasma Processing and Biomaterials**  
Paul Gagnon, *Corning Inc.*





## Vacuum Processes and Coatings for Health Care Applications

Once again, the session on Vacuum Processes and Coatings for Health Care Applications at the 2010 TechCon promises to be an excellent opportunity to keep up-to-date on developments in this important field. As implantable medical devices grow ever smaller, the critical ability to see them by fluoroscopy becomes increasingly difficult.

The first presentation in the session is an invited talk by Scott Russell (NDC) on how coatings can be used to provide radiographic visibility and the challenges associated with making this happen. Polymer coatings play a crucial role in numerous medical applications. For example, they provide the reservoirs on stents used to store and elute drugs that prevent the reclosing of arteries.

Enrico Gallino (Laval University, France) describes methods for plasma polymerizing allylamine coatings for stents and correlates the plasma properties with the resulting films. This is followed by an invited talk by Diego Mantovani (Laval University, Canada) that will

discuss the potential of coatings and surface treatments to produce biomimetic and tissue regenerating surfaces within the body.

Turning to the important field of diagnostics, blood glucose sensors are an important part of the treatment of diabetes for millions of people. Sputtered coatings on flexible substrates have helped contribute to the reduction in the amount of blood needed for these tests and the next presentation describes the most important technologies available today.

Finally, we will hear from Carlo Misiano (Romana Film Sottili S.r.l., Italy) about nanostructured coatings designed to improve the growth of bone into surgical implants. This year's session highlights many of the existing and rapidly developing opportunities to use vacuum technology to improve lives every day. Whether you serve the health care industry now, are looking for opportunities to do so, or are simply someone who is justifiably awed by progress in this field, you'll want to be sure to attend this session on Wednesday morning.

*David Glocker, Isoflux Incorporated (585/349-0640; [dglocker@isofluxinc.com](mailto:dglocker@isofluxinc.com)) is the Vacuum Processes and Coatings for Health Care Applications TAC Chair. Hana Baránková, Uppsala University, Sweden (46/18-4713118; [hana.barankova@angstrom.uu.se](mailto:hana.barankova@angstrom.uu.se)) and Ludvik Martinu, École Polytechnique de Montréal, Canada (514/340-4099; [lmartinu@polymtl.ca](mailto:lmartinu@polymtl.ca)) are the Assistant Chairs.*

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## High Power Impulse Magnetron Sputtering (HIPIMS)

The new High Power Impulse Magnetron Sputtering (HIPIMS) session in 2010 reflects a dynamic research and development atmosphere within the community. The invited speaker, Val Lieberman (Systec GmbH) will give an industrial perspective of the past 10 years of development. Spanning from the academic to the application side, the session unfolds in the following way. New advances in plasma processes show an understanding of reactive HIPIMS and the influence of magnetic field. Brand new developments will be shown in bipolar HIPIMS and deposition control in oxygen atmosphere with the latter theme featuring prominently with both HIPIMS and MPP techniques. Process-microstructure correlations are beginning to emerge. Industrial scale implementation of carbon-containing self-organizing films, nanoscale multilayers and DLC for tribological applications will be reported. First implementation in cryogenic space applications will be presented. Be part of this development and discuss all existing and new aspects of this technology.

Arutun P. Eghasarian, Sheffield Hallam University, UK (44/114-225-3646; [a.eghasarian@shu.ac.uk](mailto:a.eghasarian@shu.ac.uk)) is the High Power Impulse Magnetron Sputtering (HIPIMS) Chair. Ralf Bandorf, Fraunhofer Institute for Surface Engineering and Thin Films IST, Braunschweig, Germany (49/ 531-2155-602; [ralf.bandorf@ist.fraunhofer.de](mailto:ralf.bandorf@ist.fraunhofer.de)) and Jolanta Klemberg-Sapieha, École Polytechnique de Montréal, Canada (514/340-5747; [jsapieha@polymtl.ca](mailto:jsapieha@polymtl.ca)) are the Assistant Chairs for the HIPIMS sessions.



## Joint Session on Atmospheric Plasma Technologies

Non-thermal atmospheric plasma has a great potential for application in surface treatment and coating. It is important to realize what are the pros and cons of the atmospheric plasma technologies when compared with reduced pressure processes. The Joint Session on Atmospheric Plasma Technologies scheduled for Monday afternoon will proceed

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- very low temperatures (and the magic of cryopumping)
- how materials change from solid to liquid to gas and back (more vacuum coating magic)
- what the “mean free path” is (and why vacuum wizards care)
- why low pressures are needed to make pure coatings (and why the “low” pressures needed can be so different in different applications)

Everyone is welcome—conference registrants, exhibitors, short course attendees, students, and teachers. However, the number of attendees is limited so that everyone can see the demonstrations.

*There is a small fee of \$35 to attend this Special Event. Preregister using the SVC On-line TechCon registration form.*

with topics addressed by the Technical Reviews on Emerging Technologies, Atmospheric Plasma and Healthcare applications held on Monday morning.

The session begins with the invited paper on PE CVD process using the Dielectric Barrier Discharge, by Nicolas Gherardi (Université de Toulouse, France). In order to obtain uniform coatings with well controlled properties, the discharge must operate in a diffuse mode. Different reactive gases, electrical parameters and the role of the reactive transport in the process will be discussed.

Masuhiko Kogoma (Sophia University, Japan) will make an invited presentation on development of a new adhesive-free lamination technique using the atmospheric pressure glow (APG) plasma surface treatment and the thermo-compression of the treated films. The lamination materials, as PET/PE and NY/PE are treated in N<sub>2</sub>/He or He APG plasma reactor. The maximum adhesive strength of the laminated film exceeded the value of 500 N/m.

The program will also feature a presentation by Roland Gesche (Ferdinand-Braun-

Institut, Germany) on the design of a new integrated microwave driven microplasma source, where the active element is a GaN HEMT developed in the Ferdinand-Braun-Institut. In the reactor, an auxiliary electrode is placed in the afterglow zone of the plasma. Possible applications are presented.

A presentation devoted to the surface treatment of energy system components by cold atmospheric plasma will be given by Lad Bardos (Uppsala University, Sweden). The wind turbine blade surface and steel surfaces used in the linear Wave Energy Converters are treated by the Fused Hollow Cathode (FHC). Results of tests under different plasma parameters are discussed.

Join us to hear about new designs and applications of the non-thermal atmospheric plasma technologies.

Session Organizer: Hana Baránková, Uppsala University, Sweden (46/18-4713118; [Hana.Barankova@angstrom.uu.se](mailto:Hana.Barankova@angstrom.uu.se))

This Joint Session is organized in collaboration with the Plasma Processing, Vacuum Web Coating and Emerging TACs and Ladislav Bárdoš, Uppsala University, Sweden (46-18-4713034; [ladislav.bardos@angstrom.uu.se](mailto:ladislav.bardos@angstrom.uu.se)) is a co-organizer of the session.



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# Advanced Pulsed DC Technology for Material Processing Applications

## Part 4. Arc Free Magnetron Discharge for High Deposition Rate of AlN Reactive Films

Roman Chistyakov and Bassam Abraham, Zond Inc/Zpulsar LLC, Mansfield, MA

Contributed Original Article

*This is the fourth in a several part series of contributed articles on advanced pulsed DC technology and related processes.*

### Arc Free Discharge for Reactive Sputtering

In the preceding contributed articles, the high power pulse plasma generator (Zpulsar) was described. It was shown that this generator can produce negative unipolar arbitrary voltage pulse shapes with voltage oscillations within the pulse. These voltage oscillations have frequency in the range of  $\sim (20-50)$  kHz. It was also shown that due to the design of the plasma generator the output voltage value is a function of the voltage oscillations frequencies. Usually, a higher voltage equates to lower voltage amplitude. For example, if the output voltage is in the range of  $\sim (800-900)$  V the amplitude of voltage oscillations can be in the range of  $\sim (5-10)\%$  from the peak voltage value.

A new plasma generator was developed where the voltage oscillations amplitude can be more than 70% from the peak voltage value. It was found that, at some unipolar negative voltage pulse shapes with specific voltage oscillations frequency and amplitude, it was possible to generate arc free magnetron discharge in a reactive Ar – N<sub>2</sub> atmosphere. It is well known that arc free magnetron discharge can be formed in reactive gas atmosphere under pulsed DC operation conditions [1-2]. In this case, the output voltage pulse should have negative and positive voltage portions. According to the literature, the positive voltage is attracting the electrons to the target surface and discharging the surface therefore prevents arc formation [1-2]. The important part is that the stable arc free discharge with the newly developed plasma generator was formed without applying the positive voltage portion. This arc free magnetron discharge was used for reactive sputtering of AlN stoichiometric films.

The typical output voltage pulse shape with duration 1000  $\mu$ s is shown in Fig. 1. The output voltage was  $\sim -640$  V and voltage amplitude is about 540 V. The voltage oscillations amplitude is in the range of 80%. The specific voltage pulse shape for arc free discharge is a function of peak power and magnetron size. The voltage and current waveforms of the voltage pulse shape with high voltage oscillations experience complicated transformation as a function of reactive gas. A more detailed explanation will be given at the SVC TechCon 2010.

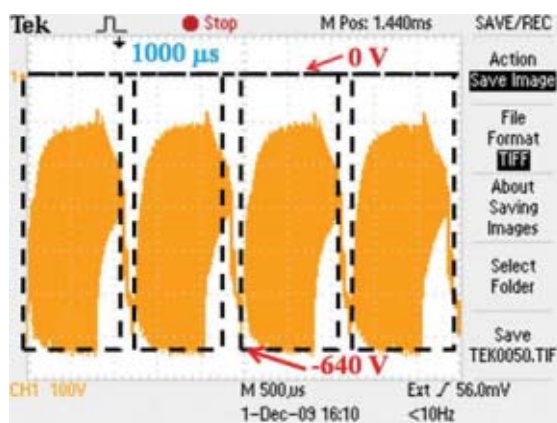


Figure 1. Discharge voltage waveforms from oscilloscope screen for pulses with duration 1000  $\mu$ s and pulse repetition rate 1000 Hz.

### Experimental

The present experiments were carried out in the large stainless steel vacuum chamber. The chamber height is about  $\sim 100$  cm and chamber diameter is in the range of  $\sim 100$  cm. Two magnetrons with different Al targets diameters were positioned inside the chamber.

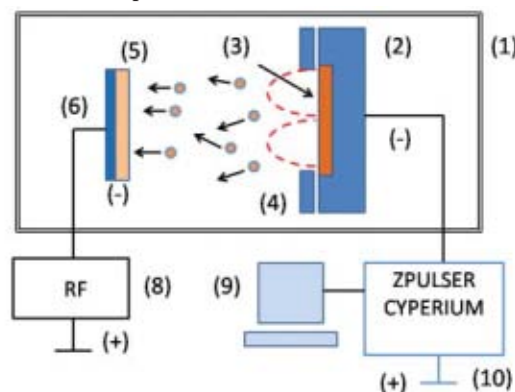


Figure 2. Experimental set up for reactive sputtering AlN films.

The experimental set up is shown on the Fig.2. Vacuum chamber (1) was pumped down with a turbo pump and typically had base pressure approximately  $5 \times 10^{-5}$  Torr. Magnetron (2) had Al (5N) target and standard anode ring (4). The second magnetron is not shown. During the depositions the Ar gas was injected near the magnetron (2) and N<sub>2</sub> gas was injected near the substrate. Silicon wafers with orientations Si (111) and Si (100) were used as a substrates. A substrate (5) was positioned on substrate holder (6). Substrate holder was electrically connected with RF power supply. Before each sputtering process wafer was cleaned with RF bias -600 V during 120 sec. Distance between each magnetron and substrate was 6.5 cm. The target-cathode of the magnetron was connected with negative output of the new Zpulsar plasma generator "Cyperium."

AlN films were reactively sputtered in the Ar – N<sub>2</sub> atmosphere. In the first set of experiments samples S#10, S#14, S#15, S#16, S#17 and S#18 were sputtered from the circular magnetron with 10 cm diameter Al target. In the second set of experiments samples S#21, S#22, S#23, S#24, S#25 and S#28 were sputtered from the circular magnetron with 15 cm diameter Al target. The magnetic field (the component parallel to the target surface) was in the range of 350 G for both magnetrons.

For the first set of samples the Ar gas flow was kept constant at 100 sccm that was corresponded to approximately 3 mTorr. For the second set of experiments the total Ar and N<sub>2</sub> gases flow was kept constant and was equal 125 sccm.

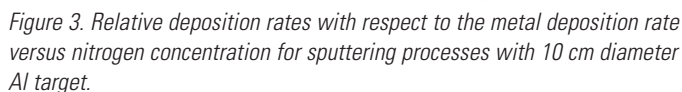
The parameters of the applied voltage pulse were optimized in order to get arc free discharge in the presence of Ar and N<sub>2</sub>. Two pulses were chosen. First pulse had duration 1000  $\mu$ s and the second one had duration 3000  $\mu$ s. The voltage oscillations frequency and amplitude were the same for each pulse. During the pulsing in pure Ar atmosphere the discharge voltage -700 V and discharge current 25 A were achieved. The phase shift between discharge voltage and current was a function of the ratio between Ar and N<sub>2</sub>. The pulse repetition rate 1000 Hz was used with 1000  $\mu$ s pulse and 330 Hz with pulse 3000  $\mu$ s. Samples S#16 and S#17 were sputtered with two pulses in order to form nano-layered structure of AlN film. Every layer was sputtered during 3 sec. This



All samples were sputtered at floating potential.

### AlN films deposition with 10 cm diameter target

The cross-sectional SEM images for AlN films (S#14 and S#17) are shown in Figures 4 and 5.



*continued on page 22*

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## Advanced Pulsed DC Technology

continued from page 21

X-ray diffraction ( $\Theta$  -  $2\Theta$ ) scan patterns for samples S#18, S#17, S#16 and S#14 are shown in Fig. 6. The (002) texture of AlN was observed for samples S#17 and S#14. The sample S#16 that was sputtered with two pulse shapes at high  $N_2$  pressure did not show the (002) texture.

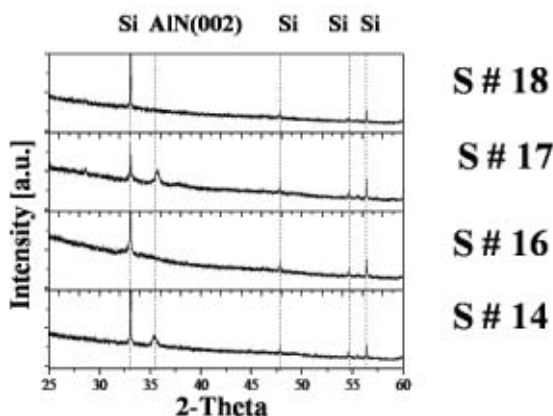


Figure 6. X-ray diffraction ( $\Theta$  -  $2\Theta$ ) scan patterns obtained for AlN films for the following samples: S#14, S#16, S#17, and S#18

### AlN films deposition with 15 cm diameter target

The relative deposition rate with respect to the metal deposition rate for the same level of average power as a function of  $N_2$  concentration is shown in Fig. 7. The sample S#23 had deposition rate 1600 Å/min and correct stoichiometric composition.

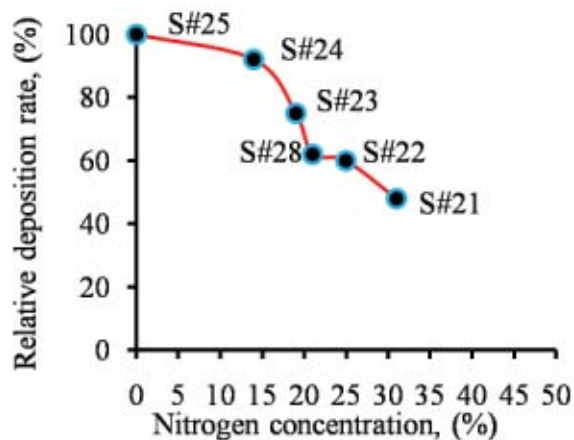


Figure 7. Relative deposition rates with respect to the metal deposition rate versus nitrogen concentration for sputtering processes with 15 cm diameter Al target.

The cross-sectional SEM image and SEM image of the surfaces of AlN film for sample S#23 are shown in Figures 8 and 9.

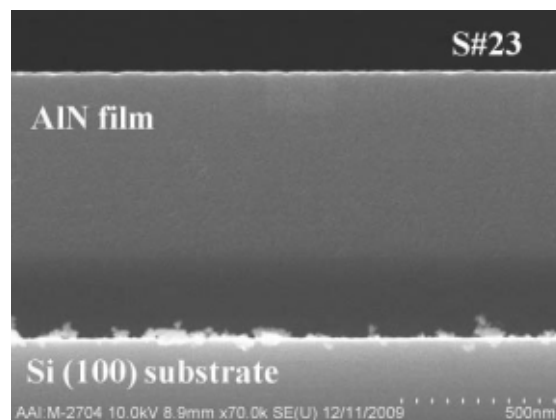


Figure 8. Cross-sectional SEM image of AlN film; sample S#23, Ar = 100 sccm,  $N_2$  = 20 sccm.

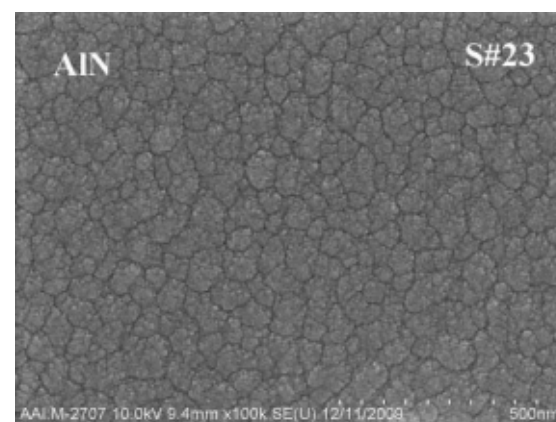


Figure 9. SEM image of the surface of AlN film; sample S#23, Ar = 100 sccm,  $N_2$  = 20 sccm.

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## Conclusion

During these experiments it was shown that by adjusting the voltage oscillation frequency and amplitude within the unipolar negative pulse it is possible to generate and sustain arc free magnetron discharge with Al target in Ar – N<sub>2</sub> atmosphere. The relative deposition rate of AlN films with respect to metal deposition as high as 75-80% was achieved for two magnetrons with different sizes. The arc free magnetron discharge was forming without applying a positive voltage during or after applied voltage pulse. The mechanism of the pulsed, arc free discharge is not clear yet.

The results are very important for industrial scale high rate reactive magnetron sputtering processes.

## Acknowledgment

The authors would like to thank Dr. Jianliang Lin of the Colorado School of Mines for XRD measurements.

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Roman Chistyakov



Bassam Abraham

**Bassam Abraham**, president and co-founder of Zpulser, LLC, co-founded Zond, Inc. in 2002 and served as VP Engineering/Business Development. Prior to that, he was Sr. Mechanical/Manufacturing Engineer and Honorary Co-Founder of Telephotonics, Inc., (Wilmington, MA); and earlier a Sr. Mechanical Design Engineer at AVS, Inc. (Ayer, MA). His various responsibilities included a variety of startup executive, manufacturing and engineering management roles. He received his B.S. Mechanical Engineering in 1997 and M.S. Engineering Management in 1999 from Northeastern University, Boston, MA.

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# Oblique Incidence and Dielectric-Coated Metals

Angus Macleod

Thin Film Center, Inc, Tucson, AZ

Contributed Original Article

## Introduction

As soon as we move to oblique incidence, the properties of surfaces, and any accompanying coatings, exhibit increased complexity. There is a sensitivity to polarization that does not appear at normal incidence, and phenomena such as total internal reflectance, discussed in an earlier article [1]. In this article we look at some effects that occur at oblique incidence in a simple system of a metal coated with a dielectric layer. Some of these are unwanted, some of purely academic interest (at least at present) and some can be useful.

## Fundamentals

The complications of polarization are eased somewhat by expressing any arbitrary polarization state in terms of the two eigenmodes of polarization,  $p$  and  $s$ -polarization, characterized by the electric vector parallel and normal to the plane of incidence, respectively.

The theory of the effects is then exactly that at normal incidence with the characteristic admittances and phase thicknesses replaced by those corresponding to the polarization and the angle of propagation in the particular layer or medium. We will make much use of the admittance diagram in what follows and so we shall use the modified versions of the tilted admittances. They retain the normal incidence value  $y_0$  for the admittance of the incident medium, regardless of polarization or incidence, so that the isorefectance circles remain as at normal incidence, nested about  $y_0$ .

The theory was developed in an earlier article [2]. The important results given there in equations (7), (8) and (9) are:

$$\begin{aligned}\eta_s &= \frac{[n^2 - k^2 - n_0^2 \sin^2 \vartheta_0 - i2nk]^{1/2}}{\cos \vartheta_0} \\ \eta_p &= \frac{(n - ik)^2}{\eta_s} \\ \delta &= \frac{2\pi d}{\lambda} [n^2 - k^2 - n_0^2 \sin^2 \vartheta_0 - i2nk]^{1/2}\end{aligned}\quad (1)$$

where the angle of incidence is  $\vartheta_0$  in the incident medium of index  $n_0$ , and the film has optical constants  $(n - ik)$  and physical thickness  $d$ . The film modified admittances are  $\eta_s$  and  $\eta_p$  for  $s$  and  $p$ -polarizations respectively, and  $\delta$  is the tilted phase thickness. The root is to be taken in the fourth quadrant. Note that the  $\cos \vartheta_0$  in the denominator of  $\eta_s$  assures the value of  $y_0$  (or  $n_0$ ) for the incident medium independent of  $\vartheta_0$ .

There are two common cases. Perfect dielectric materials have zero  $k$ . These are then given by

$$\begin{aligned}\eta_s &= \frac{[n^2 - n_0^2 \sin^2 \vartheta_0]^{1/2}}{\cos \vartheta_0} \\ \eta_p &= \frac{n^2}{\eta_s} \\ \delta &= \frac{2\pi d}{\lambda} [n^2 - n_0^2 \sin^2 \vartheta_0]^{1/2}\end{aligned}\quad (2)$$

Metals have large  $k$  that dominates their properties so that the term  $n_0^2 \sin^2 \vartheta_0$  is small compared with the remainder of the expression in the numerator of  $\eta_s$  in (1), and has little influence on it. If we neglect  $n_0^2 \sin^2 \vartheta_0$  then the results for metals become

$$\begin{aligned}\eta_s &= \frac{(n - ik)}{\cos \vartheta_0} \\ \eta_p &= (n - ik) \cos \vartheta_0 \\ \delta &= \frac{2\pi(n - ik)d}{\lambda}\end{aligned}\quad (3)$$

that are good enough approximations to use in explaining the effects.

## Dielectric-Coated Metal

Front surface mirrors, for example, normally consist of a suitable metal layer that yields the necessary broad-band high reflectance, together with a protective overcoat of dielectric material. Some interesting effects occur in this very simple system.

A study, reported in a 1980 paper by Nevière and Vincent [3] and inspired by some effects observed in overcoated diffraction gratings, predicted that for  $s$ -polarization and very high angles of incidence, close to grazing, the reflectance of a metal overcoated with a dielectric layer could fall to zero. The analysis was rather involved, and observation of the phenomenon appears never to have been reported, but it certainly must exist. We shall take a different route towards an explanation and show that a similar phenomenon exists also for  $p$ -polarization [4].

Figure 1 shows the admittance loci. The diagonal line is drawn from the origin to pass through the point  $(n - ik)$ , corresponding to the metal admittance at normal incidence. As the angle of incidence increases, the  $p$ -admittance of the metal moves down the line towards the origin and the  $s$ -admittance up the line and further away, as given by (3). At the same time, following (2), the  $p$ -admittance of the dielectric overcoat falls while its  $s$ -admittance rises. Thus the corresponding  $p$ -admittance circles shrink in radius and move towards the origin, while the  $s$ -admittance circles grow and move away from the origin. At a particular angle of incidence, the second intersection of the  $p$ -locus with the real axis will correspond to the point  $y_0$ , where the reflectance is zero, and similarly at a certain angle the first intersection of the  $s$ -admittance with the real axis will correspond to the point  $y_0$ . The actual reflectance will be zero only if the appropriate locus terminates at  $y_0$  and that condition implies a certain optical thickness. Now let the wavelength vary as well. As the wavelength increases or decreases the loci will shrink or grow in length, respectively. If we allow both wavelength and incident angle to vary then there will be some combination of wavelength and of angle that will assure zero reflectance. This will apply both to  $s$  and  $p$ -polarizations although not simultaneously at the same wavelength and angle. In fact, with films of reasonable thickness there will be multiple solutions. There will, of course, be dispersion of the optical constants, but that will simply perturb the values of the incident angle and wavelength.

We take, as an example, a protected aluminum front-surface mirror for the visible region. The aluminum is protected with a halfwave thickness of silica at a wavelength of 510 nm to give maximum luminous reflectance. Figure 2 and Figure 3 show the performance for  $s$  and  $p$ -polarizations, respectively. Note that the wavelength scales are slightly



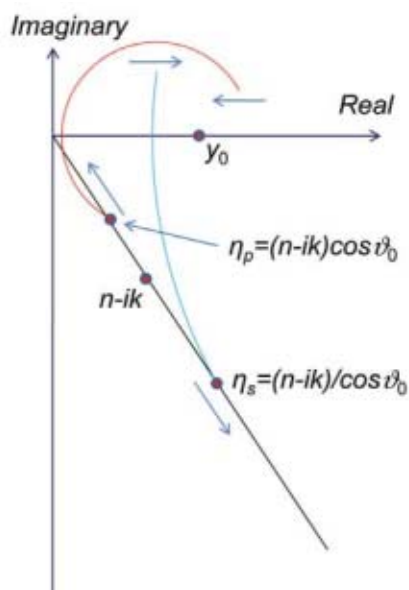


Figure 1. The admittance diagram showing the p-locus (red) and s-locus (blue) of the dielectric overcoat. As the angle of incidence increases the p-circle radius shrinks and the circle moves to the left while the s-circle radius expands and the circle moves to the right.

different to make the resonant features clearly visible. In fact, calculation in the 200 nm to 300 nm region would reveal further expected resonances.

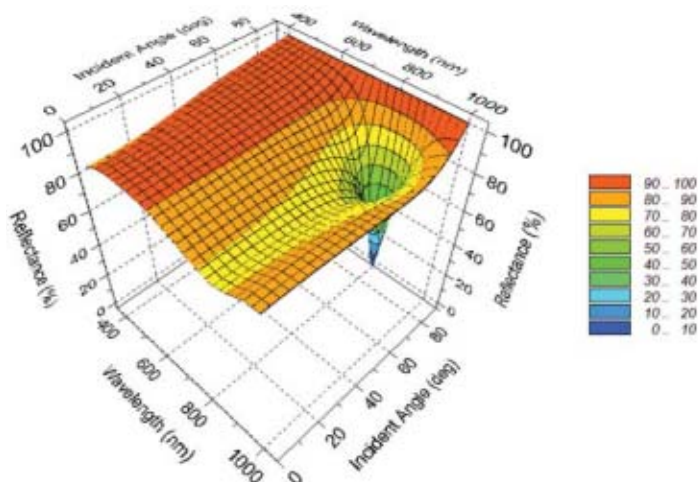


Figure 2. The s-reflectance as a function of wavelength and incident angle showing the deep resonant feature just beyond 800 nm and at almost grazing incidence.

The critical angle and total internal reflection were reviewed in a previous Bulletin article [1]. Briefly, given the angle of incidence and the two refractive indices on either side of the boundary, Snell's Law predicts the angle of propagation in the emergent medium. When the incident medium has higher refractive index than the emergent, the angle of propagation becomes 90° at an angle of incidence known as critical. Beyond that angle, the solution to Snell's Law becomes imaginary, propagation of a progressive wave into the emergent medium becomes impossible and total reflection is the consequence. The electromagnetic field that does enter the emergent medium, decays exponentially with distance from the boundary, and is known as evanescent. If a thin film is added to the surface and the material index is less than that of the incident medium, then it too can exhibit the same critical angle phe-

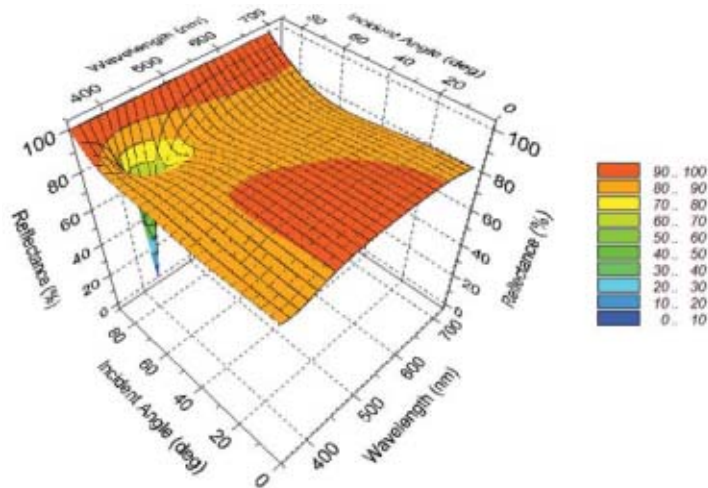


Figure 3. The p-reflectance as a function of wavelength and incident angle showing the deep resonant feature at about 430 nm and at almost grazing incidence.

nomenon and evanescent field. A thin film implies limited thickness and in addition to the tilted admittances we must also consider what happens to the phase thickness,  $\delta$ . The set of equations (2), apply and we can adjust them slightly to make the results clearer. Beyond the critical angle the quantity inside the square brackets is negative real, and for the square root to be in the fourth quadrant, it must be negative imaginary. We can write the relationships as

$$\eta_s = -i \frac{\left[ n_0^2 \sin^2 \vartheta_0 - n^2 \right]^{1/2}}{\cos \vartheta_0} = -ih \quad (4)$$
$$\eta_p = \frac{n^2}{\eta_s} = i \frac{n^2}{h}$$
$$\delta = -i \frac{2\pi h d}{\lambda}$$

where  $h$  is positive real.

Both  $\eta_s$  and  $\delta$  are negative imaginary. Thus a film of this material at the appropriate angle of incidence will behave for s-polarization as a perfect metallic film. Admittance loci will be perfect arcs of circles, described clockwise and starting at the point  $h$  on the positive limb of the imaginary axis and terminating at  $-h$  on the negative limb. The behavior for p-polarization is more interesting. Here  $\eta_p$  is positive imaginary while  $\delta$  remains negative imaginary. The admittance loci are still arcs of circles, but the circles are described *counter clockwise*, starting at  $-n^2/h$  on the negative limb of the imaginary axis and terminating at  $n^2/h$  on the positive limb.

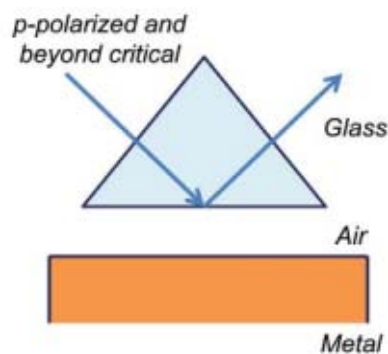


Figure 4. Form of coupling into a surface plasmon on the surface of bulk metal.

continued on page 26

## Oblique Incidence

continued from page 25

An important application is in coupling into a surface plasmon. We looked briefly at a surface plasmon resonance in an earlier Bulletin [2]. There the metal was a thin film, of closely controlled thickness, deposited on a surface illuminated by *p*-polarized light beyond the critical angle. The plasmon was excited on the outer surface. The present alternative technique [5] can excite a plasmon on the surface of bulk metal. The arrangement is sketched in Figure 4 and is usually known by the name Otto.

The admittance locus starts at the interface with the substrate or emergent medium, and, in this case, it is the surface of the metal. For a high-performance metal, like silver, the starting point will therefore be close to the imaginary axis in the fourth quadrant. The tilted admittances of both the metal and the air coupling layer, vary with angle of incidence, but the variation of the air admittance is very much faster. There is a very precise angle, where  $-in^2/h$  is very close to the admittance of the metal, and where the circular locus of the air, which starts at the metal, passes through the point corresponding to the incident glass medium, Figure 5. Then if the air layer is of exactly the correct thickness, the reflectance of the system is zero. The conditions vary rapidly with angle and so the drop in reflectance is a very narrow angular feature, Figure 6. These calculations used silver, borosilicate crown glass and a wavelength of 632.8 nm.

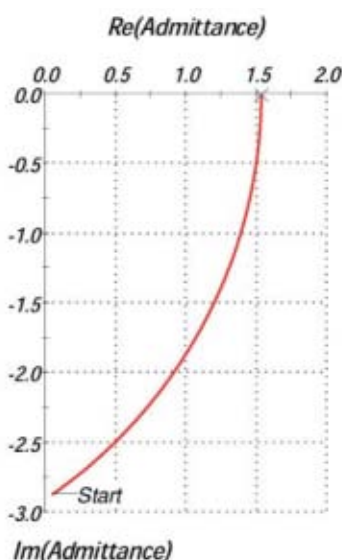


Figure 5. The *p*-polarized admittance locus of the coupling into the surface plasmon as in Figure 4. The starting point is the surface of the bulk metal.

A 1985 paper [6] reported an unexpectedly high transmittance of a system involving a metal film surrounded by two dielectric films. the angle of incidence was set beyond the critical angle for the dielectric films. The arrangement is shown schematically in Figure 7. Since the two dielectric films are tilted to an angle beyond critical, they present the same behavior as the air film in the Otto coupling arrangement just discussed. We can understand the effect as a double application of this coupling, so that the low-index films act as perfect antireflection coatings for the metal. By a happy coincidence, the arrangement also produces a minimum of electric field amplitude in the middle of the metal, reducing its losses.

We take borosilicate crown glass as the prism materials, cryolite ( $\text{Na}_3\text{AlF}_6$ ) as the dielectric film, and silver as the metal. We use a wavelength of 632.8 nm, an angle of incidence of  $73^\circ$ , beyond critical for the cryolite, and arbitrarily choose a thickness of 60 nm for the silver.

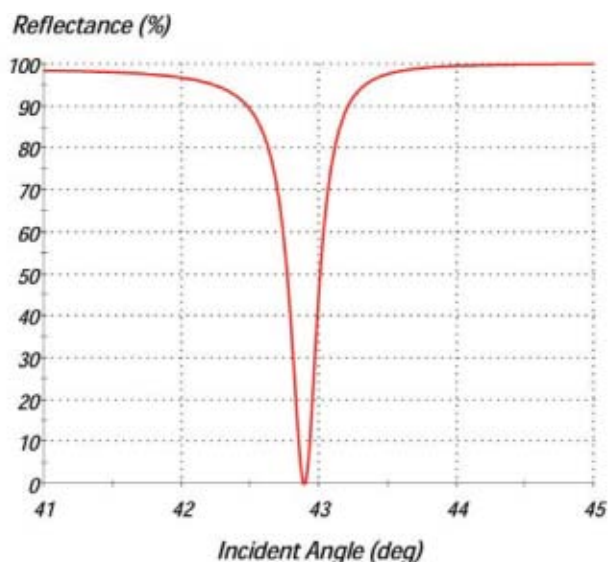


Figure 6. The *p*-reflectance associated with the Figure 5 coupling into the surface plasmon resonance.

Some adjustment of the thicknesses of the two cryolite layers results in the admittance locus of Figure 8, where, since the starting and finishing points coincide, we achieve zero reflectance. The resulting *p*-transmittance at 632.8nm is shown in Figure 9 and the reason for the high transmittance revealed as the very low electric field amplitude in the silver film, Figure 10. This electric field distribution in the silver layer is reminiscent of the distribution in a metal layer with transmittance optimized by potential transmittance theory [7] and indeed we can use this theory to maximize the transmittance in this arrangement [8] when the thicknesses of the dielectric films become completely symmetrical. Some small adjustment of the angle of incidence or of the thickness of the metal film is necessary if maximum potential transmittance is to be achieved.

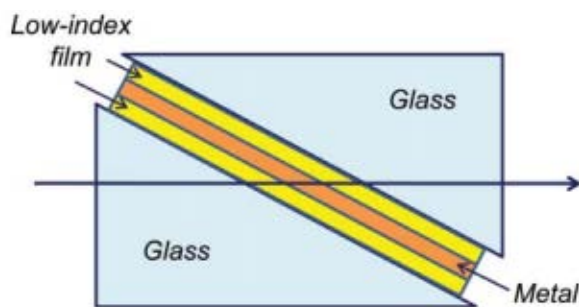


Figure 7. The arrangement giving enhanced metal transmittance.

The appearance of the field distribution in Figure 10 supports the idea of Otto coupling to a surface plasmon on either surface of the metal film and leads to an alternative explanation of the phenomenon. It is possible to couple into a surface plasmon in other ways. In particular, a diffraction grating of the correct grating constant can permit coupling from a normally incident beam into a surface plasmon and this is a well-known loss mechanism in diffraction gratings. The grating in this case can consist of a regular two-dimensional array of small holes in the metal film [9, 10], or bumps on its surface [10], and the effect shown in Figure 9 can then be reproduced at normal incidence. The grating spacing fixes the wavelength at which the effect occurs most strongly. It is important to note that the maximum achievable transmittance, is still that given by potential transmittance theory. This combination of scattering and interference effects is a fruitful area of current research in nanotechnology.



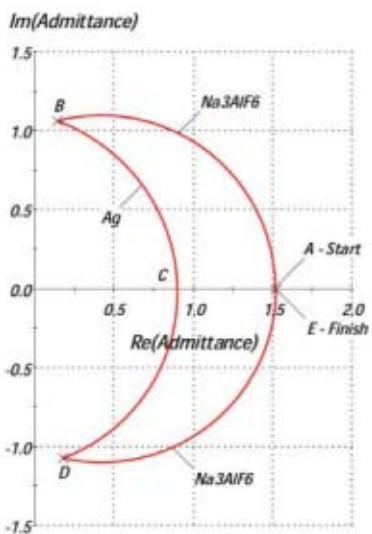


Figure 8. The admittance locus at 632.8 nm, for p-polarized light and for 73° incidence, of the arrangement shown in Figure 7. The locus is described from emergent to incident medium in the order ABCDE. Note that the cryolite ( $\text{Na}_3\text{AlF}_6$ ) segments are described A to B and D to E, that is counter clock-wise. The thicknesses from incident to emergent media are: Cryolite 230 nm, Ag 60 nm and Cryolite 250 nm.

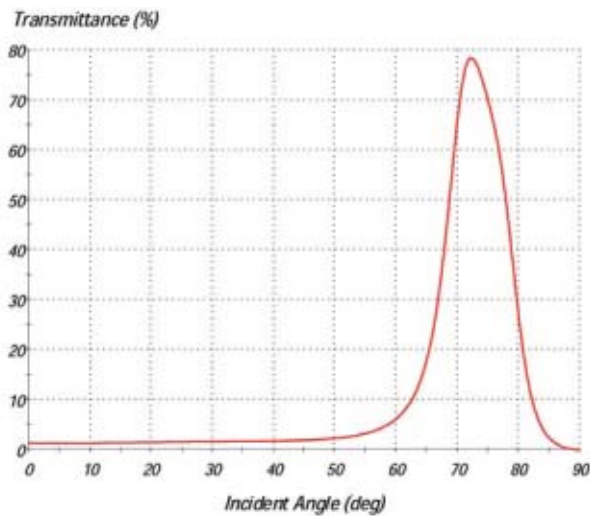


Figure 9. The p-transmittance, at 632.8 nm, of the design of Figure 8.

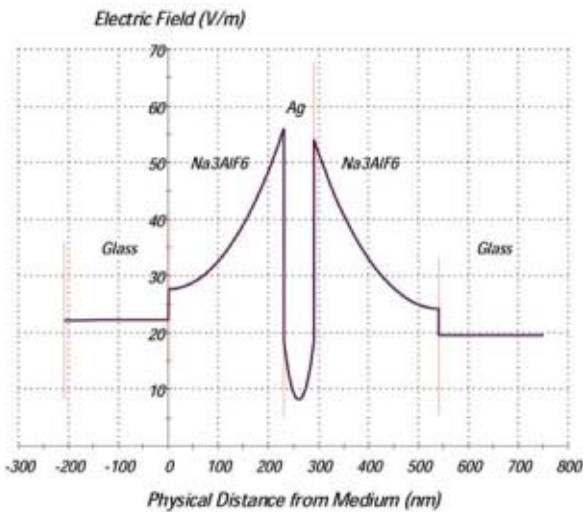


Figure 10. The distribution of total electric field amplitude through the struc-  
ture corresponding to an incident irradiance of  $1 \text{ Wm}^{-2}$ . continued on page 28

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## Oblique Incidence

continued from page 27

So far, we have been dealing with completely lossless dielectric films. Since metal-coated front-surface mirrors are frequently used over very wide spectral regions, their protective dielectric overcoats are not always completely free from absorption. Aluminum as the metal, and silicon oxide as protection, is probably the most common combination in this application. In the infrared, silicon monoxide is sometimes preferred over the dioxide, because its onset of absorption at a slightly longer wavelength yields marginally better performance at longer wavelengths. Figure 11 shows the normal incidence performance, over the range 6 to 13  $\mu\text{m}$ , of a silicon monoxide protected aluminum front-surface mirror. The silicon monoxide layer is some 350 nm thick. There is a slight dip at just beyond 10  $\mu\text{m}$ , due to unavoidable absorption in the silicon monoxide, but the overall performance is very satisfactory. It came as a great surprise when S.F. Pellicori reported that there was a serious problem at oblique angles of incidence.

The observation was quickly matched by calculation [11], and the effect appeared to be associated with the reststrahlen band of silicon monoxide, shown in Figure 14. The strange feature was that the major effect was confined to the short-wave threshold of the band, and not the center where the absorption is highest. Why is this?

The answer is in the tilted admittances. We retain the modified ones, but the explanation is the same for the unmodified. At the threshold of the reststrahlen band, the refractive index,  $n$ , falls to a quite low value, less than unity, while the extinction coefficient,  $k$ , is rising, but not too much. The incident medium now has an index rather greater than that of the film. The conditions are somewhat similar to those for  $p$ -polarization beyond the critical angle, where the tilted admittance of the lower index dielectric film becomes positive imaginary. Here, the tilted admittance of the silicon monoxide briefly enters the first quadrant instead of remaining in the fourth. The calculated real and imaginary parts of the tilted admittance are shown in Figure 15.

The phase thickness,  $\delta$ , is always in the fourth quadrant. When the admittance is in the first quadrant and the phase thickness in the fourth, the spiraling locus that is normally described clockwise, switches to counter clockwise. Thus, instead of hugging the imaginary axis, like the  $s$ -polarized admittance, the  $p$ -locus curves the other way, as shown in Figure 16. It terminates very close to the admittance of the incident medium. Low reflectance is the result.

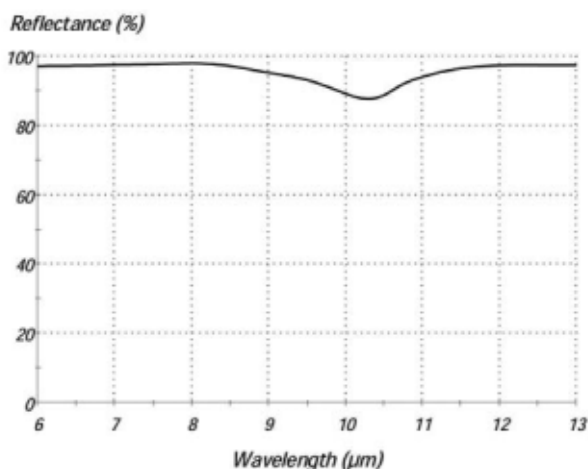


Figure 11. The performance at normal incidence of an aluminum mirror protected by a thin (350 nm) film of silicon monoxide.

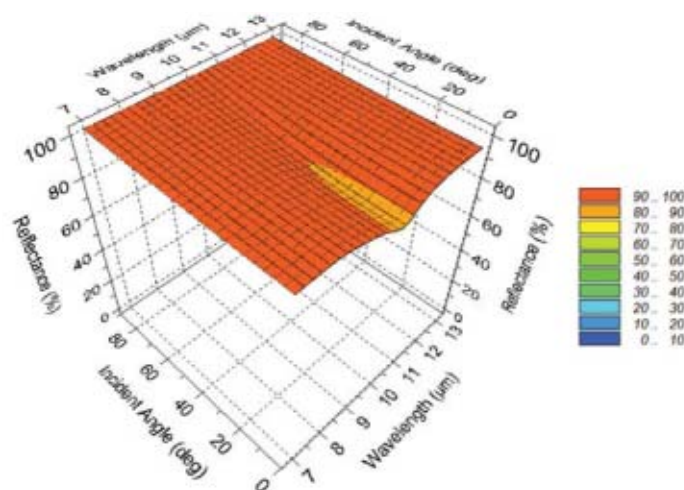


Figure 12. The  $s$ -reflectance of the protected aluminum mirror as a function of wavelength and incidence. As the angle of incidence increases the slight dip just beyond 10  $\mu\text{m}$  gradually disappears.

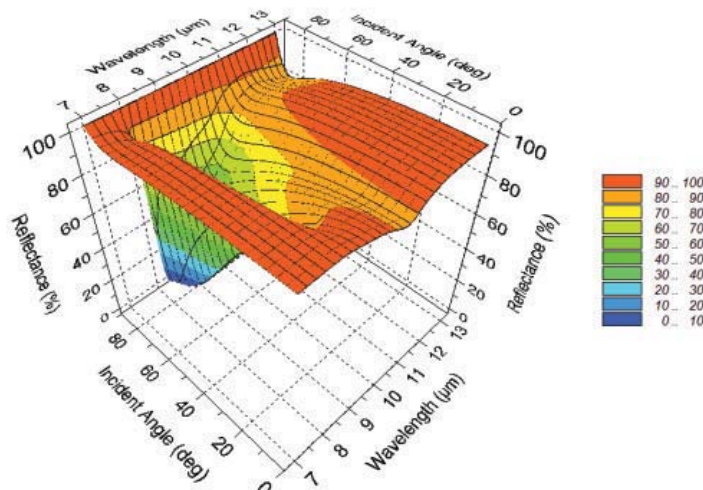


Figure 13. The  $p$ -reflectance shows that as the angle of incidence increases an enormous dip opens up at around 8.5  $\mu\text{m}$ .

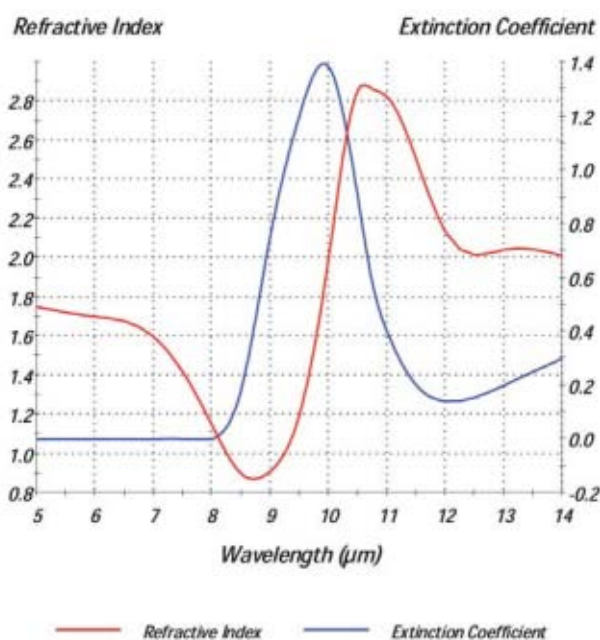


Figure 14. The optical constants of silicon monoxide in the infrared [12].



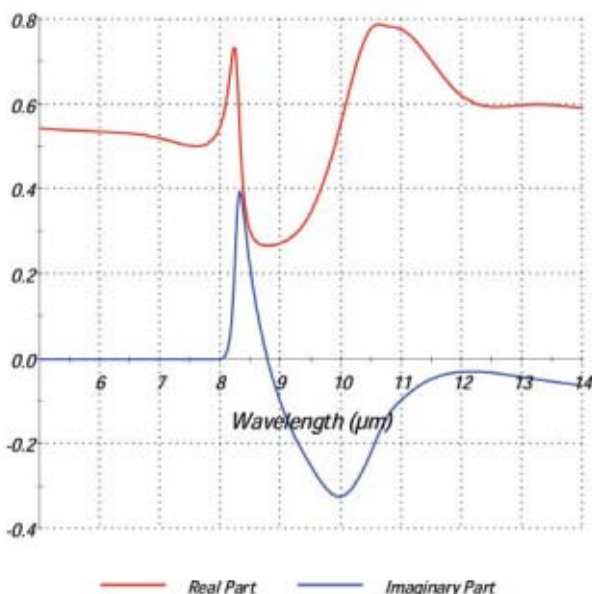
Real and imaginary parts of  $p$ -admittance

Figure 15. The real and imaginary parts of the modified tilted  $p$ -admittance of silicon monoxide at  $75^\circ$ . Over most of the region between 8 and 9  $\mu\text{m}$  the admittance is in the first quadrant.

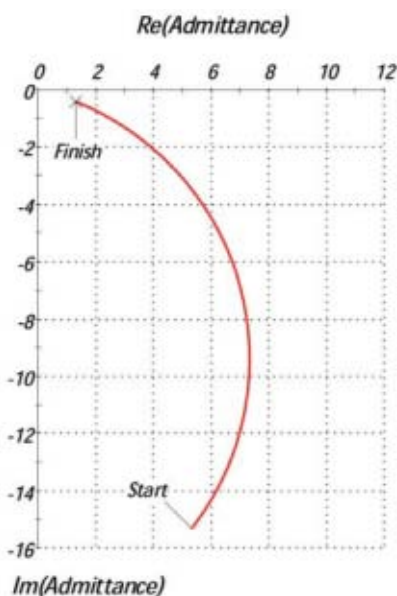


Figure 16. The  $p$ -admittance locus at 8.6  $\mu\text{m}$  and  $75^\circ$  of the silicon monoxide layer. Note the counter clockwise rotation.

## Conclusion

A metal overcoated with a dielectric layer seems at first sight to be a quite simple system but there are all kinds of interesting effects associated with it. This article has looked at just a few of these.

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# SVC Education Guide | Surface Preparation

## Cleaning Lines

Donald M. Mattox, *Management Plus, Inc., Albuquerque, NM*

A cleaning line is a sequence of procedures that complement each other and result in a surface being cleaned to the desired level, at least temporarily. The cleaning line may be manual, where the parts are transferred from one stage to the next by an operator, or it may be automated, where the movement of the parts is automatic and pre-timed, or it may be a mixture of the two. In some cases the parts to be cleaned may be held by special cleaning fixtures (racks) and the parts must be placed on the holders ("racked") and removed from the rack after cleaning. In other situations the cleaning rack is also used as the deposition fixture. This has the advantage that only the fixture has to be handled in transferring the parts from the cleaning line to the deposition system. A disadvantage is that the fixtures may have to be stripped of deposited film before they can be used for cleaning again. In some cases the cleaning line is integrated into the deposition line so there is no handling or storage between the cleaning sequence and the film deposition process. More commonly, however, cleaned parts are handled, stored, and transported either individually or in their fixture after the cleaning operation.

Figure 1 shows a typical tank-type cleaning line using aqueous alkaline cleaning. The cleaning solution is applied both by immersion and spraying followed by both spray and

immersion rinsing and finally hot-air blow drying. Immersion with chemical action is used for removing films and surface layers from substrate surfaces. Immersion with agitation and perhaps mechanical brushing, is often effective in removing contaminants such as particulates. In some cases ultrasonic cavitation and agitation are desirable. Electrocleaning can be incorporated into the alkaline cleaning tank. If there is appreciable oil contamination, the first tank should be equipped with a "skimmer" or it should use "overflow" to skim the surface so that the parts are not extracted through an oil film when they are lifted out of the tank.

Immersion cleaning has the advantage that "soaking" can be used for removing or "loosening" contaminants. Immersion cleaning has the disadvantage that cavities fill with fluid, and the cleaning fluid can become saturated with contaminants and stagnant in that region. Spray cleaning and rinsing has the advantage that "hideouts," such as cavities, are continuously drained and refilled. Spray pressure should be as high as possible without damaging the substrates or knocking them loose from the rack. It may be desirable to mechanically move the parts in each step to aid in cleaning and draining.

It is important that the parts are not allowed to dry between cleaning stages. This means that the transfer between tanks

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should be as rapid as possible and the air above the tanks should be humid. In some cases the cleaning line should be enclosed in a plenum to obtain better control of the environment surrounding the cleaning line. The plenum can be solid with access doors, or a "soft-wall" to allow access to the cleaning line at any point. The soft-wall can be made of plastic sheets or strips. The plenum can be slightly pressurized with clean filtered air to further control the cleaning environment. The plenum also allows easier venting of vapors from the cleaning area.

Rinsing is important at several stages of cleaning. Rinsing between cleaning steps prevents the "drag-out" of chemicals from one cleaning stage to the next. Intermediate rinsing can often be done with "soft water" rather than with pure or ultrapure water. The final rinse is usually done with pure or ultrapure water. Pure water is produced by membrane filtering using reverse osmosis. Ultrapure water uses ion exchange columns to lower the ionic content of the water below that achieved by reverse osmosis. Both purification methods use carbon filters to remove organic materials and mechanical filters to remove particulates. One key to effective rinsing is to use copious amounts of rinse water. This means that some method of recycling of the rinse water may be desirable.

In some cases the final rinse may contain a material that inhibits recontamination after cleaning. For example, a "flash-rust inhibitor" may be used to prevent rusting of mild steel after the alkaline cleaning operation which removes oxide surface layers. This protective material may be removed in the PVD deposition chamber by *in situ* cleaning. The final rinse fluid may be a material that has a surface tension less than pure water such as a water-alcohol mix (1:1) or a drying solution. These materials can penetrate into "hideouts" better than water to displace cleaning fluids. These low surface tension fluids can be "blown off" more easily in the drying stage. If the rinse fluid has a high vapor pressure this will also aid in drying.

Ultrasonic agitation can be used in any of the fluid tanks. Ultrasonic power should be about 100 watts per gallon of fluid. For some materials, care must be taken when using ultrasonic cavitation because prolonged high-power cavitation can fracture the surface

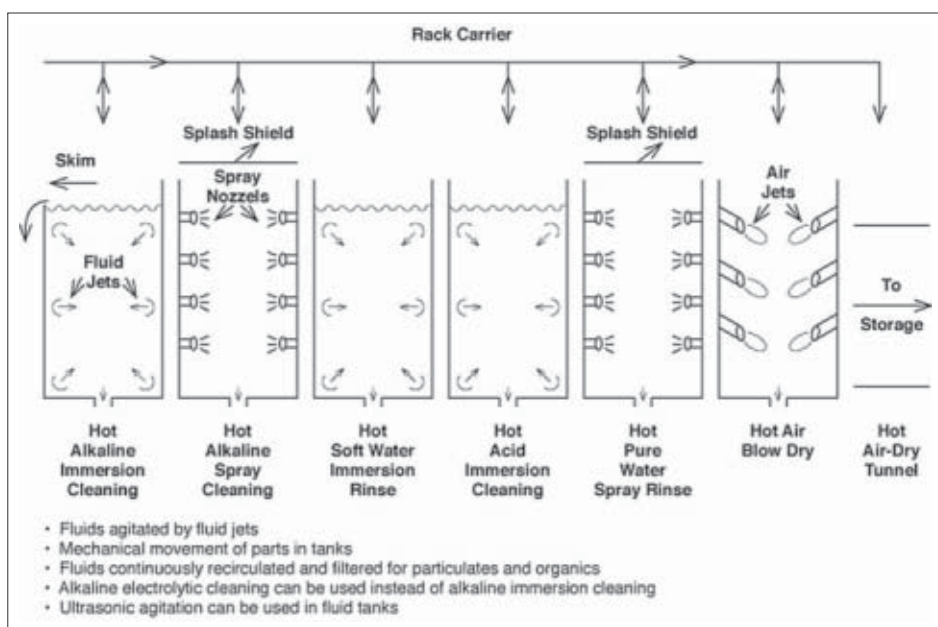


Figure 1. Typical tank-type cleaning line for parts mounted on a rack.



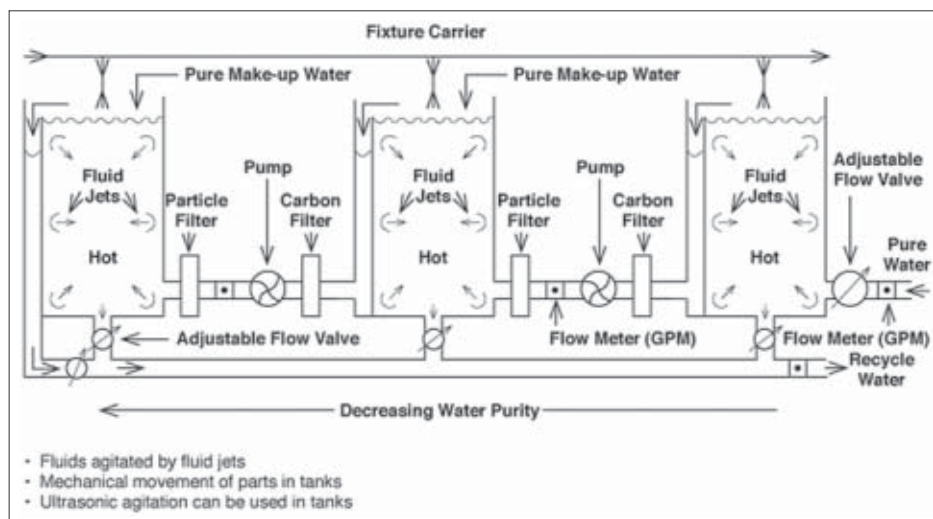


Figure 2. Cascade (counterflow) rinse tanks.

of brittle materials and deform, erode and microroughen the surface of ductile materials. These surface features can then affect film growth, properties, and adhesion.

When the cleaning requirements are very stringent it may be desirable to use "cascade" or "counterflow" rinsing. Figure 2 shows a cascade rinse tank arrangement where there are three rinse tanks with increasing water purity. The parts move from the lowest-purity to the highest-purity tank. The water between each stage is filtered. The condition of the

water in each tank is monitored by measuring the ionic conductivity. The conductivity in the tank is controlled by the flow of water from the previous tank and the amount of pure or ultrapure "make-up" water used. It should be realized that the conductivity measurements do not indicate the presence of organic or particulate contaminants that can build up in the system if they are not removed by filtering.

The final step in the cleaning line is drying, which ensures that there is no significant amount of residue left on the surface.

Water tends to dry by "puddling-up" which gives local contamination ("water spots"). In the cleaning line shown, drying is achieved by blow-off with hot air to remove as much water as possible, along with mechanical movement of the parts to promote draining. The parts can be further dried on their way to the storage or deposition area through a low-humidity, warm drying tunnel. Drying can also be done using an enclosed vapor dryer. Vapor drying is particularly useful when there are hideouts that retain water by capillary action.


After drying, the cleaned parts should be stored and transported in a manner that does not allow undue recontamination of the parts. This can best be done by incorporating the cleaning line into an in-line deposition system. This is commonly done in coating mirrors and architectural glass panels.

Often the final cleaning of the substrate surface is done in the deposition chamber (*in situ* cleaning). *In situ* cleaning can include: sputter cleaning, plasma cleaning, reactive plasma cleaning, and/or heating.


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Thin Film Characterization



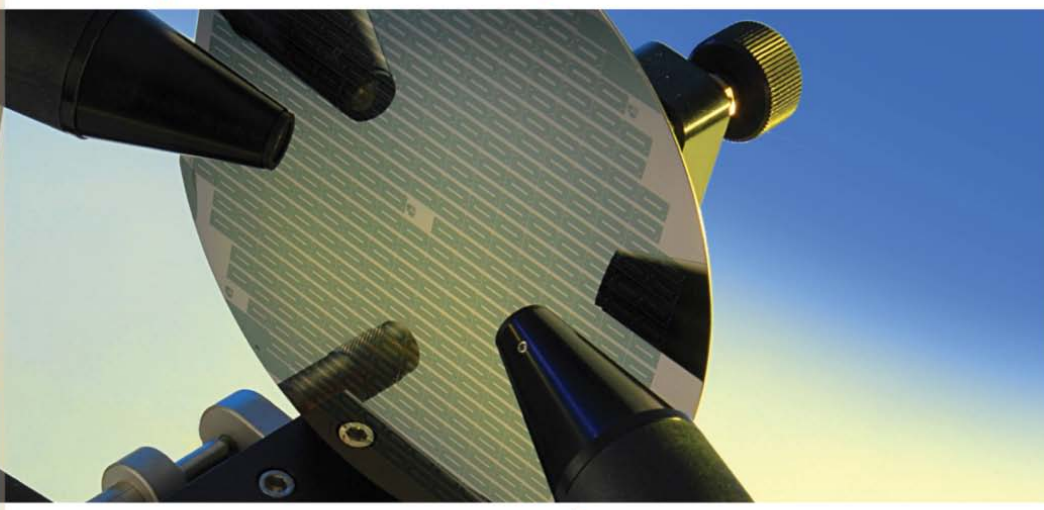
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# Mass/Energy Analysis of a Modulated Pulse Power Plasma Compared to a DC Plasma

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## Abstract

An electrostatic quadrupole plasma mass spectrometer was used to characterize the plasma during modulated pulse power (MPP) and conventional DC sputter deposition of Cr films with a pair of opposed-cathode in a closed field unbalanced magnetron sputtering system. Experiments were run with the different types of power applied to just one of the cathodes, but with the closed field configuration. The mass analysis detected  $\text{Cr}^+$ ,  $\text{Ar}^+$ ,  $\text{Cr}^{+2}$ , and  $\text{Ar}^{+2}$  ions. The intensity of the  $\text{Cr}^+$  ions when the MPP power is used is significantly higher compared to when DC power is used. As the peak power and the average power of the MPP pulse were increased, the intensity of the ions also increased in the closed field condition as it did when DC power was used. The energy analysis revealed that the average energy for both the  $\text{Cr}^+$  and  $\text{Ar}^+$  ions in the MPP plasma is about 2 eV. However in the DC plasma, the average energy for the  $\text{Cr}^+$  ions is about 4 eV, and it is about 3 eV for the  $\text{Ar}^+$  ions. The ion energy distribution is relatively narrow, and there is a small high energy ion energy distribution tail that extends out to about 10 eV for  $\text{Cr}^+$  and  $\text{Ar}^+$  ions in both the MPP and DC plasmas.

## Introduction

High power pulse magnetron sputtering (HPPMS), which is also known as high power impulse magnetron sputtering (HIPIMS), was first introduced to the world in a paper published by Kouznetsov et al. [1] in 1999. By applying a large amount of power to the sputtering target for a short period of time and then repeating the pulse periodically, they showed that it is possible to obtain a high degree of ionization of the sputtered material. Power densities on the target were on the order of  $1,000\text{--}3,000\text{ W cm}^{-2}$  during the pulse, but the pulse width (full width half maximum) was only about  $100\text{--}150\mu\text{s}$ . Pulse duty cycles were usually less than one percent.

The ability to produce a highly ionized flux of coating material from a sputtering process was particularly enticing because the potential could be seen to produce fully dense films with more uniform coverage, particularly on 3-dimensional substrates. Petrov et al. [2] demonstrated that for coating fluxes with high ion to neutral ratios, it is possible to achieve fully dense films with low ion energies on the order of 20 eV. The low ion energy leads to less damage in the films from the arriving ions and hence the stress in the film can be low.

The advantages of HPPMS were quickly recognized, and research efforts to understand the HPPMS process were started first in Linköping University in Sweden in Professor Ulf Helmersson's group and shortly thereafter at Sheffield Hallam University in the UK in Professor Wolf-Dieter Münz's group. From the efforts at these two universities, the word quickly spread about the advantages of HPPMS, and several other organizations in Europe became involved with HPPMS. In the United States, early work on HPPMS was carried out at Advanced Energy Industries, Inc. in Colorado under the direction of Dr. David Christie.

Although the advantages of HPPMS are important, there is one disadvantage with the technique, which is that there is a significant loss in

deposition rate compared to conventional DC sputtering. The HPPMS deposition rate is typically only about 25-30% of the DC rate for an equivalent amount of power input [3]. Christie [4] developed a model to explain the loss in the HPPMS deposition rate that shows that sputtered atoms that are ionized can be attracted back to the target surface instead of going to the substrate for film formation.

There is an alternative form of HPPMS called modulated pulse power (MPP) [5,6,7] sputtering that overcomes the rate problem with the Kouznetsov style of HPPMS. An MPP pulse is actually a multi-step pulse that is made up of packets of micro pulses [8]. Typically an MPP pulses has three parts to it. The first part is the ignition of the plasma, the second part is the stabilization of a weakly ionized plasma, and finally the third part is the transition to the strongly ionized plasma regime. This latter transition is accomplished by increasing the voltage applied to the sputtering cathode.

The peak power in an MPP pulse is typically less than what it is in a Kouznetsov type HPPMS pulse, and the peak MPP power is typically in the  $100\text{--}300\text{ W cm}^{-2}$  range compared to  $1,000\text{--}3,000\text{ W cm}^{-2}$  range for the Kouznetsov pulse. The MPP pulse length can be up to 2-3ms long.

Another distinct difference between these two different forms of HPPMS is that it is possible with MPP to not only equal the DC deposition rate, but to actually exceed it [6]. The reasons for the high deposition rate with MPP are not fully understood yet, but it is believed that the high rate is due to both sputtering and evaporation/sublimation processes taking place on the target surface [9].

Optical emission spectroscopy of the MPP plasma has shown that there is a high degree of ionization of the sputtered material [5], but with the equipment used to measure the optical emission only plus one peaks of the sputtered material were detected, which seemed unusual. There should be multiply ionized peaks in the MPP plasma, and thus in this work an electrostatic quadrupole plasma (EQP) mass spectrometer was used to characterize and compare the plasmas during sputtering of chromium using both conventional DC and MPP power. The positive ion mass distributions and the positive ion energy distributions (IED) were determined.

## Experimental Procedures

Experiments were carried out in an opposed-cathode closed field unbalanced magnetron sputtering system with a pair of sputtering cathodes. During this work, only one cathode was powered at any given time. The average power was varied between 0.8 and 2.8kW. The distance between cathodes was 240 mm, and the sputtering pressure was 0.67Pa (5mTorr). The cathodes are from Teer Coatings Ltd., and the target size is 106mm x 298mm. A Hidden Analytical EQP was used to determine the time averaged positive ion mass distributions and the positive ion energy distributions during sputtering with MPP or DC power. The EQP probe was located where a substrate would normally be placed during deposition, but it was also tried in different orientations with respect to the target surface. It was found that the probe position influences the intensities of the ions but not the species detected. For the data reported in this paper, the barrel of the probe was parallel to the target surface, and



the inlet to the orifice at the end of the barrel was perpendicular to the target surface. Also the inlet to the probe at the end of the barrel was 120mm from the target surface and 2.5cm off of the centerline between targets. To show the effect of the closed-field unbalanced magnetrons on the plasma intensity, experiments were run with and without the closed field condition.

## Results

The EQP ion mass scans detected ions of  $\text{Cr}^{+1}$ ,  $\text{Ar}^{+1}$ ,  $\text{Cr}^{+2}$ , and  $\text{Ar}^{+2}$  at a point in the plasma where a substrate would normally be placed. In addition trace amounts of what is believed to be  $\text{Cr}^{+3}$  and  $\text{Cr}^{+4}$  have been detected. In Figure 1, the ion intensities in counts per second (cps) as a function of the average target power are shown for the principal ions detected during the sputtering of Cr with either MPP or DC power. The number of ions in the MPP plasma increases as the average power (and peak power) increases in the power range investigated in this work, but the  $\text{Ar}^{+1}$  ions in the DC plasma level off after about 2kW. Why the number of  $\text{Ar}^{+1}$  ions remains steady after 2kW is not known at this time. Additional work needs to be done to determine the effect of high average and peak power levels on the number of ions produced.

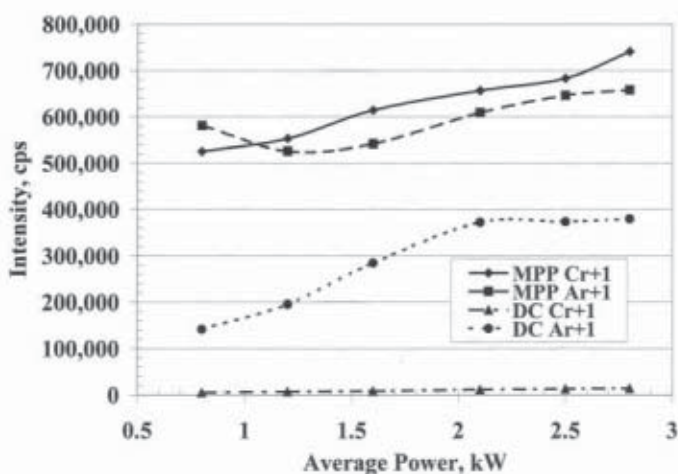


Figure 1. MPP and DC positive ion intensities as a function of the average target power.

There are significantly more ions, both  $\text{Cr}^{+1}$  and  $\text{Ar}^{+1}$ , produced in the MPP plasma compared to the number of ions produced in the DC plasma. For the DC plasma, the  $\text{Ar}^{+1}$  ions dominate, and the number of  $\text{Cr}^{+1}$  ions is small compared to the  $\text{Ar}^{+1}$  ions.

It is somewhat surprising as to the number of  $\text{Ar}^{+1}$  ions detected in the MPP plasma because earlier work reported by Vlcek [10] showed that there is significant rarefaction of the Ar gas in front of the target due to the high flux of energetic sputtered particles leaving the target surface and colliding with the Ar gas atoms. It may be that the closed magnetic field is very effective in confining the large number of secondary electrons that are emitted from the target surface. These secondary electrons can then undergo multiple electron impact ionization of the Ar atoms in the space where the substrate is placed. Why the number of Ar ions is so high is another one of the unanswered questions about the MPP process that needs further study.

The EQP measurements of the time averaged IEDs are shown in Figures 2 and 3 for the  $\text{Cr}^{+1}$  and  $\text{Ar}^{+1}$  ions, respectively, during sputtering of Cr with MPP and DC power at an average power level of 1.2kW. The number of MPP  $\text{Cr}^{+1}$  ions is significantly greater than the number of DC  $\text{Cr}^{+1}$  ions. The peak ion intensity for the MPP  $\text{Cr}^{+1}$  ions is about 536,000cps compared to a peak intensity of about 8,600cps

for the DC  $\text{Cr}^{+1}$  ions. This data shows very distinctly how little of the sputtered material becomes ionized in a conventional DC sputtering process.

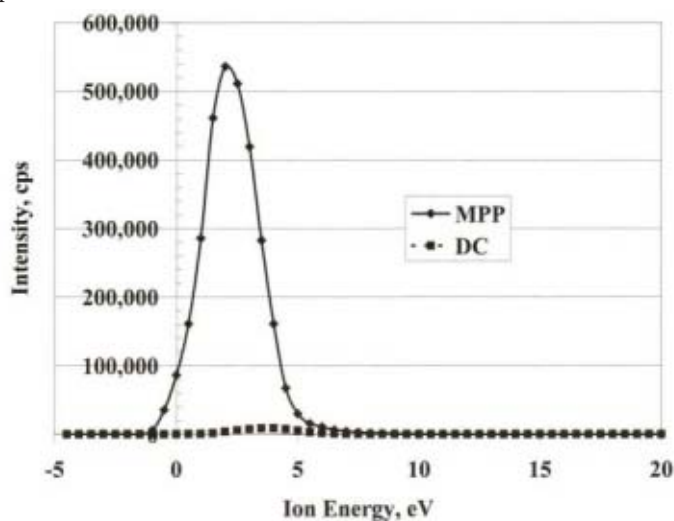


Figure 2. IED for  $\text{Cr}^{+1}$  ions produced during MPP and conventional DC magnetron sputtering of Cr.

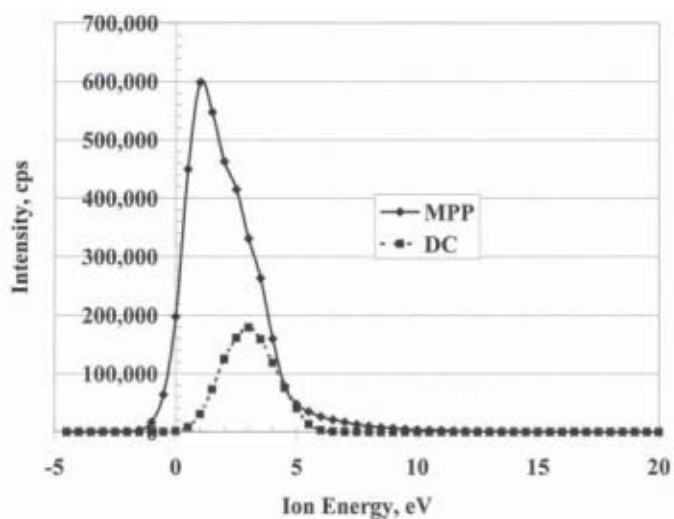


Figure 3. IED for  $\text{Ar}^{+1}$  ions produced during magnetron sputtering with MPP and conventional DC power.

The time averaged IEDs for the  $\text{Cr}^{+1}$  ions are relatively narrow for both types of power as is shown in Figure 2. The average energy for the  $\text{Cr}^{+1}$  ions is 2eV, and only a small number of ions have an energy exceeding 5eV. The average energy for the DC  $\text{Cr}^{+1}$  ions is slightly higher than that of the MPP  $\text{Cr}^{+1}$  ions and is about 4eV. Both the MPP and DC  $\text{Cr}^{+1}$  IEDs show a relatively small high energy tail. The upper energy value is about 10eV for the  $\text{Cr}^{+1}$  ions produced by both types of power.

The time averaged IEDs for the MPP and DC  $\text{Ar}^{+1}$  ions are shown in Figure 3. The difference in intensities for the  $\text{Ar}^{+1}$  ions produced by both types of power is not as great as it was for the  $\text{Cr}^{+1}$  ions. The MPP  $\text{Ar}^{+1}$  ions have the highest intensity at about 600,000cps compared to an intensity of about 180,000cps for the DC  $\text{Ar}^{+1}$  ions. The average ion energy for the MPP  $\text{Ar}^{+1}$  ions is about 2eV, but it is higher for the DC  $\text{Ar}^{+1}$  ions at about 3eV. Similar to the  $\text{Cr}^{+1}$  IEDs, both the MPP and DC  $\text{Ar}^{+1}$  IEDs have a relatively small high energy tail that extends out to about 10eV.

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## Mass/Energy Analysis

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Both IEDs plots for the  $\text{Cr}^{+1}$  and  $\text{Ar}^{+1}$  ions show a small negative energy region. It is believed that that this negative energy region is an artifact of ions being created inside the EQP probe during the measurements. For more details on this phenomenon, see the work by Lin et al. [8].

## Summary

An electrostatic quadrupole plasma (EQP) mass spectrometer was used to characterize the plasmas during magnetron sputtering of chromium using both MPP and conventional DC power. The time averaged positive ion mass distributions and the positive ion energy distributions were determined. In the MPP plasma, ions of  $\text{Cr}^{+1}$ ,  $\text{Ar}^{+1}$ ,  $\text{Cr}^{+2}$ , and  $\text{Ar}^{+2}$  ions were readily detected. The intensity was highest for the  $\text{Cr}^{+1}$  ions, but the  $\text{Ar}^{+1}$  ions were also abundantly present at the position in the plasma where a substrate would be placed. For the DC plasma, the  $\text{Ar}^{+1}$  ions were the dominant species in the plasma. There were a small number of  $\text{Cr}^{+1}$  ions, but they were significantly less than what was found in the MPP plasma. There were only trace amounts of the  $\text{Cr}^{+2}$  and  $\text{Ar}^{+2}$  ions in the DC plasma. The measurement of the IEDs for the  $\text{Cr}^{+1}$  and  $\text{Ar}^{+1}$  ions showed that the average  $\text{Cr}^{+1}$  ion energy was about 2eV in the MPP plasma and about 4eV in the DC plasma at a position where a substrate would be placed. The  $\text{Ar}^{+1}$  IED revealed that the average ion energy in the MPP plasma was about 2eV whereas it was about 3eV in the DC plasma. For both IEDs for the  $\text{Cr}^{+1}$  and  $\text{Ar}^{+1}$  ions, there is a small high energy tail extending out to about 10eV.

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**William D. Sproul** is the founder and president of Reactive Sputtering, Inc. Throughout his technical career, he has been involved with reactive sputtering of oxide, nitride, and carbide coatings. He is the inventor of the high-rate reactive sputtering process, and he was instrumental in the development of multi-cathode unbalanced magnetron sputtering processes. More recently he has been involved with high power pulsed magnetron sputtering. He has authored or co-authored over 162 publications, he holds 11 U.S. patents, and he has given over 250 technical presentations. He teaches short courses on Tribological Coatings, Sputter Deposition, and The Practice of Reactive Sputtering, and he is currently a Research Professor at the Advanced Coatings and Surface Engineering Laboratory at the Colorado School of Mines. He was president of the AVS in 1996, and he also served as a member of the AVS board of directors. He recently completed a 3-year term on the SVC board of directors. In 2003, he was selected as the winner of the AVS Thornton Award and the SVC Mentor Award. He serves on the editorial boards for Surface and Coatings Technology and for Vacuum. He received his Sc.B., Sc.M., and Ph.D. degrees in Materials Science Engineering from Brown University in 1966, 1968, and 1975, respectively.



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# In Situ Spectroscopic Ellipsometry for Atomic Layer Deposition

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## Abstract

The application of *in situ* spectroscopic ellipsometry during thin film synthesis by atomic layer deposition (ALD) is examined for results obtained on  $\text{Al}_2\text{O}_3$ ,  $\text{TaN}_x$ , and TiN films with thicknesses ranging from 0.1 to 100 nm. By analyzing the film thickness and the energy dispersion of the optical constants of the films, the layer-by-layer growth and material properties of the ALD films can be studied in detail. The growth rate per cycle and the nucleation behavior of the films can be addressed by monitoring the thickness as a function of the number of cycles. It is shown that from the energy dispersion relation, insight into the conductive properties of metallic films can be derived. Moreover, the shape of the dispersion relation can be used to discriminate between different material compositions.

## Introduction

With the optical, mechanical, electrical, and chemical properties of ultrathin films (<100 nm) being used in numerous applications, the synthesis of such functional thin films has become a key technology in present-day society. In this respect, the miniaturization and diversification in the semiconductor industry can be considered the main technological driver for developments in ultrathin film synthesis [1]. In particular for manufacturing steps where the emphasis lies on atomic scale thickness control and on conformal film growth in high-aspect ratio structures, atomic layer deposition (ALD) is currently the primary candidate to fulfill the strict requirements on ultrathin film growth [2,3].

By the virtue of separate self-limiting surface reactions, ALD has the ability to control film growth and material properties at the atomic level, as schematically illustrated in Figure 1. The amount of material deposited in an ALD cycle is determined by the amount of surface adsorption sites initially available and becomes at a certain point independent of the particle flux impinging on the surface. When sufficient precursor and reactant molecules are dosed to saturate the surface chemistry, a (sub)monolayer of material is deposited per cycle. ALD provides therefore “discrete” thickness control, i.e., the ability to increase the film thickness layer-by-layer by repeating ALD cycles. Moreover, ALD film growth is highly uniform and yields excellent conformality because at every available surface site (a maximum of) one precursor/reactant molecule can adsorb regardless the incoming particle flux or whether these surface sites are distributed over large surface areas or in demanding 3D topologies.

Over the years many ALD processes for thin films of inorganic materials have been developed, ranging from pure elements to compounds with oxygen, nitrogen, and sulphur, as reviewed by others [2,4]. Recently, an ALD scheme for organic materials was even designed using bifunctional monomers [5]. Well-established ALD processes have already been implemented for synthesis of ultrathin  $\text{Al}_2\text{O}_3$ ,  $\text{HfO}_2$ , and TiN films in industrial applications.

The successful integration of ultrathin films in industrial applications relies, however, not only on the development of methods to synthesize these ultrathin films, but also on the availability of accurate analytical or metrology techniques to determine the thickness and properties of these films. The ALD process lends itself particularly well for *in situ* studies, because the inherent cycle-by-cycle deposition process allows halting

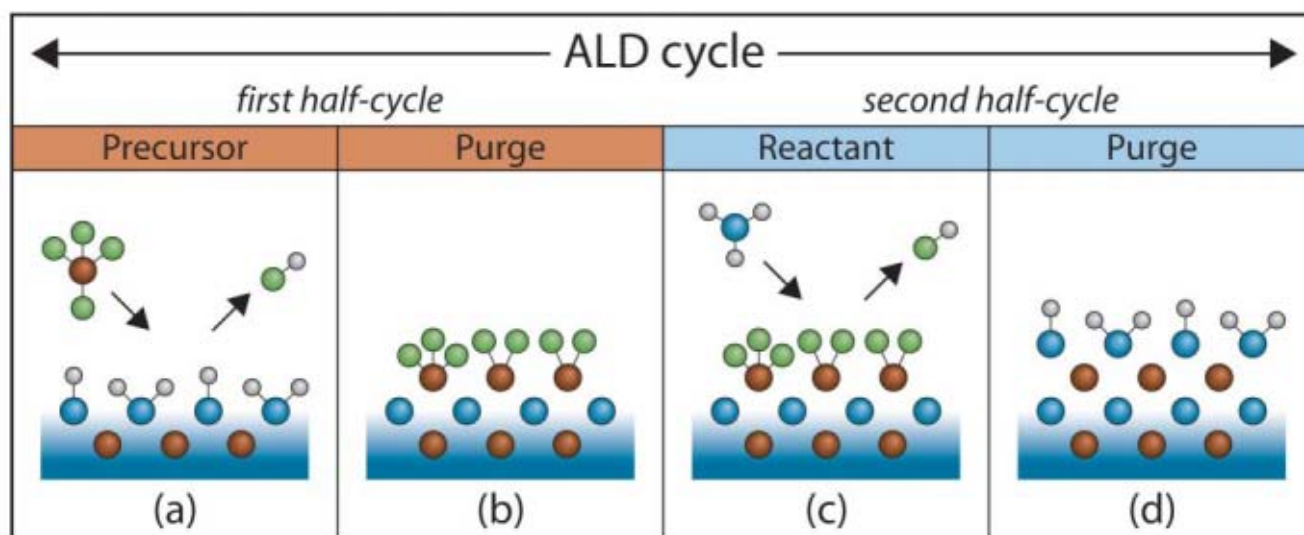


Figure 1. Atomic layer deposition (ALD) illustrated for two half-cycles of a typical deposition process. The first half-cycle consists of (a) self-limiting adsorption of the precursor molecules on the surface groups and (b) a purge step to remove the volatile reaction by-products and the excess of precursor dosed. After the first half-cycle, a submonolayer of precursor has chemisorbed on the surface. During the second self-limiting surface reaction (c), the surface is exposed to reactant molecules that react with the surface groups of the adsorbed precursor. The second half-cycle is completed by (d) another purge step to remove the volatile reaction by-products and the excess of reactant dosed. After the full ALD cycle, a submonolayer of material is deposited with the surface groups similar to those at the start of the cycle. Subsequently, the cycle can be repeated to deposit a film with the thickness targeted.



the deposition for sensitive measurements in between the ALD cycles. Data acquisition in between the cycles provides, thus, the opportunity to monitor and address various aspects of the ALD growth process. Considering the amount of data that can easily be acquired, i.e., from cycle-by-cycle acquisition to, typically, acquisition after every 10-100 cycles, the influence of thickness on the material properties can be addressed in detail.

The majority of *in situ* studies have mainly focused on elucidating the fundamentals of the ALD reaction mechanism. Commonly employed techniques are infrared spectroscopy, mass spectrometry, and quartz crystal microbalance to provide insight into the surface species and volatile reaction by-products that are formed in the ALD half-cycles. Recently more emphasis has been put on *in situ* diagnostics that can be used online for process optimization, process monitoring, and

for additional control of the deposition process at the atomic level.

In this paper, the merits of the optical technique of spectroscopic ellipsometry are discussed for *in situ* monitoring the film growth of  $\text{Al}_2\text{O}_3$ ,  $\text{Ta}_2\text{N}_x$ , and  $\text{TiN}$  films by ALD. In this respect, it is mentioned that an extensive review has recently been published discussing the application of *in situ* spectroscopic ellipsometry to study various aspects of ALD of  $\text{Al}_2\text{O}_3$ ,  $\text{HfO}_2$ ,  $\text{Er}_2\text{O}_3$ ,  $\text{TiO}_2$ ,  $\text{Ta}_2\text{O}_5$ ,  $\text{TiN}$ , and  $\text{Ta}_2\text{N}_x$  films [6].

### Spectroscopic ellipsometry

Over the years, spectroscopic ellipsometry (SE) was demonstrated to be a valuable diagnostic for determination of the thickness and (optical) properties of thin films. Because SE is an optical and non-intrusive technique detecting the change in polarization of light upon reflection from a surface, it has been commonly applied *in situ* to study the film



Figure 2. Photograph of a J.A. Woollam, Inc., M2000 spectroscopic ellipsometers fitted on (a) the FlexAL™ and (b) the OpAL™ reactors of Oxford Instruments [11,12]. Both commercial reactors are installed in the clean room facility of the Eindhoven University of Technology.

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## In Situ Spectroscopic Ellipsometry

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growth as reported for many physical and chemical vapor deposition methods [7,8]. The most important requirement to employ *in situ* SE during ALD is optical access on the reactor and the deposition on optically flat substrates that allow for specular reflection of the ellipsometer light. The concept of *in situ* SE for thickness monitoring during an ALD process was already reported by Klaus et al. [9], however, the application of *in situ* SE did not settle in ALD research until approximately a decade later [10]. The knowledge, accuracy, and also user-friendliness of ellipsometer systems and related data analysis have improved in the recent years, as can be expressed by the ability to detect changes in nominal film thickness equivalent to 0.01 monolayer.

The *in situ* SE measurements described in this work were carried out by J.A. Woollam, Inc., M2000 rotating compensator ellipsometers. The M2000U visible and near-infrared extended (0.75–5.0 eV) ellipsometer was proven particularly powerful to study metallic films. The M2000D visible and ultraviolet extended (1.2–6.5 eV) ellipsometer was particularly suited to study (high) band gap materials. The typical configuration of the ellipsometers on the ALD reactors used in this work is shown in Figure 2. The angle of incidence of the light was fixed to 68 degrees with respect to the normal of the substrate.

From the ellipsometric data obtained over a certain photon energy range, the film thickness and the dispersion relation of the optical constants can be deduced. The optical constants can be expressed in the refractive index and extinction coefficient, but they are often represented in terms of the real ( $\epsilon_1$ ) and imaginary ( $\epsilon_2$ ) parts of the complex dielectric function  $\epsilon$  [7]. From the optical constants, several material properties of thin films can be derived such as the optical band gap of

dielectric materials and the conductive properties of metallic films.

The optical behavior of a material becomes immediately apparent from its energy dispersion in optical constants. For the photon energy range of 0.75–6.5 eV of the ellipsometers employed in this work, the real and imaginary parts of the dielectric function of  $\text{Al}_2\text{O}_3$ ,  $\text{Ta}_3\text{N}_5$ , and TiN films are shown in Figure 3. These ALD-deposited materials clearly demonstrate the change in dielectric function when comparing transparent ( $\text{Al}_2\text{O}_3$ ), semi-transparent ( $\text{Ta}_3\text{N}_5$ ), and fully absorbing (TiN) materials.

$\text{Al}_2\text{O}_3$  is non-absorbing ( $\epsilon_2 = k = 0$ ) over the whole range probed and its optical constants can therefore be described by a Cauchy relationship. The refractive index of this 109 nm thick  $\text{Al}_2\text{O}_3$  film is  $1.63 \pm 0.02$  at 1.96 eV.  $\text{Ta}_3\text{N}_5$  is a semiconducting material and has an optical band gap that falls in the photon energy range of most common ellipsometers. Accordingly, the dielectric function can be parametrized using (three) Tauc-Lorentz oscillators. The refractive index and Tauc optical band gap for this 49 nm thick  $\text{Ta}_3\text{N}_5$  film are  $2.68 \pm 0.02$  at 1.96 eV and  $2.5 \pm 0.1$  eV. The conductive properties of the TiN film are evident from the large intraband absorption in the infrared part of the photon spectrum caused by free conduction electrons in the material. Describing this absorption by a Drude oscillator allows to extract electrical properties from the optical dielectric function, such as electrical resistivity, electron mean free path, and electron density [12,13]. Moreover, two Lorentz oscillators are added to the Drude term to account for interband absorptions in TiN. The 12 nm thick TiN film has a refractive index of  $1.3 \pm 0.02$  at 1.96 eV. More details on the optical parametrizations employed and the method of direct inversion in Figure 3 can be found in Ref. [6].

### ALD Studied by In Situ SE Monitoring ALD film growth

The film thickness is among one of the most important parameters for the application of ALD films. The thickness can be precisely controlled by selecting the appropriate number of ALD cycles. Monitoring the ALD process by *in situ* SE allows determining the film thickness at any stage during the process and to calculate the ALD growth per cycle during the film growth. Moreover, SE provides the opportunity to control the process such that the film deposition can be actively stopped when the thickness targeted has been reached.

The film thickness as a function of ALD cycles as determined by *in situ* SE is shown in Figure 4 for the ALD processes of  $\text{Al}_2\text{O}_3$  [14],  $\text{Ta}_3\text{N}_5$  [15], and TiN [13]. As generally expected for an ALD process, the thickness increases linearly with the number of cycles; although in some cases a (pronounced) film nucleation effect can occur.

In the linear region, the growth rates, i.e., the amount of material deposited per cycle, can be obtained from linear regression analyses of the data. For the data in Figure 4 this resulted in growth rates of  $0.118 \pm 0.005$ ,  $0.054 \pm 0.005$ , and  $0.041 \pm 0.005$  nm/cycle for the  $\text{Al}_2\text{O}_3$ ,  $\text{Ta}_3\text{N}_5$ , and TiN films, respectively. It is noted that the growth rates of ALD processes typically are (considerably) smaller than one monolayer ( $\sim 2\text{--}3$  Å) per cycle. Among others, this can be related to the number of adsorption sites available on the surface and to steric hindrance effects during precursor adsorption.

The increase in film thickness during the first deposition cycles reveals that the ALD growth of  $\text{Al}_2\text{O}_3$  proceeds immediately on an H-terminated Si substrate. Similarly, ALD of  $\text{Ta}_3\text{N}_5$  on a native oxide covered Si substrate shows immediate linear growth. These two growth curves demonstrate that these metal-organic precursor molecules readily react with the substrates employed. A completely different nucleation behavior is observed for ALD of TiN on a thermally grown  $\text{SiO}_2$  surface. A distinct nucleation delay is observed and the growth

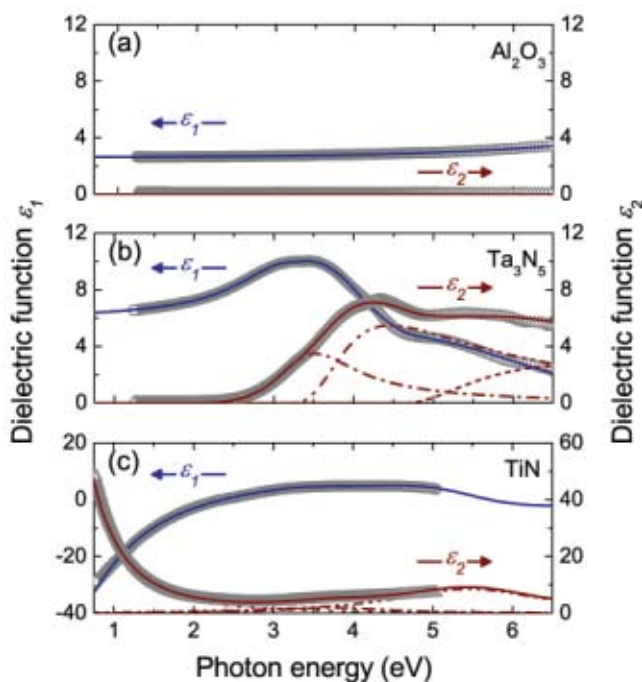


Figure 3. Real ( $\epsilon_1$ ) and imaginary ( $\epsilon_2$ ) parts of the dielectric function of (a)  $\text{Al}_2\text{O}_3$  [Cauchy], (b)  $\text{Ta}_3\text{N}_5$  [Tauc-Lorentz], and (c) TiN [Drude-Lorentz] films deposited by ALD. The dielectric function is shown as obtained by direct inversion (symbols) and as described by the optical parametrization (solid lines) [6]. The optical parametrizations used are indicated in between parentheses. The dotted/dashed lines indicate the separate contributions of the oscillators to the imaginary part of the dielectric function.



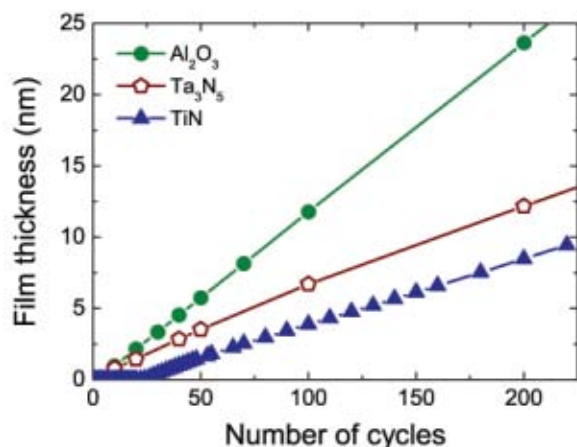


Figure 4: Film thickness as a function of number of ALD cycles for growth of (a) Al<sub>2</sub>O<sub>3</sub> from Al(CH<sub>3</sub>)<sub>3</sub> precursor and O<sub>2</sub> plasma on a H-terminated Si substrate, (b) Ta<sub>3</sub>N<sub>5</sub> from Ta[N(CH<sub>3</sub>)<sub>2</sub>]<sub>5</sub> precursor and NH<sub>3</sub> plasma on a native oxide covered Si substrate, and (c) TiN from TiCl<sub>4</sub> precursor and H<sub>2</sub>-N<sub>2</sub> plasma on a thermally grown SiO<sub>2</sub> substrate. The film thicknesses are calculated using the optical parametrizations shown in Figure 3.

starts only after ~20 ALD cycles. This behavior is consistent with the inability of the TiCl<sub>4</sub> precursor molecules to react with the siloxane bridges mainly present on the thermal SiO<sub>2</sub> substrate. The slow nucleation is caused by the limited surface density of defect sites and OH groups on which the TiCl<sub>4</sub> can absorb and nucleate to start film growth. These results demonstrate the ability of *in situ* SE to accurately determine the film thickness of the nanometer thick ALD films. Moreover, cycle-by-cycle data acquisition enables to monitor the

film nucleation and linear growth region in detail. In this respect it is mentioned that the determination of the growth rate during deposition allows for fast optimization of the ALD process, where the influence of deposition parameters on the growth rate can easily be obtained from a single deposition run [6].

### Monitoring electrical film properties

Insight into the electrical properties of conductive films can be derived from the dielectric function by adopting the Drude parameterization. Therefore, monitoring the ALD film growth by *in situ* SE provides the opportunity to investigate the influence of ALD process conditions on the electrical film properties obtained [6,11,13]

The resistivity of the TiN films as determined from *in situ* SE and *ex situ* four-point probe (FPP) measurements is shown in Figure 5 as a function of deposition temperature in the range from 100 to 400 °C. In order to make a proper comparison with the FPP resistivity determined at room temperature, first the *in situ* SE resistivity values obtained at the deposition temperature were corrected to values representing room temperature [13]. The resistivity values obtained by *in situ* SE and *ex situ* FPP were in good agreement, especially for films deposited at substrate temperatures above 200 °C. Both techniques show that the resistivity of the TiN films increases for depositions at lower temperatures. This effect can be related to the increase in chlorine impurity content of the films, as was determined by Rutherford backscattering spectroscopy (RBS) and shown in the inset of Figure 5. In turn, the increase in impurity content causes the electron mean free path to decrease due to more pronounced electron-impurity scattering in the film [4]. In addition, the discrepancy between the resistivity values determined by SE and FPP at low temperatures (100 °C) can also be related to the impurity content.

*continued on page 40*



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Concentrations, process gas	
N <sub>2</sub>	73.39%
O <sub>2</sub>	19.65%
Ar <sub>2</sub>	0.88%
H <sub>2</sub>	4.37%
He	1.68%
CO <sub>2</sub>	300 ppm



**PROCESS INSTRUMENTS**

## In Situ Spectroscopic Ellipsometry

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The higher impurity content and the related lower film density make the films more susceptible to post-deposition oxidation when the films are exposed to air. This directly affects the *ex situ* measurements.

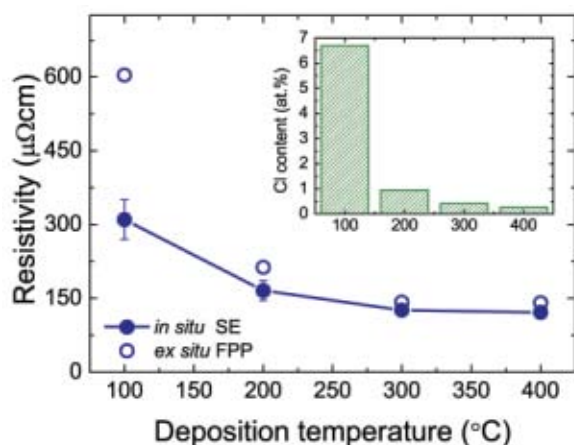


Figure 5. Electrical resistivity of plasma-assisted ALD TiN films as a function of deposition temperature. The resistivity is determined by *in situ* spectroscopic ellipsometry and *ex situ* four point probe (FPP) measurements. The change in resistivity with deposition temperature can be related to the chlorine impurity content of the films as shown in the inset.

The agreement in the electrical resistivity deduced from the optical model and obtained by the FPP validates the optical Drude-Lorentz model employed to describe the dielectric function of these thin TiN films. Moreover, these results demonstrate that *in situ* SE provides an accurate means to investigate electrical properties of conductive films and their dependence on the deposition conditions.

### Distinction of different material phases

The dispersion in the optical constants gives immediate insight into the optical properties of the films and, therefore, on the material properties. The influence of the ALD deposition parameters on the materials properties can therefore be deduced by monitoring the dispersion in optical constants by *in situ* SE. This is demonstrated for tantalum nitride ( $\text{Ta}_x\text{N}_x$ ) that can exist in different crystalline phases and for which it was shown that the  $\text{Ta}_x\text{N}_x$  phase and film properties can be tailored by varying the plasma step in the remote plasma ALD process [15].

Figure 6 shows the imaginary part ( $\epsilon_2$ ) of the dielectric functions of the  $\text{Ta}_x\text{N}_x$  films that were deposited using different plasma conditions in the ALD cycle. The inset shows the film composition as determined by Rutherford backscattering spectroscopy. Adding more nitrogen into the plasma, result in a transition from conductive, cubic  $\text{Ta}_x\text{N}_x$ ,  $x \leq 1$  to semi-conductive  $\text{Ta}_3\text{N}_5$  films. This transition is clearly visible in the dielectric function of the  $\text{Ta}_x\text{N}_x$  films obtained.

The dielectric function of the  $\text{Ta}_x\text{N}_x$  film obtained using a pure  $\text{H}_2$  plasma in the ALD process contains a prominent Drude absorption that is related to the free conduction electrons in the film. Moreover, it is observed that the strength of the Drude absorption, i.e., a measure of the conductivity, can be increased by extending the  $\text{H}_2$  plasma exposure time used in the ALD cycle. Admixing little  $\text{N}_2$  (2%) to the  $\text{H}_2$  plasma strongly reduces the magnitude of the Drude absorption in the film and the two Lorentz oscillators become clearly visible. The dielectric function of the  $\text{Ta}_3\text{N}_{4.7}$  film deposited using a  $\text{H}_2\text{-N}_2$  (1:1) plasma clearly differs in shape. This dielectric function is best described by a parametrization employing a Tauc-Lorentz oscillator and an additional

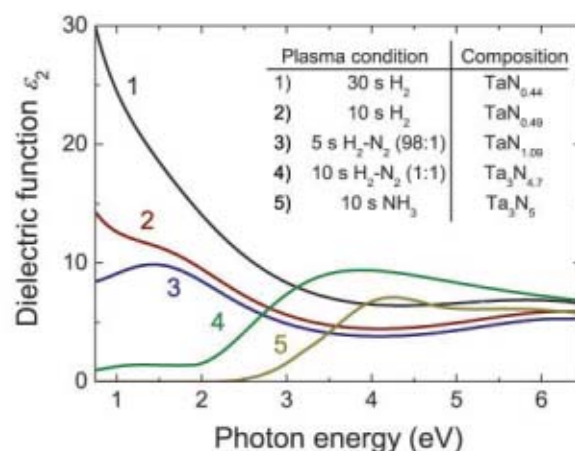


Figure 6. Imaginary part of the dielectric function of different  $\text{Ta}_x\text{N}_x$  films as determined by *in situ* ellipsometry. Depending on the plasma condition employed in the plasma-assisted ALD cycle, the  $\text{Ta}_x\text{N}_x$  phase can be tuned from conductive  $\text{Ta}_x\text{N}_x$  to semiconductive  $\text{Ta}_3\text{N}_5$  as apparent in the dielectric function and the film composition shown in the inset.

Lorentz oscillator, which is added to account for the small absorption below the optical band gap. The dielectric function of the  $\text{Ta}_3\text{N}_5$  film deposited using a  $\text{NH}_3$  plasma clearly shows an optical band gap and is best described by a parametrization consisting of three Tauc-Lorentz oscillators.

From the above mentioned, it is evident that by monitoring the dielectric functions by *in situ* SE, the change in film composition and crystalline phase can already be probed during the ALD process when the film is being deposited.

## Conclusions

In this paper, the versatility of *in situ* spectroscopic ellipsometry to study atomic layer deposition processes has been exemplified. It has been shown that:

- Monitoring the thickness as a function of number of ALD cycles enables to calculation of the growth rate *during* the ALD process;
- Insight into the nucleation behavior of the ALD films can be obtained by acquiring cycle-by-cycle data during initial film growth;
- Optical film properties, such as refractive index, extinction coefficient, and optical band gap, can be obtained from the energy dispersion of the optical constants;
- Electrical properties of conductive films can be calculated from the Drude absorption by conduction electrons in the film
- For certain materials, insight into film composition can be derived from the "shape" of the optical dispersion in the dielectric function;

The value of SE in monitoring the film growth has recently been recognized by researchers and ALD tool manufacturers and has led to the development of commercial ALD reactors with integrated *in situ* spectroscopic ellipsometry capability (cf. Figure 2). It is, therefore, anticipated that *in situ* SE has a bright application prospect in the field of ALD.

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# Sputtering Sources

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## Introduction

Since it was first observed in the mid 1800s, the sputtering of solid materials in glow discharges, or simply “sputtering,” has become one of the most versatile and widely used methods of thin film and coating deposition. Many advances over the years, from Penning’s use of magnets to enhance the discharge in 1939 [1], to Chapin’s invention of the planar magnetron in 1974 [2], to more recent developments using high-power pulsed DC sputtering [3], have greatly increased the versatility and use of the sputtering processes. The sputtering sources commonly used generally fall into two categories: glow discharge sources (diode, triode, and magnetron) and ion beam sources. The magnetron, since its introduction in the 1970s, has quickly become the workhorse of the industry [4]. In this chapter, the primary focus will be the discussion of the glow discharge method and sputtering sources.

## Pre-Magnetron Sputtering

### DC Diode

Perhaps the simplest sputtering technique is the DC diode. Figure 1 shows the basic design of a DC diode sputtering system. It consists of two electrodes enclosed in a vacuum chamber equipped with suitable pumping and gas flow. The cathode, or target of material to be sputtered, is simply a plate held at a negative potential. The anode, which can be the substrate, can be grounded, floating, or biased. If grounded, then the entire vacuum chamber serves as the anode and accumulates deposits during the sputtering process.

Positive ions, usually  $\text{Ar}^+$ , bombard the target and eject mostly neutral target atoms, which are subsequently condensed onto the substrate [5]. In DC diode sputtering, electrons are accelerated away from the cathode and ionize the process gas, thereby sustaining the discharge. In order to maintain the discharge, an optimum gas density is required. If the gas density is too low, electrons will strike the anode without ionizing any Ar atoms; whereas if the gas density is too high, the electrons will not have gained enough energy to cause ionization before they hit an Ar atom [6].

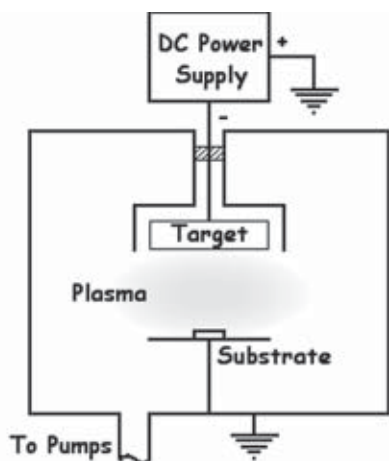


Figure 1. Schematic diagram of a DC diode sputtering system.

The ions accelerate back to the cathode and perhaps cause secondary electron emission. These secondary electrons are the principle source of

the ionizing electrons in the discharge. Because the secondary electron yields of many typical sputtered materials are low (only up to about 25% in most cases), most of the energy arriving at the cathode due to ion bombardment results in target heating. Thus, some target cooling mechanism is typically included.

In spite of the relative simplicity of DC diode sputtering, the main disadvantages are typically low deposition rates due to the low plasma densities, high gas densities, high discharge voltages, and the lack of versatility. Only conducting targets can be used [6]. Growth of insulating films via reactive sputtering of conductive targets is also prohibited due to the formation of compound dielectric layers on, or poisoning of, the target surface [5].

### Triode Sputtering

In order to increase the ionization of the plasma in DC diode sputtering, a heated filament injects electrons directly into the plasma, independently of the target, as shown in Figure 2. This increase in electron density provides more control of the ion energy and flux, and results in higher deposition rates (up to several thousand  $\text{\AA}/\text{min.}$ ) at lower target voltages (approximately 500 V) and lower pressures (0.5 to 1 mT) [4,5,7].

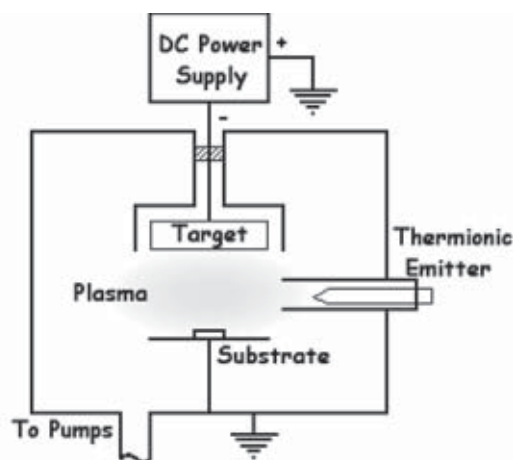


Figure 2. Schematic diagram of a DC triode sputtering system.

Problems with triode sputtering include scaling up and the interactions of the filament with reactive gas species. The filament tends to erode rapidly during reactive deposition. There are also problems with film uniformity and general film quality due to the lack of means to confine the plasma and electron path [8]. Triode sputtering became out-of-fashion with the development of magnetron sputtering, which allowed for the generation of a much higher plasma density.

### RF Sputtering

RF sputtering was developed as a means to produce insulating coatings and films. The initial work in RF-sputtering was performed in the 1960s. Davides and Maisel used RF sputtering in 1966 to produce dielectric films [9,10,11]. In 1967 Miller and Shirn co-sputtered glass and metals to form cermet resistor films [12]. Modern commercial use of RF sputtering is limited due to the high cost of the power supplies



and relatively complicated matching networks that are needed to match the impedance of the system to reduce reflected power.

In RF sputtering, an RF frequency of 13.56 MHz is coupled to the target material via an impedance matching network and blocking capacitor, as shown in Figure 3. The blocking capacitor ensures that the time average net current to each electrode is zero [13]. The target and the counter-electrode, which may be the substrate holder, act as the two electrodes. As the RF power is applied, electrons oscillate between the two electrodes with the frequency of the applied power. Ion mobility is too low at the typical industrial radio frequency of 13.56 MHz to experience much oscillation, and most remain essentially in the center of the plasma between the electrodes [5]. During the positive half of the cycle, that target acts as anode and will acquire many electrons, but the counter-electrode will not acquire as many ions (and vice versa) during the negative half of the cycle. Thus, both electrodes acquire a negative bias with respect to the plasma [6]. Eventually, due to its negative bias, the target will no longer capture as many electrons during the positive half-cycle and it will acquire enough ions during the negative half cycle to cancel any of the electron gains [6]. At this point, the target has a net negative DC bias, attracting the process gas ions and resulting in the sputtering and deposition of the target material [14]. One must note the symmetry of this process though. If the target and substrate are the same size, there will be complete symmetry. Neither electrode will acquire the negative DC bias relative to each other. However, an anti-symmetric cathode/anode arrangement can be used in which the chamber acts, in addition to the substrate, as the anode. The ratio of the voltages, with respect to the plasma, measured at the target,  $V_t$ , and substrate,  $V_s$ , are proportional to the ratio of the substrate and target areas as follows:

$$\frac{V_t}{V_s} = \left( \frac{A_s}{A_t} \right)^n$$

where  $n$  is in the range 1.5-4 and depends on the experimental set-up [4,5,14]. Thus, an increased substrate/anode/chamber area increases the relative target potential. If the area ratio is high enough, the sputtering of the anode and chamber walls will be negligible.

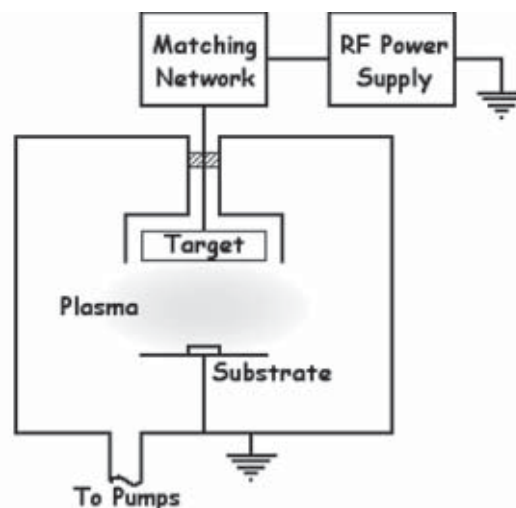


Figure 3. Schematic diagram of an RF sputtering system.

Because the power is being split between the two electrodes, the effective power at the cathode is typically only 50% of the power

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## Sputtering Sources

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delivered in DC sputtering. Thus, there are usually considerably lower deposition rates in RF sputtering processes than in an equivalent DC process. Also, due to the high cost of power supplies and matching networks, scale-up of the RF process is difficult [14].

One major problem with these earlier sputtering systems includes nonuniform plasma densities. This leads to nonuniform current density and subsequently to nonuniform film thickness. With the increasing need for uniform films in the electronics and optical coating industries, DC diode, triode, and RF sputtering are not acceptable techniques.

## Early Magnetrons

### Introduction

Following the work done by Penning, the magnetic confinement of the electrons was exploited to enhance the plasma density at or near the surface of the targets. The earliest were the post-cathode and hollow cylindrical magnetron structures. In 1968, Clarke developed a sputtering source, which came to be known as sputter-gun or S-gun [15,16]. In August 1979, J.S. Chapin was issued a patent for his 1974 design of the planar magnetron [2,17]. In the basic design, a magnetic field is added to the cathode, providing an  $\mathbf{E} \times \mathbf{B}$  drift path for the electrons to follow. Proper alignment of the magnetic field helps confine the electrons to a region close to the target as follows. The magnetic field is oriented parallel to the cathode surface. Thus, the secondary electrons leaving the cathode surface with speed,  $v$ , experience a Lorentz force and begin to move in a circular path of radius  $r$ . As long as no collisions occur, the electrons are returned to the cathode surface with the same speed  $v$ . If an electron has a lower speed, it will have a smaller radius circular orbit, as shown in Figure 4. If a linearly decreasing electric field is introduced, as in Figure 5, then the electrons will have a decreasing orbital radius as it moves away from the cathode and increasing orbit as it moves back toward the cathode. The result is a cycloidal path as shown in Figure 5. Both with and without the electric field, the electron is trapped near the surface of the cathode. With the electric field, it is allowed to move about over the surface of the cathode, thereby allowing it to make ionizing collisions with the process gas before being lost to the anode or other chamber surfaces [5]. Thus, the addition of the magnetic field significantly increases the ion density [18]. Operation is thereby possible at lower pressures and, thus, the ions bombard the cathode at maximum voltages of a few 100s V up to about 1000 V, and the sputtered atoms easily traverse the distance to the substrate with minimal collisions and scattering in the plasma [6].

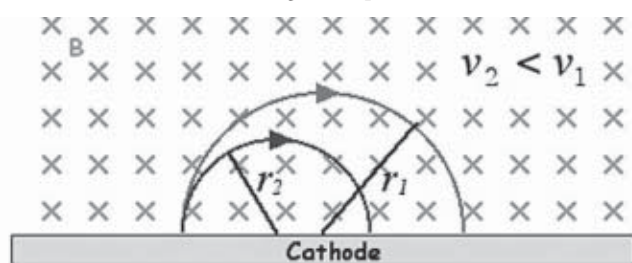


Figure 4. Electron motion in a uniform magnetic field follow a circular path according to the Lorentz Force. The magnetic field points into the page.

The discharge is typically characterized by the relationship between the plasma current and applied voltage, which are related by the equation:

$$I = kV^n$$

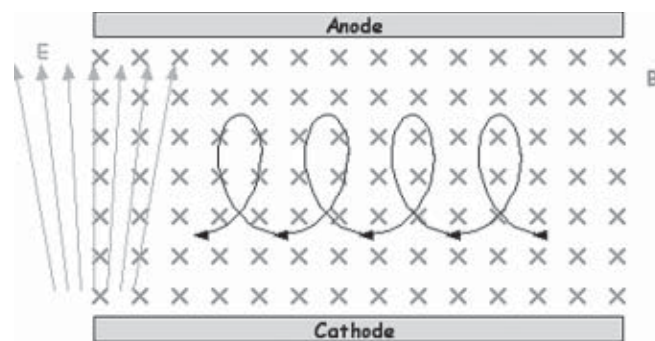


Figure 5. In the presence of crossed electric and magnetic fields, where the electric field is linearly decreasing away from the cathode, the electrons will follow a cycloidal path.

where  $n$  is in the range 3–15.  $K$  and  $n$  depend on the type of magnetron being used, the cathode, and the sputtering gas [6]. Typical magnetron characteristics are: cathode current density about 20 mA/cm<sup>2</sup>, discharge voltage 250–800 V, minimum pressure approximately 1 mT, typical target to substrate distance up to about 5–10 cm, and deposition rates of several thousand Å/min for metals and up to a couple thousand Å/min for dielectrics [4].

### Planar Magnetrons

Figure 6 shows the most common magnetron configuration, the planar magnetron. It is similar to the DC and RF diode arrangements described earlier but has an array of permanent magnets behind the cathode arranged in such a way as to create a region of magnetic field directly above the target [18]. A couple of common magnet arrangements are shown schematically in Figure 7. In both cases, the magnetic field is oriented radially and directly above the cathode surface, and the electric field decreases away from the surface. Therefore, the  $\mathbf{E} \times \mathbf{B}$  drift path forms a circle along the target surface, resulting in a region of high plasma density along this path. This nonuniformity leads to a preferential sputtering of the target around a circular region known as the “racetrack,” as shown in Figure 8. Typical target utilization is only 20% to 45% due to this preferential sputtering in the racetrack. Substrate and magnet motion is a common means to reduce the effects of the race-track, but this leads to time-varying deposition rates and incident angles and ultimately can affect the film properties [18].

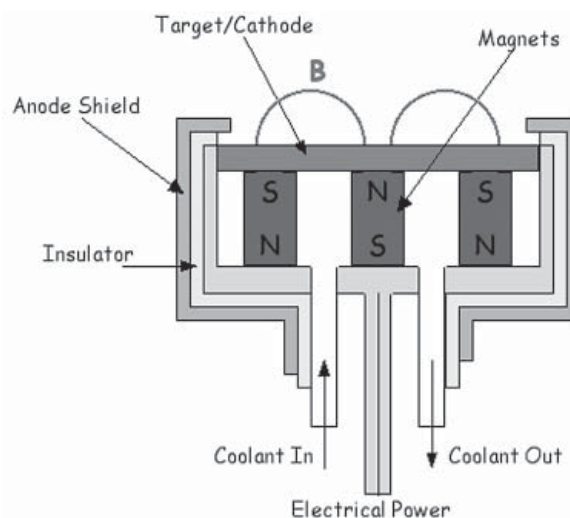


Figure 6. Planar magnetron.



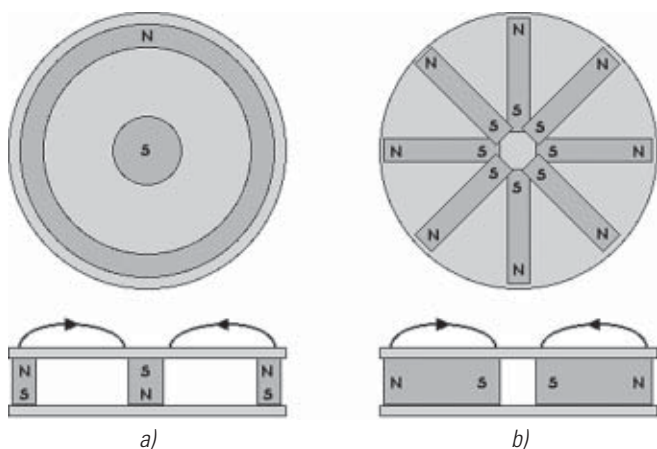


Figure 7. Some common planar magnetron magnet arrangements.

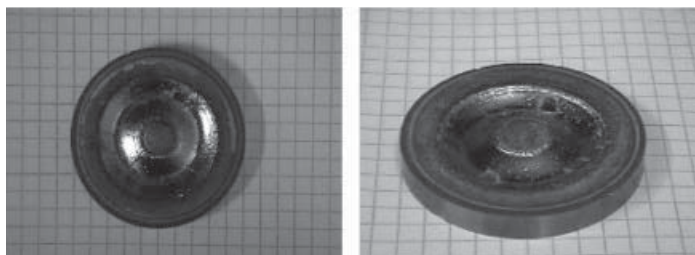


Figure 8. The "racetrack" in a 2" circular Si planar magnetron sputtering target.

Permanent magnets, electromagnets, and combinations of these have been used. With a combination of types, fine-tuning of the magnetic fields for optimum target utilization is possible. The transverse component of the magnetic field is typically in the range of 200–500 G [18].

The high power delivered to the cathode results in substantial target heating. Therefore, cathode cooling is necessary, typically using water or another coolant flowing around the magnets behind the cathode surface.

A number of variations of the basic design have been developed. In 1991 Krug et al. reported the design of a high rate planar magnetron in which the magnets are brought up beside the target as opposed to sitting below. This flattens the magnetic fields and spreads out the racetrack region, thereby using more of the target surface. The magnetron is shown in Figure 9 [19]. Note the differences in the magnetic field lines between this magnetron design and the one in Figure 6 of a conventional magnetron.

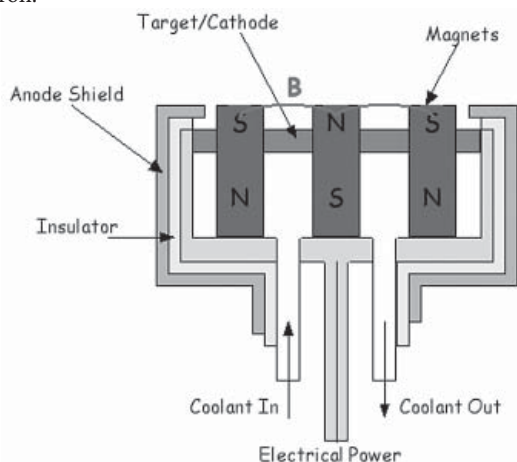


Figure 9. Variation in the design of a magnetron source by Krug, et al. (1991) [19].

Another variation is the rotatable cylindrical magnetron designed by Wright and Beardow in the early 1980s [20]. Designed to solve the

problem of low target utilization, the target takes the form of a cylindrical tube with the magnetic array inside, as shown in Figure 10. The target is rotated around the magnets, thereby exposing all target surfaces to the magnets. This design also has the advantage of minimal buildup of insulating materials during reactive sputtering and is now widely used in large area applications such as for coating architectural glass.

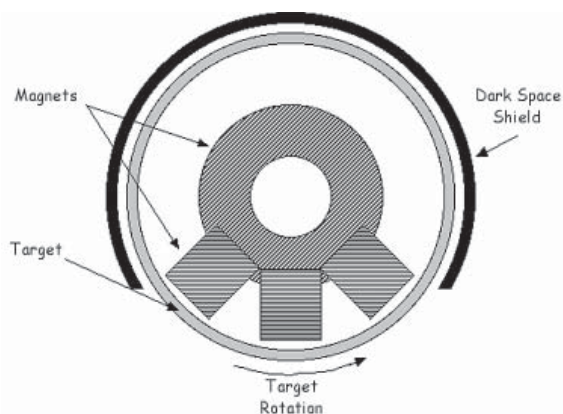


Figure 10. Rotatable cylindrical magnetron by Wright and Beardow.

### Cylindrical Magnetrons

One of the most common variations on the magnetrons described is the cylindrical magnetron. Cylindrical magnetrons have been widely used for coating fibers and wires, as well as a means of applying decorative coatings on complex shaped substrates [21]. There are a number of varieties of configuration of cylindrical magnetrons, including: cylindrical post magnetrons, in which the cathode is along the axis and the anode is a concentric tube, and the cylindrical hollow magnetron (or inverted

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magnetron), in which the anode is along the axis and the cathode is a concentric tube [22,23]. The electric field is, therefore, oriented radially. If a magnetic field is directed along the axis, an  $E \times B$  drift path is established in the form of concentric circles around the anode (as shown in Figure 11a and b). But, if the electrons have any axial component of velocity, they will follow helical paths and drift along the axis and soon leave the magnetron. Thus, electron reflecting surfaces, sometimes known as “wings,” are often attached to the cathode, as seen in Figure 11c and d [22,23]. Due to fringe effects, the magnetic field at the ends of the magnetron, near the wings, is weaker than within the magnetron. Thus, the wings have a lower sputtering yield than the walls and accumulate sputtered material faster than they sputter. Therefore, the wings are often made of a different material than the cathode target [22,23].

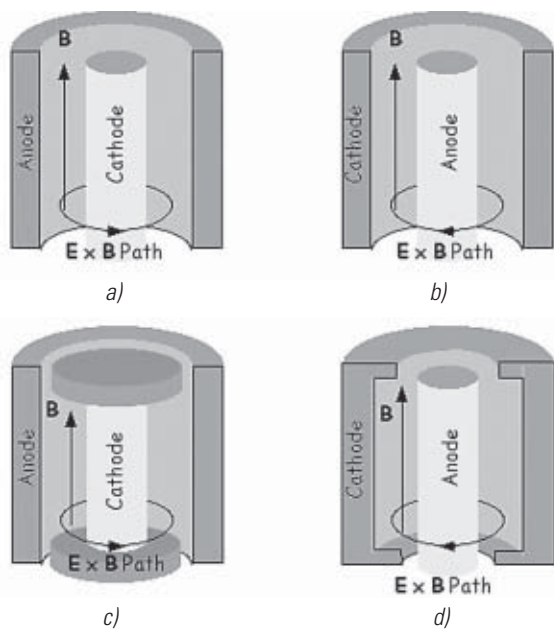


Figure 11. Cylindrical magnetrons; a) cylindrical post magnetron; b) cylindrical hollow magnetron; c) cylindrical post magnetron with reflecting surface; and d) cylindrical hollow magnetron with reflecting surface.

There have been a number of variations on this basic design. In the cylindrical hollow cathode design, as shown in Figure 12, the anode can take the form of end caps as opposed to a post through the center of the magnetron. This allows one to insert three-dimensional substrates within the cavity. In this case, the three-dimensional design of the cylindrical magnetrons causes the sputtered material to either deposit on the substrate or re-deposit back on the other side of the cavity. Therefore, there is very high target utilization, up to about 90%, allowing the use of thinner targets than those used with planar magnetrons [24].

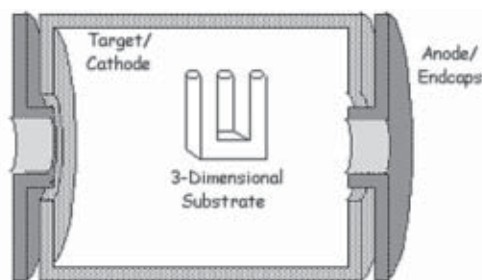


Figure 12. Hollow cathode cylindrical magnetron.

In 1999, Wang & Cohen attached a hollow cathode structure (HCS) to a planar magnetron, as shown in Figure 13. This HCS, made of stainless steel, is attached to the rim of the planar magnetron cathode. This addition helps to confine the plasma and increases the ionization. Thus, the magnetron can operate at considerably lower pressures than conventional magnetrons under similar deposition conditions [25]. A lower gas pressure helps prevent incorporation of contaminants into the growing film. Also, a weaker dependence of current on the cathode bias voltage is achieved at lower gas pressures. The HCS can be attached either electrically or it can be insulated. This allows for separate control of the HCS potential.

In 1999, Bradley, Willett, and Gonzalvo report much higher discharge currents, for the same voltage, with the introduction of a groove machined into the target surface, as shown in Figure 14. This higher current has been attributed to the production of a more dense plasma close to the cathode surface (up to 20 times more dense). A higher plasma density is also observed downstream at the substrate position [26].

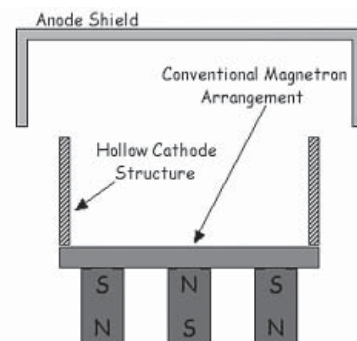


Figure 13. Hollow cathode structure attachment for a planar magnetron by Wang and Cohen.

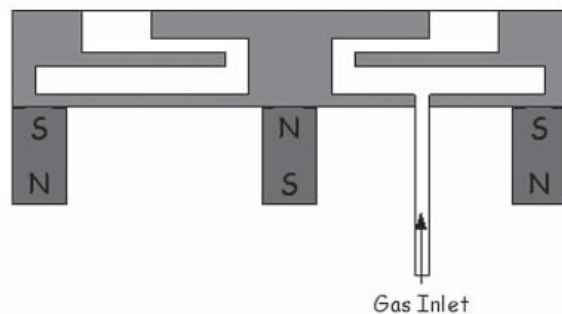


Figure 14. Machined groove in a target surface.

In 2002, Pradhan and Shah built a hollow cathode structure for reactive sputtering consisting of a hollow cylindrical magnetron with end caps on both ends, as shown in Figure 15. This device did not exhibit the normal hysteresis effects commonly seen with reactive sputtering, although target poisoning did occur at lower oxygen concentrations than with conventional reactive sputtering. Both of these observations can be attributed to the structure. Because the end wings only have small holes along the axis, the sputtered flux is not as likely to escape the hollow cathode chamber. Therefore, it is redeposited on the cathode and prevents the complete oxidation of the cathode during reactive sputtering. But, for the same reason, the oxygen introduced to the hollow cathode is trapped in the axial region, leading to a more rapid transition to the poison mode. With this device, Pradhan and Shah report comparable growth rates at lower power densities by up to an order of magnitude [27].

The cylindrical magnetron provides many advantages over the planar magnetron design. The more uniform magnetic field and three-dimensional arrangement allow for more uniform target utilization (up to



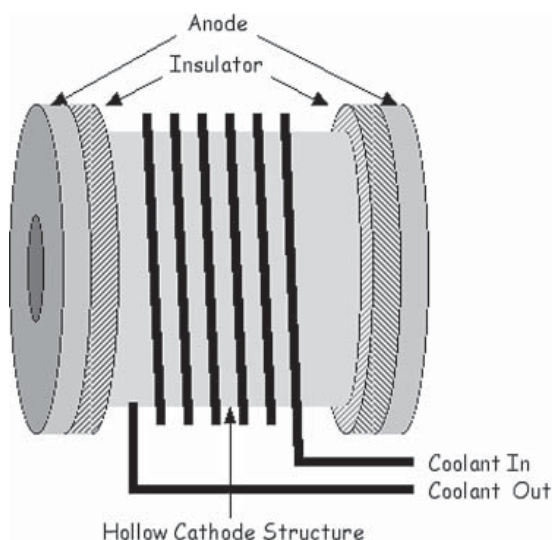


Figure 15: Hollow cathode structure by Pradhan and Shah.

about 90%), as well as more uniform deposition over complex shaped substrates. The use of end plates, or wings, confines the secondary electrons emitted from the surface to the interior of the cylinder and results in an intense plasma produced directly next to the target surface [24].

## Unbalanced Magnetrons

### Introduction

In 1985, Window and Savvides introduced a new unbalanced magnetron design in which different strength magnets are used and produce a net magnetic flux either to or from the magnetron. By using an unbalanced magnetron, they found they could increase the ion bombardment

of the growing films, which makes the films denser and preferentially orients the crystallites in the growing films [27].

By changing the magnet strength, a variety of configurations from a balanced magnetron to unbalanced magnetrons are possible. Figure 16 shows the two types of unbalanced magnetrons. Type I has a stronger central magnet and decreases the ion and electron fluxes to the substrate. The lower ion and electron bombardment are advantageous in such applications as the growth of films for electronics applications. Type II has stronger outer magnets and increases the ion and electron fluxes to the substrate. The higher densities near the substrate surface subsequently promote beneficial ion bombardment effects [29]. Ion currents in the range of 3 to 10 mA/cm<sup>2</sup> have been reported [28,29].

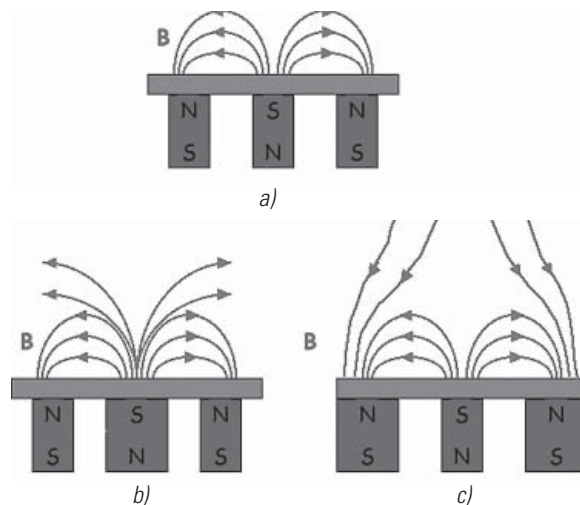


Figure 16. Unbalanced magnetrons; a) balanced magnetron; b) type I; and c) type II.

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### Reactive Sputtering

#### Introduction

Reactive sputtering has long been a method used to deposit insulating and dielectric films such as oxides and nitrides. In fact, some of the earliest sputtering processes reported actually involved reactive processes due to the poor vacuum capabilities and the addition of residual oxygen and nitrogen during sputtering.

DC reactive sputtering of metallic targets is often more convenient than RF sputtering of dielectric targets due to the expense of RF power supplies, matching networks, and the low deposition rates. Among the advantages are the ease of metal target fabrication and the versatility by simply changing the metallic target(s) and reactive gases and gas compositions [4].

But, DC reactive sputtering has some of its own disadvantages and difficulties that must be overcome. Two of the primary problems encountered in reactive sputtering processes are the formation of a compound dielectric layer on the target and subsequent charging of the target surface leading to a low sputter yield. As the target becomes covered with insulating compound, the sputtering rate decreases for at least two reasons. First, the sputter yield of the compound is usually lower than that of pure metal. Second, usually, the secondary electron emission for the compound is higher than that of the pure metal. This injects more electrons into the plasma and decreases the plasma impedance. As the ions build up on the target (and do not subsequently get neutralized by electrons conducted through insulating layer), the potential drop across the dark space decreases and the ions bombard the target with lower energies, thereby reducing the sputtered flux [30].

Also, a “disappearing anode” problem exists in that the insulating film deposits on all chamber surfaces including the anode. As the anode becomes coated, it can no longer conduct electrons away from the plasma [31].

There have been a number of methods and devices discovered over the years that help to alleviate some of these problems, among which are control methods including partial pressure control, mid-frequency AC reactive sputtering, pulsed DC sputtering, and high-power pulsed magnetron sputtering (HPPMS). The recent advances in HPPMS will be discussed later in this chapter.

### Control Methods

Target poisoning, or the formation of a dielectric layer on the target surface, is a result of an increased reactive gas flow. As the reactive gas flow increases, initially the sputtered flux getter pumps the reactive gas. This initially increases the relative coverage of the substrate with the compound material. As the reactive gas composition is further increased, a point is reached at which the flux to the substrate is essentially all compound material as opposed to pure metal. At this point (labeled A in Figure 17), the getter pumping is saturated, and a dielectric film is successfully deposited on the substrate. But, with the addition of more reactive gas, the reactive gas partial pressure increases, and a dielectric film begins to cover the target surface as well. Very quickly, the cathode becomes covered with this insulating compound (it becomes “poisoned”). This point is labeled B in Figure 17. The most efficient deposition of dielectric films is achieved with reactive gas compositions between A and B, but there is typically a very rapid transition between A and B. Point B can usually be detected via monitoring process parameters such as deposition rate, voltage, cathode current, partial pressure, etc. But point A is usually difficult to determine [4]. With the introduction of two reactive species, such as nitrogen and oxygen simultaneously, one must determine the critical region of target

contamination as a function of the flow of both reactive gases. The two gases can either compete with each other, or they can interact with each other in the formation of a compound target layer [32].

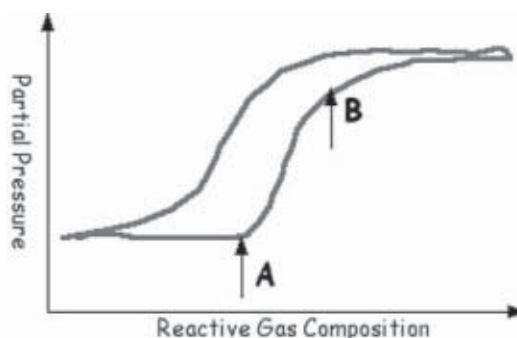


Figure 17. Partial pressure versus reactive gas composition.

As a means to perform reactive sputtering in the transition region, Sproul and Tomashek introduced partial pressure control in 1983. They used a differentially pumped mass spectrometer to measure the reactive gas partial pressure. Automatic feedback control adjusts the reactive gas flow rate to maintain a constant partial pressure in the transition region [33]. Once the target poisoning begins, the reactive gas flow is quickly reduced, thereby keeping the partial pressure in the chamber relatively low.

### Mid-Frequency AC Reactive Sputtering

As a means to help deal with the formation of a compound layer and the subsequent charging of the target, Cormia et al. pioneered the use of mid-frequency AC power in the 1970s [34]. By the mid 1980s, researchers such as Este and Westwood had improved the deposition rates and efficiency of this method substantially using a dual magnetron method [35].

The use of dual magnetrons was introduced by Este and Westwood in 1987 and refined by Scherer in 1991 and Glocker in 1993 [35,37]. Mid-frequency AC magnetron sputtering is essentially the same as the DC method described earlier except the cathode and anode switch places every half cycle. The most efficient use is with two targets [36]. As the potential continually switches, the compound buildup is maintained at a constant level. This prevents the “disappearing anode” problem previously encountered in reactive sputtering and also provides a more efficient use of the power being supplied to the process. In RF sputtering systems, only 50% of the applied power is used. This, in turn, can lead to increased deposition rates. Este and Woodward report up to 80% higher deposition rates for AlN films being grown this way versus RF magnetron sputtering at 13.56 MHz [37].

The buildup of charge on the target surface once the insulating layer has been established has been a problem for DC reactive sputtering. If too much charge accumulates, arcing can occur, which can eject macro-sized particles toward the substrate. With the high rate of switching in AC sputtering, this can be avoided. Typical frequencies used for the deposition of dielectric layers such as  $\text{Al}_2\text{O}_3$ ,  $\text{SiO}_2$ , and  $\text{Si}_3\text{N}_4$  range from about 10 kHz to about 100 kHz. Above about 10 kHz, there is not enough time for charge to build up on the target surface, thereby preventing any arcing [38].

One problem that arises is the increase in substrate heating during AC sputtering processes as opposed to DC processes. This increased substrate heating has been attributed to charged particle, both electron and ion, bombardment [39,40].

### Pulsed DC Sputtering

Similar to AC sputtering, a pulsed method of DC sputtering was first suggested around 1986. But the absence of suitable power supplies and fre-



quency generators prevented much real work with this technique until the early 1990s.

Two approaches to the pulsed magnetron sputtering (PMS) process have been used. The first is single magnetron sputtering (SMS). In SMS, the voltage is periodically reversed, allowing the buildup of charge to be removed from the target surface. In that the compound layer is not actually removed, the disappearing anode problem is not resolved in this method. The second method is called dual magnetron sputtering (DMS). In DMS, the discharge is switched between two magnetrons, with one magnetron always acting as the anode [41,42,43].

This differs from the mid-frequency AC sputtering in that the pulses are used as opposed to AC voltages. When the polarity of the target is negative, ions will be attracted and sputtering will occur. But there is also the formation of an insulating compound layer in many reactive processes. During the positive part of the cycle, electrons are attracted to the target to remove the charge buildup. Now, with the neutralization of the target, during the next negative pulse the ion bombardment of the target sputters some of the compound [44,45]. Power supplies are usually operated in a constant current mode. This way, when returning to the negative pulse, an initially high voltage rapidly accelerates ions to the target and re-establishes the current and deposition rate. Otherwise, the current takes a short time to build up and drop the plasma impedance, which was increased slightly during the positive pulse [46]. The duration of the plasma buildup and stationary plasma (maximum ion current) regimes depends on a number of factors such as: pulse duration, repetition frequency, pulse power, and operating pressure. Therefore, for high-frequency and short duration pulses, the plasma build-up phase dominates, and the pulsed magnetron operates in essentially a voltage mode. Whereas, for lower frequencies and longer pulse durations, the stationary plasma phase dominates, and the magnetron operates in a current mode [47].

Either a bipolar or unipolar pulse can be used to eliminate the charge buildup and prevent arcing [48]. In unipolar mode, a pulsed square wave voltage is applied to a single cathode. The anode is "hidden" in such a way that it will not easily be coated. In bipolar mode, voltages with alternating polarity are applied to two magnetrons, one acting as anode while the other acts as cathode [49]. When operating in the bipolar mode, either symmetric or anti-symmetric configurations can be used. In a symmetric configuration, equal positive and negative pulses are applied in each cycle; whereas, in anti-symmetric use, the magnitude of the positive pulse to the target is typically much smaller than that of the negative pulse, and its duration is typically smaller as well. This small, short, positive pulse is sufficient for the discharging that needs to occur during the positive cycle [50].

Because it usually takes considerably longer than one pulse cycle to poison a target, it is not necessary to reverse the polarity as often. But discharging is needed. In a pulse-packet supply, which is used with a dual magnetron system, a unipolar pulse (pulse frequency) is applied to one magnetron a number of times, and then the polarities are reversed (pole changing frequency), and the other magnetron is pulsed a number of times. This unipolar pulsing prevents charge accumulation and resulting arcing, and the insulating layers are eventually removed when the poles are reversed [51].

## High-Power Pulsed Magnetron Sputtering (HPPMS) Introduction

In October of 2001, V. Kouznetsov was awarded a U.S. Patent for a method of "magnetically enhanced sputtering." He showed that the application of very high instantaneous power, up to 100 times those normally used, results in regions of very highly ionized gas in which both the process gas as well as the sputtered species are ionized [52,53].

The results of this highly ionized plasma are a more uniform target utilization and a more uniform film deposition on the substrate. The pulsing Kouznetsov reported used pulses of at least 0.1 kW to 1 MW with peak voltages of 0.5 kV to 5 kV. The pulses were shorter than 1 ms in duration and occurred at intervals of 10 ms up to 1000 s [52]. Although the peak power can be up to 100 times the power normally used in conventional magnetron sputtering, the average power is in the same range [3,54].

This process provides numerous advantages over other sputtering methods. Up to 90% of the sputtered species can be ionized with the high-power pulses, and these ions can then be directed via electrical or magnetic fields as they approach the substrate, thereby providing a high degree of control over the deposition. Theoretical and experimental studies suggest that film density can be greatly enhanced with a high ion to neutral flux ratio at the substrate and a high ion energy flux [55]. For example, carbon films deposited with HPPMS exhibit densities up to 2.7 g/cm<sup>3</sup> as opposed to conventional DC sputtered films with densities below 2.0 g/cm<sup>3</sup> [56].

This method of deposition control yields a much more uniform, smooth, and dense film with equiaxed grains without the use of substrate heating and other methods such as arc-evaporation, which typically generate macro-particles [3,57]). Also, conversion of existing systems is relative easy. Many sources can already be used with HPPMS, and all that is needed is a power supply capable of the high power pulses [3].

In 2005, Christyakov was granted a patent for a variation in which the pulse is split into two phases. In the first part, a weakly ionized plasma is created, and the second phase this plasma is boosted to its highly ionized state. This method overcomes previous problems with deposition rates and power consumption [58,59]. In the second pulse, instabilities are created in the plasma that heat the electrons and result in an increase in ionizing collisions [3]. Higher deposition rates (up to 150%) than conventional DC sputtering can be achieved, as observed with Cu, Ti, and Al targets [3].

## Conclusions

From the earliest days of DC diodes until the present, there have been numerous significant improvements in sputtering technology. Magnetrons permitted the robust use of lower pressures over large areas and thereby enabled far superior coating quality. More recently, the use of feedback control of reactive gases and various types of AC and pulsed DC power supplies have made it possible to sputter electrically insulating materials at high rates and virtually eliminate arcing in the process. And unbalanced magnetrons and HPPMS produce significant levels of ionization, enabling more effective bias sputtering with still denser and harder coatings. Without these advances, many important applications would be impossible.

Because of these changes over the last 50 years, sputtering has moved from a laboratory-scale process to one that has enabled us to alter the way we live in dramatic ways. It is probably not too extreme to say that the digital age would not have been possible without the advent of high-rate, well-controlled sputtering processes. Every new technological improvement or combination of improvements has resulted in new opportunities and products. One need only look at the widespread use of controlled reactive sputtering from rotatable magnetrons with pulsed power supplies in the architectural glass industry for evidence of that.

In spite of these advances, there are still many fundamental questions about the sputtering process that remain unanswered and, if history is any guide, many unrealized opportunities. But any technology that combines plasma physics, chemistry, material science, electrical engineering and so many other fields is sure to continue to attract bright researchers to maintain the progress.

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**Matthew M. Waite** is an Associate Professor of Physics in the Department of Physics at West Chester University. He received a PhD in 1995 from the University of Delaware, and served as a member of the faculty at Gettysburg College and the University of Dallas before arriving at West Chester in 2001. Current research interests include physics education, and the growth and characterization of magnetic thin films, as well as metal-silicides for spintronics applications.

**S. Ismat Shah** graduated from the University of Illinois at Urbana-Champaign in 1986 from the Department of Materials Science and Engineering. He worked for the DuPont Company as senior Staff Scientist for 12 years before joining the University of Delaware in 1999, where he has a joint appointment in the Department of Materials Science and Engineering and the Department of Physics and Astronomy. He has been involved in the field of thin films and nanostructured materials for 22 years. He has over 145 publications in the field and six patents awarded. He is the Chair of the SVC Education Committee. He teaches the first on-line course offered by the SVC, in collaboration with the University of Delaware, on Vapor Deposition Processes.

**David Glocker** is President of Isoflux Incorporated, a manufacturer of magnetron equipment, which he founded in 1993. He has more than 20 years' experience in thin film research, development, and manufacturing and has taken a number of new processes from laboratory-scale feasibility studies through successful production. He is an inventor or co-inventor of 25 U.S. patents and an author of more than 25 research papers in the areas of sputter source design, plasmas and plasma characteristics, sources of substrate heating in sputtering, and the control of sputtering processes and sputtered film properties. He also is the co-editor of *The Handbook of Thin Film Process Technology*, a major reference work in the field.



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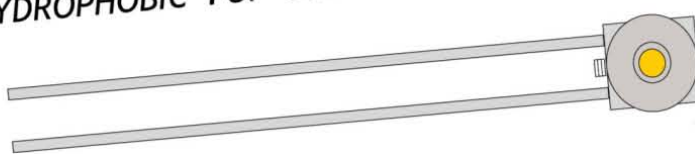
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## 2010 | SVC Education

### Problem-Solving Tutorial Courses at the 2010 TechCon

SVC is offering 19 of our most popular Tutorial courses at the 2010 SVC TechCon presented by industry professionals. Each instructor facilitates and encourages registrant/instructor interaction and networking between participants.

In addition three **New!** Tutorial courses are being offered as half-day programs to enable more of the TechCon registrants to participate – but not miss too many of the important technical presentations. A description and topical outline for each new tutorial is provided.

#### Registration for Tutorial Courses

- It is NOT necessary to register for the TechCon or be a member of SVC to attend the Tutorial courses or visit the Exhibit. Visiting the Exhibit is a productive additional education opportunity for every tutorial registrant. SVC typically has over 200 booths devoted to vacuum technology and coating.
- Tutorial Registration **Discounts** of 50% offered for Unemployed SVC Members and Non-Members. The current economy has left many industry professionals without jobs. The SVC Education Committee has stepped forward to implement a policy that will support the future of our members and the vacuum coating community. (SVC will need a copy of your letter of discharge.)
- **Discounts** Offered to Multiple Registrants from one company. SVC is offering a 25% discount on each Tutorial registration for the second or more employees in a company who enrolls in any Tutorial. (Note: this discount does not apply to the Student rate).
- **Note:** For any of the discounts listed above, you will need to pay the full Tutorial Registration fees on the On-line Registration system. Then you will send an E-mail to [svcinfo@svc.org](mailto:svcinfo@svc.org) and request the discounted fee. Discounts will be refunded after the TechCon.
- SVC reserves the right to cancel any Tutorial. If a Tutorial is cancelled, registrants will be notified and a full refund of tuition will be made or a discount provided if you are willing to switch to a different tutorial.

The fees for the Tutorials are the same for SVC Members and Non-Members; however, full-time student fees are substantially lower (SVC will need a copy of your student ID card).

#### General Conference Information

- **Register early!** Individual tutorial fees and conference registration fees are **\$100 higher** after March 27, 2010 (this does not apply to students or the Young Members Group).
- **Only tutorial cancellations received on or before March 17, 2010, will be refunded.** Refunds will be made upon receipt of a written notice, less a \$25 service fee for each tutorial. No refunds will be made for cancellations received after March 17, 2010.

### NEW Half-day Tutorial Courses at the TechCon

#### New! C-328 Properties and Applications of Tribological Coatings

Presented on Monday, April 19 1:00 p.m. – 4:30 p.m.

This tutorial is intended for design engineers, materials scientists, and coatings developers who have a need to specify and develop coatings for tribological applications (i.e., those in which wear must be reduced or prevented and/or friction minimized). The coatings also may need to have corrosion-resistant properties to operate in arduous conditions. The tutorial begins with a description of the mechanics of friction and wear and discusses the problems of selecting coatings for optimal tribological performance. An overview of the main processes for producing tribological coatings is given, emphasizing plasma assisted vacuum deposition methods. Tribological test methods also are overviewed, including tests for adhesion and mechanical properties. Coatings developed for enhanced tribological properties are described, and information is provided on applications for these coatings.

**Instructor:** Allan Matthews, *University of Sheffield, UK*

#### New! C-327 Introduction to Photoactive Materials and Photovoltaics

Presented on Tuesday April 20 8:30 a.m. – 12:00 p.m.

In addition to traditional semiconductors, photovoltaics technology now encompasses thin films, organic materials, low dimensional materials, nanotubes and biomaterials. This tutorial provides an introduction to the basic principles of photoconductivity and photoactivation, solar cell operation, photovoltaic devices, photocatalytic materials and the wide range of photovoltaic technologies and systems. Principles of photoconductivity and solar cell operation will be presented using basic solid state physics and graphic examples. Specific examples addressed are silicon solar cells, amorphous thin film silicon cells, Gratzel (dye sensitized) cells, organic cells and multijunction cells. This course will address current PV cell structures and power systems and the factors that are preventing them from achieving theoretical efficiencies. Solar concentrators and industrial PV systems will also be presented. Finally, future directions will be addressed.

**Instructor:** Peter Martin, *Columbia Basin Thin Film Solutions LLC*

#### New! C-326 Manufacture of Precision Evaporated Coatings

Presented on Thursday April 22 8:30 a.m. – 12:00 p.m.

This tutorial provides detailed information on how to establish and improve evaporative coating processes for precision optical coatings. Design considerations for coating chambers, such as source placement, substrate fixturing, control of film thickness uniformity, and thickness monitors will be discussed. Trade-offs in the selection of source materials, means of controlling film structure, and the influence on the performance of the coated component will be considered. Process details will be approached with a focus on practicality; film properties must be measurable and system designs must be practical and cost-effective. These process concepts are readily implemented in standard evaporation systems, providing significant improvements in existing coating facilities.

**Instructor:** Jim Oliver, *Vacuum Innovations, LLC and University of Rochester LLE*





# 2010 TechCon Education Program

April 17-22, 2010

## SVC Preliminary Tutorial Roster

*You do not have to register for the TechCon or be a member of SVC to attend tutorials.*

Anyone can take advantage of the practical problem-solving tutorials developed by the SVC. Taught by some of the most respected professionals in the vacuum coating industry, these tutorials cover every aspect of vacuum coating. Twenty-two tutorials will be offered, including three new tutorials on Hot Topics! Tutorials complement the technical conference sessions and Exhibit. Discounted fees are available for students. For detailed information, visit the education section of the SVC Web Site at [www.svc.org](http://www.svc.org). Register on-line or contact the SVC at 505/856-7188 or by E-mail to [svcinfo@svc.org](mailto:svcinfo@svc.org).

### EDUCATION PROGRAM SCHEDULE

	April 17 Saturday *****	April 18 Sunday *****	April 19 Monday *****	April 20 Tuesday *****	April 21 Wednesday *****	April 22 Thursday *****
Vacuum Systems, Materials and Operation (O'Hanlon)	V-204					
An Introduction to Physical Vapor Deposition (PVD) Processes (Shah)	C-103					
Thin Film Growth and Microstructure Evolution (Greene)	C-311					
Sputter Deposition (Greene) - Day 1 of 2-Day Tutorial		C-203				
Vacuum System Gas Analysis (O'Hanlon)		V-202				
ITO and Other Transparent Conductive Coatings: Fundamentals, Deposition, Properties, and Applications (Bright)		C-304				
Plasma Modification of Polymer Materials and Plasma Web Treatment (Grace)		C-314				
High Power Impulse Magnetron Sputtering (Ehiasarian & Anders)		C-323				
Sputter Deposition (Greene) - Day 2 of 2-Day Tutorial			C-203			
Numerical Methods for Optical Coatings (Dobrowolski)			C-303			
<b>NEW!</b> Properties and Applications of Tribological Coatings (Matthews) Half-day p.m.			C-328			
Sputter Deposition in Manufacturing (Glocker)				C-208		
Introduction to Plasma Processing Technology (Baránková & Bárdos) Half-day p.m.				C-210		
Reactive Sputter Deposition (Greene)				C-315		
<b>NEW!</b> Introduction to Photovoltaic Materials and Photovoltaics (Martin) Half-day a.m.				C-327		
Practical Aspects of Vacuum Technology: Operation and Maintenance of Production Vacuum Systems (Langley)					V-207	
A Primer on Thin Films and Vacuum Technology (McCrary)					C-101	
Troubleshooting for Thin Film Deposition Processes (Ash)					C-212	
The Practice of Reactive Sputtering (Sproul)					C-317	
Diamond Like Carbon Coatings – from Basics to Industrial Realization (Schuelke, Van de Kolk, and Bewilogua) Half-day a.m.						C-320
Alternative Transparent Conductive Oxides (TCOs) to ITO (Bright) Half-day a.m.						C-321
Atmospheric Plasma Technologies (Baránková & Bárdos) Half-day a.m.						C-324
<b>NEW!</b> Manufacture of Precision Evaporative Coatings (Oliver) Half-day a.m.						C-326

### Tutorial Classification System

The tutorial codes are intended to provide the prospective attendee with some guidance as to whether the emphasis in the tutorial is primarily on vacuum technology (V code), or vacuum deposition coating processes and technology (C code), or other miscellaneous topics (M code). The tutorial number is intended to indicate the level of tutorial specialization—the lower numbers refer to tutorials that are basic or introductory in nature, and the higher numbers refer to tutorials that offer a more specialized treatment of a specific topic. Tutorials are full day (8:30 a.m. to 4:30 p.m.) unless otherwise noted.

**For details on all tutorials in the SVC portfolio, including the tutorial description, topical outline, tutorial syllabus and biographical sketches of the instructors, explore the Education button on the new SVC Web Site at [www.svc.org](http://www.svc.org)**

## Orlando 2010 | SVC Exhibit



### SVC Recognizes 2010 TechCon Sponsors Sponsorships Are Still Available for the April event in Orlando

Now more than ever, the SVC relies on the generosity of companies within the international vacuum coating community to guarantee the continued financial success of the annual Technical Conference and Exhibit in this new decade.

In 2009 we introduced a level sponsor program that included Gold, Silver and Bronze sponsorships, along with a large selection of specialized sponsorship opportunities, including Badge Lanyards, Conference Tote Bags, Specialty Coffee Stations, Bottled Water, and many more.

The success of this level program has carried over to the 2010 Sponsor program, with a new Platinum Level Sponsorship and additional specialty sponsorship opportunities, including a Cookie Sponsorship, Exhibit Hall Massage Chair, Entertainment Sponsor, and brand new Flash Drive sponsorship.

Conference organizers are pleased to report that companies continue to be extremely generous – even in the midst of these challenging economic times – and recognize the benefits of making the SVC TechCon part of their 2010 marketing program. While many sponsors are also exhibitors, the sponsorship program is open to any company with an interest in reaching companies in vacuum coating and related technologies.

It's not too late to add your corporate logo to our list of distinguished sponsors. Any sponsorship can be combined with ads in the *Bulletin* and TechCon Exhibit Guide, or SVCnnnnnnections, and a pre-conference banner on the SVC Web Site! The possibilities are endless!

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### Business Unusual – The 2010 SVC TechCon Exhibit

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Join us in Orlando, Florida, for the 2010 TechCon Exhibit! We still have a limited number of booths available for this two-day exhibit.

#### Exhibit Hours:

Tuesday, April 20, 12:00 p.m.–6:00 p.m.

Wednesday, April 21, 10:00 a.m.–5:00 p.m.

To help exhibitors get the most out of their participation in the Exhibit, SVC provides a variety of special programs and networking opportunities within the Exhibit Hall.

- Poster Session on Tuesday afternoon
- Vendor Innovators Showcase in the Exhibit Hall on Wednesday
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- Flexible Technical Conference Program schedule with long breaks for attendees to visit the Exhibit.

### Get Connected! SVCConnections E-marketing Program

This new E-marketing program is a perfect place to promote your participation in the TechCon Exhibit before the conference.

SVCConnections is distributed to our extensive E-mail marketing list in a monthly E-marketing campaign. Our next issue is March 2010! For more information, visit [www.svc.org](http://www.svc.org) and click on Advertising/Sponsorships.

### New for 2010! Business Topics Program

The SVC introduces a new **Business Topics Program** in Orlando. The goal of this program is to help the companies who represent our vacuum coating industry and who strongly support our society gain a better understanding of where our complicated and diverse business is headed, put forth from a business-to-business (B2B) perspective. This session will be held on Tuesday, April 20 from 10:30 a.m. to 11:45 a.m.

Organizers are pleased to announce the first speaker in this new program: Richard Sager with Williams Advanced Materials. Sager's talk is titled "SVC 2010 and Beyond – What's in Store for Us in the Next Decade?" Sager will discuss how we are all responsible for making this industry/market capable of growing with the new applications and advances in technology. What is it that your company does, how does it fit in the market and what can be done differently? What is it that defines the idea of building a business that has established competitive advantages and how do we then translate that into building a business that has sustainable profitable growth? Dick will examine the idea of service, total cost, technology, innovation, and quality as key differentiators.

Stay tuned! The second speaker in this session will be announced in the Final Program and on the Web Site.





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## SVC and International Collaboration

The Society of Vacuum Coaters is dedicated to expanding the activities of the Society of Vacuum Coaters outside of the United States. As part of the SVC Strategic Plan several new and exciting projects are in the planning phase for 2011.

SVC is pleased to partner with three international conferences in 2010, and assist with promoting these gatherings to our worldwide database and community of over 15,000 vacuum coating professionals.

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This conference is organized by Sheffield Hallam University and the Network of Competence INPLAS.

SVC will offer two of its most popular full-day tutorial courses on Monday, July 5, 2010 preceding the conference.

- **SVC C-311 Thin Film Growth and Microstructure Evolution (Joseph Green)**
- **SVC C-208 Sputter Deposition in Manufacturing (David Glocker)**

To view the topical outline, description and detailed syllabus for these tutorial courses, visit the Education Page on the SVC Web Site.



**July 6<sup>th</sup> and 7<sup>th</sup> 2010**  
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### **SVC TUTORIAL COURSES** **July 5<sup>th</sup> 2010**

**SVC C-311**  
 Thin Film Growth and Microstructure Evolution  
**Dr. J. Greene**

**SVC C-208**  
 Sputter Deposition in Manufacturing  
**Dr. D. Glocker**

### **Conference Details and Information:**

**[www.shu.ac.uk/hipims](http://www.shu.ac.uk/hipims)**



ionbond

Hauzer





## SVC and International Collaboration

The Conference announces a **Call for Papers** that has the goal

- to promote the High Power Impulse Magnetron Sputtering (HIPIMS) as a novel technology for surface modification and coating deposition,
- to provide a scientific forum for discussion of the fundamentals of plasma science and exchange new ideas of applications of HIPIMS in industry,
- to bridge the academic research community with the industrial community to foster progress of plasma based technology.

For a copy of the **Call for Papers and Registration Information**, go to [www.shu.ac.uk/hipims](http://www.shu.ac.uk/hipims)

**Call for Papers – Deadline:** Submission of one page abstract by February 28, 2010. Submit the abstract by E-mail to [hipims2010@shu.ac.uk](mailto:hipims2010@shu.ac.uk)

### *SVC Collaborates with PSE 2010 to present a Tutorial Course and organize an Industrial Workshop*

#### **PSE 2010**

**Twelfth International Conference on Plasma Surface Engineering Conference and Exhibition**  
Kongresshaus, Garmisch-Partenkirchen, Germany  
September 13-17, 2010



This conference is organized by the European Joint Committee on Plasma and Ion Surface Engineering (EJC/PISE). The focus of the PSE Conference is on the fundamentals and applications of plasma and ion beam techniques in surface engineering. PSE provides an opportunity to present recent progress in research and development and industrial applications. Its topics span a wide range from fundamentals such as e.g. process modelling and simulation or thin physics, through empirical studies which establish the relationships between process parameters and the structural and functional properties of modified surfaces and/or thin films, towards the application in industrial production.

SVC will offer one of its most popular full-day tutorial courses on Thursday, September 16, 2010.


#### **SVC C-317 The Practice of Reactive Sputtering (Bill Sproul)**

To view the topical outline, description and detailed syllabus for these tutorial courses, visit the Education Page on the SVC Web Site.

Within the conference an Industrial Workshop – Plasma Technologies for Reduction of CO<sub>2</sub> Emission – will be held. Speakers from industrial companies will discuss the current challenge to utilize Plasma Technologies for reduction of CO<sub>2</sub> emission. The Industrial Workshop will be organized by the German PISE Group (PLASMA Germany, formerly AK Plasma) in cooperation with the Society of Vacuum Coaters.

To register for PSE 2010 and the SVC Tutorial course, visit [www.pse2010.net](http://www.pse2010.net)

**Welcome to the**  
**Twelfth International Conference**  
**on Plasma Surface Engineering**



**Conference and Exhibition**  
September 13 - 17, 2010  
Kongresshaus  
Garmisch-Partenkirchen (Germany)  
[www.pse2010.net](http://www.pse2010.net)  
Submission of Papers and Registration  
only electronically via the website.

**EFDS** Europäische Forschungsgesellschaft Dünne Schichten e.V.  
European Society of Thin Films

Deadlines: Abstracts Due Date: January 31, 2010  
Reduced Registration Fee up to: July 1, 2010



**The International Conference**  
**on Coatings on Glass and Plastics**  
Advanced Coatings for Large-Area or  
High-Volume Products



**Braunschweig, Germany**  
**Conference 13-17 June · Exhibition 14-17 June 2010**  
<http://www.iccg.eu>

**Register Now and Save!**



## SVC Foundation Golf and Give Tournament to benefit The SVC Foundation

Sunday, April 18, 2010  
Orlando World Center Marriott  
Hawk's Landing Golf Club

**Registration:** 11:30 a.m.

**Shotgun Start:** 1:00 p.m.

**Awards:** 5:00 p.m.

**Outing Fee:** \$150/per golfer  
(Clubs will be available to rent)

**Fee Includes:** Sleeve of balls, bottle of water and box lunch

### Prizes for:

- 1st and 2nd
- Longest Drive
- Longest Putt
- Special Poker Game on Par 3's

Sponsorship opportunities are available for this charitable event. All sponsors will be recognized with signage and gratefully acknowledged at the Awards presentation.

### Choose from the following sponsorships:

Corporate Event Sponsor	\$1,500
Beverage/Snack Cart	\$1,000
Lunch Sponsor	\$750
Exclusive Hole/Prize Sponsor	\$250

### Call for details on additional sponsorships.

Register for the SVC Foundation Golf and Give Tournament when you register for the conference using the on-line registration system at [www.svc.org](http://www.svc.org).

If you have questions about participating in or sponsoring the SVCF Golf and Give Tournament, please contact Steve Sedlak at 248/681-5235 or Pam Luecke at 605/578-1339 for more information.



# The SVC Foundation

## Message from the Chair

Since our inception in 2003, we have awarded 17 scholarships to students from seven countries, giving out at least three significant scholarships annually in recent years. Our support can really have an impact in the life of these students; quoting a recent award recipient: "I am very thankful to SVC for the 2008 Scholarship Award. This scholarship gave me the opportunity to attend such a wonderful technical conference which is not only a conference but a school where I learned a lot."

During the past year we have seen the endowment of the Bernard Henry Fund, thanks to the effort of the SVC and AIMCAL, joining the company of the existing Rolf and Helen Illsley Fund and, John Fenn, Sr., Fund, and the Jane and Frank Warchol Fund. These donors recognize the value added to their donations through the work of our outstanding scholarship committee.

John Fenn, Jr.'s term on the SVC Foundation Board concluded November 2009. We wish to express our thanks to him for his major contributions to the Foundation, being instrumental in its creation, helping to obtain the first endowed fund, by his father, John Fenn, and for his many other contributions, personal and financial, to the Foundation.

The SVC Board of Directors has appointed two new directors, Pam Luecke and Bryant Hichwa, to serve six-year terms on the SVC Foundation Board of Directors. Bryant, also a new member of the SVC Board of Directors, brings many years of experience in industry and academia, having a strong commitment to education as a formal activity through his role as professor at Hope College and Sonoma State University. More informally, he has mentored countless young professionals as a researcher, manager and director in several high technology companies, including OCLI, JDS Uniphase, and MetroPhotonics Inc. His commitment to the SVC is evident from his leadership of the Optical Coatings TAC. He is also president of the Audubon Canyon Ranch Board.

Pam Luecke has been very active in the vacuum coating industry for many years. Pam founded SAGE industrial sales, served on the SVC Board of Directors, and has been instrumental on the SVC Future Sites committee for many years. Deeply committed to the field, Pam joins the SVC Foundation Board of Directors to further develop ways for the industrial partners to learn about, and contribute to, the mission of the Foundation. Her organization of the upcoming Golf Tournament at 2010 TechCon in Orlando is one example of her dedication to making a difference.

The SVCF Board of Directors is very much the stronger for the participation of these individuals.

We hear with sadness of the passing of John Reading (retired from Tico Titanium). John was a strong supporter of the Foundation, using his innovative whisky tasting fundraisers at both the SVC TechCon and the AIMCAL Conference to give visibility and donations to the Bernard Henry Fund.

This is my last year as Foundation Chair, although I will continue to serve on the Board. John Felts (Nano Scale Surface Systems) will become Chair, Paolo Raugai (Galileo Vacuum Systems, Inc.) will become treasurer, and Steve Sedlak (ESK Ceramics) will continue as Secretary. I hope you will give John the support you so generously gave me. I think the SVCF offers an efficient and effective way to give back to our strangely unique industry "what brung us."

The SVCF will have an Exhibit booth at the upcoming SVC TechCon, so be sure to stop on and see us. Please support the 5K Run and the Golf Tournament at the 2010 TechCon.

— Jim Seeser, SVC Foundation Chair

## SVC Foundation Board of Directors

**John Felts**, Chair, Nano Scale Surface Systems, Inc., (510/814-0340; [jtfelts@earthlink.net](mailto:jtfelts@earthlink.net))

**James W. Seeser**, Fundraising Chair, OCLI and JDS Uniphase (retired), (314/918-0160; [jseeser@aol.com](mailto:jseeser@aol.com))

**Steve Sedlak**, Secretary and Special Events Co-Chair, ESK Ceramics - A Ceradyne Company, (800/833-7608; [ssedlak@ceradyne.com](mailto:ssedlak@ceradyne.com))

**Paolo Raugai**, Treasurer and Scholarship Committee Co-Chair, Galileo Vacuum Systems, Inc. (678/513-0303; [praugai@worldnet.att.net](mailto:praugai@worldnet.att.net))

**Wolfgang Decker**, 5K Run Organizer; SVC Board Representative; VAST FILMS, Ltd.; (724/827-8827; [w.decker@vastfilm.com](mailto:w.decker@vastfilm.com))

**Bryant Hichwa**, SVC Board Representative and Scholarship Committee Co-Chair, Professor Emeritus, Sonoma State University and OCLI; (707/785-1922; [bhichwa@earthlink.net](mailto:bhichwa@earthlink.net))

**Pamela T. Luecke**, Special Events Co-Chair, SAGE industrial sales, inc.; (605/578-1339; [pamluecke@aol.com](mailto:pamluecke@aol.com))



## The SVC Foundation

### Treasurer's Report

With a few weeks to go, I can report that the SVC Foundation has achieved positive cash flow for 2009, even though it was a thin year for donations. Although donations were down somewhat this year, the Foundation received over \$10K, and qualified for matching by SVC, raising our total donations for the year to well over \$20K. I would like to thank Jim Seeser and Nano Scale Surface Systems, Inc. for their generous donations. In addition to these donations, we have seen our investments grow by almost 15%, raising over \$20K, and derived significant income from the 5K run at TechCon in Santa Clara through sponsorships and participant donations. Additionally, the Bernard Henry Fund has exceeded the \$50K goal and will now become an endowed fund within the SVC Foundation. Thank you AIMCAL and all others who worked to accomplish this.

For 2010, we are proposing granting scholarships and are gearing up to raise more money through donations, our annual 5K Run at the SVC TechCon and our new Golf Tournament (also at the Techcon). As always, we will remain conservative in our financial planning. We would like to thank the SVC for their continued support and funding of up to \$10K in matching funds for any donations of at least \$1K.

– John Felts, SVC Foundation Treasurer

### SVC Foundation Sponsors the Fifth Annual 5K Fun Run and Walk

Join friends and colleagues for the Fifth Annual 5K Fun Run and Walk in Orlando. No matter what your ability, this early morning event is always a great experience for all runners and walkers who participate.

The 2010 5K Fun Run and Walk will be on Tuesday, April 20, 2010 at 6:00 a.m. Participating in this event will not only benefit your own health, but also the SVC Foundation, which awards scholarships to students working in the field of vacuum coating technology.

The Foundation is also looking for companies to sponsor the 5K. Each company's name and logo will be printed on the back of the T-Shirt given to every participant in the event. Please contact Wolfgang Decker at [w.decker@vastfilm.com](mailto:w.decker@vastfilm.com) for information on sponsorship. The registration fee of \$25 will include a T-shirt. Register for the 5K Run when you register for the TechCon at [www.svc.org](http://www.svc.org).

## Society and Industry News

### 2009 TopCon Report

The sunny fall skies of Albuquerque, New Mexico played host for the SVC's first Topical Conference on "Advanced Coating Technologies for Corrosion/Erosion and Decorative Coatings; Alternatives for Electroplating Techniques" for two days in early November 2009. SVC was fortunate to obtain the co-sponsorship for the Topical Conference from Sandia National Laboratories. Fifty-seven attendees participated in the tutorial courses, vendor exhibits and listened to the technical program on replacements for electroplated chrome coatings. The attendance was slightly lower than projected, but given our economic times, the conference organizers were pleased with how many made an effort to participate in this focused conference.

A product of SVC strategic planning, the Topical Conference, or TopCon, was developed to address rapidly developing or disruptive technologies that influence our daily work lives. It is also our goal that, in the future, this smaller conference on a focused topic can be held at international venues in conjunction with international partners.

The technical program included a variety of applications and technologies. Abstracts of all presentations are included in the 2009 Topical Conference Final Program on the SVC Web Site at <http://www.svc.org/ConferencesExhibits/2009-TopCon-Exhibit.cfm>. Doug Wall from Sandia National Laboratories in Albuquerque presented our keynote talk, "The Role of Corrosion Resistant Materials in the Proposed Yucca Mountain Repository." Other invited speakers included Sabrina Lee of Benét Laboratories, Bruce Sartwell, US Department of Defense, Keith Legg of the Rowan Technology Group, Ahmet Alpas of the University of Windsor, Canada, Javier Barriga from Tekniker, Spain, and Jaume Amigó of Sidasa, Spain.

The presentations represented a broad spectrum from scientific towards commercial applications, while keeping within the focused conference objective. Most survey respondents learned of the conference from colleagues and made their attendance decisions due to the conference topic and networking possibilities, while the most beneficial aspect to many at the TopCon was the networking opportunity. Clearly, the exhibit hours were too long and the break periods for people to visit the exhibit were too short. We received good constructive criticism, ideas and compliments. Many thanks to all who attended, and to all who assisted to make this first TopCon a success.

– Gary Vergason, 2009 TopCon Chair

### 2009 Election of Directors by the SVC Membership

Under the SVC Constitution, the SVC membership voted in 2009 by secret ballot to elect two new Directors for three-year terms starting at the Annual Business meeting, April 18, 2010.



Second Term Director:  
Ladislav Bardos  
Uppsala University, Sweden  
46/184 713 034  
[ladislav.bardos@angstrom.uu.se](mailto:ladislav.bardos@angstrom.uu.se)



First Term Director:  
David Sanchez  
954/261-2120  
Williams Advanced  
Materials, Ft. Lauderdale, FL  
[david\\_sanchez@beminc.com](mailto:david_sanchez@beminc.com)

### SVC Young Members Group Seeks Volunteer Mentors Sunday, April 18, 2010 2:00 p.m. – 4:00 p.m.

Our Young Members are the focus of a unique networking event on Sunday afternoon, April 18, 2010, that will offer Young Members the opportunity to engage in one-on-one discussions with various TAC representatives and Mentors in an informal setting.

To make this event work, we need a few people from the different TACs and different walks of life (government, business, academia) to be part of this new networking program for the Young Members. It will be a similar format to the popular Technology Forum Breakfast meetings at the TechCon except that we will ask the young members to move around every 20 minutes.

If you are interested in becoming a Mentor, please contact the Committee Chair or any member of the Committee (see page 14 for contact information), or send an E-mail to [svcinfo@svc.org](mailto:svcinfo@svc.org).

## Society and Industry News

### General Plasma Appoints Quanyuan Troy Shangguan as Chief Technology Officer (CTO)

General Plasma Inc. (GPI) is pleased to announce Troy Shangguan has joined the company as its Chief Technology Officer (CTO).

Shangguan is a recognized visionary in the large area thin film industry with a strong track record of innovation in low temperature polysilicon (LTPS) technology, thin film transistor (TFT) process technology, and chemical vapor deposition (CVD) process chamber development. Shangguan is acknowledged as an originator of remote plasma source (RPS) cleaning technology and the commercial use of inkjet for color filter technology. In his prior role as Director of Advanced Technology at Applied Materials, Shangguan led technology initiatives enabling Applied to achieve and maintain its dominant market position in PECVD amorphous silicon TFT processing equipment, and increase its LTPS market share from 30% to 70%.

Shangguan's achievements in large area processing and equipment technology have been widely recognized. In 1999, R&D Magazine awarded Shangguan the 100 Best Products award for a solution to greenhouse gas reduction during chamber cleaning.

In 2007, Shangguan was presented with the "Hall of Fame" patent award for significant, commercially successful innovations. Shangguan has been granted over 50 United States and international patents and has 40 additional patents pending.

John Madocks, President of GPI, commented, "We are delighted to have Troy at GPI. His unmatched thin film process knowledge and experience will greatly enable GPI's disruptive large area plasma source technology. We are excited about our future in providing superior, cost effective solutions to solar and other large area coating industries."

Shangguan said, "GPI is focused on aggressively developing the next generation plasma process technology and equipment for flat panel displays, solar, and semiconductor manufacturing that will dramatically improve performance and reduce cost. I am excited to be taking on this new and challenging role."

### Print and Digital Marketing with SVC New! SVConnections E-marketing Program

E-mail marketing to our extensive SVC database has become a useful tool for promoting our annual TechCon, Exhibit and Education program. To help our exhibitors reach potential customers and promote participation in the 2010 TechCon Exhibit, we have developed an E-marketing Program. SVConnections will be presented as a monthly E-mail update to promote TechCon exhibitors and SVC advertisers, and inform the vacuum coating community of news of special interest. This new program offers two options:

1. Once monthly E-marketing campaign that includes a logo, photo or unanimated graphic with link plus 50 words. Choose from two different options: 6 months \$600 or 12 months \$950.
2. 3-month E-marketing campaign that includes a logo with link and 20 words for \$250.

We welcome your input and invite you to share on-line, non-promotional articles of interest. Don't miss the March issue, scheduled to deploy on March 3.

### Enhanced Multimedia Advertising Opportunities

SVC is moving the *Bulletin* and TechCon Exhibit Guide into the digital revolution! distributed internationally using the extensive SVC E-mail list of subscribers, this enhanced digital format enables deep linking, rich media and video content to drive reader interaction with editorial content and advertising.

Your ad in the *Bulletin* or TechCon Exhibit Guide can be enhanced by embedding a video onto the page that is aimed at moving exhibit visitors to your booth at the TechCon Exhibit. Or a simple animated starburst added to your digital ad can highlight your participation as a TechCon Sponsor or presenter in the Innovators Showcase. The opportunities are endless and remarkably affordable!

Visit <http://online.qmags.com/SVCMK> to view the SVC Digital Media Kit and get details on enhancing your ad in our digital publications.



### New! Lower Rates for Web Banner and Corporate Sponsor Logo Programs

In response to the economic climate and in efforts to support our members, affiliated companies and corporate sponsors, we have reduced the pricing on our Rotating Web Banner ad program and Corporate Sponsor logo program.

The Rotating Banner Ad and the Rotating Corporate Sponsor Logo are both located on the main page of the Web Site and include a URL link to the Web Site of choice.

### "Visit Us Now" and Company Logo Links

Choose from a variety of other web advertising options designed to complement your print advertising program. Companies that exhibit at the TechCon can increase customer awareness by taking advantage of a link on our Virtual Exhibit section that sends customers to their Web Site with a highly visible "Visit Us Now" icon from their descriptive paragraph on the SVC Web Site. To complete the connection, advertisers can also add their company logo adjacent to the descriptive exhibit text.

In the Product and Services (P&S) Locator section, advertisers' names can be highlighted on the search result page and linked with a "Visit Us Now" icon to the company's web site. Companies can also choose the Enhanced "Visit Us Now" link on the company page, featuring the company logo as the linking icon and takes users to the company's web site.

For more information on advertising opportunities with the SVC, visit [www.svc.org](http://www.svc.org) and click on Advertising/Sponsorships.

### Education Opportunities for Companies with Limited Travel Budgets

If your company has a limited budget for travel, perhaps you would like to host a Tutorial course program at your facility through the SVC On Location Education Program. For a complete listing of available courses go to the On Location Education Program button under Education at [www.svc.org](http://www.svc.org).



## Society and Industry News

### Solar Photovoltaic Industry Update

For the Solar Photovoltaic industry, 2009 was a tale of two halves. The first six months of the year saw both worldwide demand and North American demand dramatically drop off from the peak of late 2008. The Spanish demand bubble exploded and a harsh winter in Europe brought demand to a dead stop for the PV community. Industry pundits lowered forecasts, panel prices fell (in some cases 40-50%).

Major US players such as BP, General Electric and Evergreen announced plans to close North American capacity and move manufacturing to Mexico or China. On the thin film side, First Solar acquired Opti-Solar's project pipeline and continued to position itself as the thin-film leader in North America. Amorphous silicon providers continued to have a difficult time finding funding and traction in a marketplace that demanded a track record and proven technologies. From my perspective at mid-year, 2009 was shaping up to be a disaster.

Six months makes a big difference! In an anticipated turn of events, global PV shipments will eclipse 2008's record totals, probably surpassing six GWp. In North America, shipments

will top 500 MWp for 2009 and grow in 2010. The obvious question is, what changed? The obvious answer is that the global economic climate improved from the chaos of late 2008 and early 2009. In the US, it also became apparent that (finally!) some American Recovery and Reinvestment Act (ARRA) funds would be awarded to jump start production projects. Money financing prospective projects was a little more available as well as venture capital appetite for funding start-ups.

One outsized driver for the industry's success in 2010 will be the stimulus that tax credits awarded in January 2010 under ARRA will create. \$2.3 billion in tax credits were awarded to 183 companies in the renewable arena. Some significant awards: Miasole - \$101 million; CIGS manufacturer; DuPont - \$50 million; First Solar - \$16 million; General Electric - \$107 million; Solarworld - \$82 million. Although these are tax credits rather than outright cash grants, many of the awardees have positive income that will let them take advantage of the credits in an efficient and timely manner. It is also worth noting that wind and Concentrated Solar Power (CSP) technologies received substantial monies too-the DOE appears to be taking a broad look at technolo-

gies that can succeed in the renewable arena.

So what will 2010 bring? Predictions are risky, but here are a few:

- Demand will continue to grow for PV products, but will be dominated by c/Si products. First Solar's low-cost CdTe technology will be a continued success but low pricing for modules in general will continue to drive growth in more mature technologies.
- CIGS will finally emerge as a market force. The technology is going to succeed, but who will bring CIGS to market is the real issue.
- Germany and European countries will cut feed-in tariffs, slowing growth of the largest market in the world. France has already announced cuts in its program with Germany likely to follow as early as mid-year 2010
- China becomes the low-cost manufacturing center for the world for PV modules. I hope this does not happen, but firms manufacturing in China continue to drive costs down and quality up. Take a look at Thomas Friedman's columns in The New York Times for an eloquent argument warning of our loss of competitiveness in North America.

For further information, contact Ed Wegener at [edwegener@charter.net](mailto:edwegener@charter.net).

MATERIALS RESEARCH SOCIETY



**2010 MRS SPRING MEETING**  
San Francisco, CA • April 5-9



**FUNCTIONAL MATERIALS**

- A Amorphous and Polycrystalline Thin-Film Silicon Science and Technology
- B Silicon Carbide—Materials, Processing, and Devices
- C Solution Processing of Inorganic and Hybrid Materials for Electronics and Photonics
- D Plasmonic Materials and Metamaterials
- E Chemical Mechanical Planarization as a Semiconductor Technology Enabler
- F Materials, Processes, Integration, and Reliability in Advanced Interconnects for Micro- and Nanoelectronics
- G Materials and Physics of Nonvolatile Memories
- H Phase-Change Materials for Memory and Reconfigurable Electronics Applications
- I Materials for End-of-Roadmap Scaling of CMOS Devices
- J Materials and Devices for Beyond CMOS Scaling
- K Functional Materials and Nanostructures for Chemical and Biochemical Sensing
- L Recent Advances and New Discoveries in High-Temperature Superconductivity
- M Structure-Function Relations at Perovskite Surfaces and Interfaces

**NANOMATERIALS**

- N Functional Oxide Nanostructures and Heterostructures
- O Multifunctional Nanoparticle Systems—Coupled Behavior and Applications
- P Semiconductor Nanowires—Growth, Physics, Devices, and Applications
- Q Template-Based Nanofabrication—Nanowires, Nanotubes, and Associated Heteronanostructures
- R Carbon Nanotubes and Related Low-Dimensional Materials
- S Graphene Materials and Devices
- T Photovoltaics and Optoelectronics from Nanoparticles
- U Scanning Probe Microscopy—Frontiers in NanoBio Science
- V In Situ Transmission Electron Microscopy and Spectroscopy

**ENERGY MATERIALS**

- W Diagnostics and Characterization of Energy Materials with Synchrotron and Neutron Radiation
- Y Computational Approaches to Materials for Energy
- Z Actinides V—Basic Science, Applications, and Technology
- AA Scientific Basis for Nuclear Waste Management XXXIV
- BB Materials for Nuclear Applications and Extreme Environments
- CC Solid-State Batteries
- DD Thermoelectric Materials—Growth, Properties, Novel Characterization Methods, and Applications
- EE Defects in Inorganic Photovoltaic Materials
- FF Polymer Materials and Membranes for Energy Devices
- GG Nanoscale Charge Transport in Excitonic Solar Cells
- HH Organic Photovoltaic Science and Technology

**SOFT/BIOMATERIALS**

- II Materials Science and Charge Transport in Organic Electronics
- JJ Stretchable Electronics and Conformal Biointerfaces
- KK Micro- and Nanofluidic Systems for Material Synthesis, Device Assembly, and Bioanalysis
- LL Directed Assembly and Self Assembly—From Synthesis to Device Applications
- MM Evaporative Self Assembly of Polymers, Nanoparticles, and DNA
- NN Materials Exploiting Peptide and Protein Self Assembly—Toward Design Rules
- OO Hierarchical Self Assembly of Functional Materials—From Nanoscopic to Mesoscopic Length Scales
- PP Interfacing Biomolecules and Functional (Nano) Materials
- QQ Biological Materials and Structures in Physiologically Extreme Conditions and Disease

**GENERAL**

- X Frontiers of Materials Research

[www.mrs.org/spring2010](http://www.mrs.org/spring2010)

## Society and Industry News

### Outstanding Students Highlighted at the 2010 TechCon

The SVC Student Sponsorship Committee is pleased to sponsor these six talented students who will present their work in the oral technical sessions in Orlando.



#### **H       Suttle**

*University of Oxford, Oxford, United Kingdom*  
H       Suttle will present the paper entitled, "High Performance Gas Barrier Materials for Electronics Applications" (W-3) on Monday, April 19 at 10:10 a.m.



#### **Jan Lazar**

*University of West Bohemia, Plzen, Czech Republic*  
Jan Lazar will present the paper entitled, "Characterization of High Power Impulse Magnetron Sputtering of Zirconium" (HP-4) on Tuesday, April 20 at 9:30 a.m.



#### **Ganesh Kamath**

*Sheffield Hallam University, Sheffield, United Kingdom*  
Ganesh Kamath will present the paper entitled, "Micro-Structural and Oxidative Mechanical Wear Study on TiAlCN/VCN Nanostructured Multilayer Coating Deposited by HIPIMS/HIPIMS Technique - Impression of High Density Metal-Ion Irradiation in Reactive Atmosphere" (HP-7) on Tuesday, April 20 at 11:10 a.m.



#### **Phitsanu Poolcharuansin**

*University of Liverpool, Liverpool, United Kingdom*  
Phitsanu Poolcharuansin will present the paper entitled, "Low Pressure HiPIMS Operation Using a Pre-Ionizer Technique" (HP-5) on Tuesday, April 20 at 3:10 p.m.



#### **Kayne Dunn**

*McMaster University, Hamilton, Canada*  
Kayne Dunn will be presenting two papers, "Calibration and Comparison of SiC<sub>x</sub>N<sub>y</sub> Thin Films Deposited by ICP CVD" (O-11) on Thursday, April 22 at 9:10 a.m. and "Luminescent SiC<sub>x</sub>N<sub>y</sub> Thin Films Deposited by ICP CVD" (O-15) Thursday, April 22 at 11:10 a.m.



#### **Koen Van Aeken**

*University of Ghent, Ghent, Belgium*  
Koen Van Aeken will present the paper entitled, "The Angular Distribution of the Arriving Metal Flux during Magnetron Sputter Deposition" (A-6) Thursday, April 22 at 11:10 a.m.

### In Memoriam

#### *David Cushing 1941 – 2009*

David Cushing began his career working in the thin film field as a production technician in a small lab processing cemented all-dielectric filters made by one of the pioneers in the business, Edgar Barr, at Baird Atomic Inc. He received his BSEE degree from Northeastern University in 1969. Eventually, he was given responsibility for the manufacture of ultra-violet filters. This led to establishing improved methods of filter assembly. David further advanced to supervisor of all filter production for the now-10 person group. He later became Filter Department Manager (1965-1971) for the expanding group that eventually contained 50 people.



David then went on to establish MicroCoatings, Inc., a two-person partnership for the production of filters for medical electronics and defense. The company was sold in 1986 and became OCA, where David continued as Technical Director until 1990.

David joined JDS Fitel Optics (1990-2001) and formed a Filter Department. He designed and fabricated a thermal vapor deposition coater specifically to make WDM filters. The coating machine was subsequently set up in Ottawa, Canada and manufacturing of the first (worldwide) production filters for WDMs commenced.

In 2001, David joined the Corning Precision Lens team to head their thin film R&D effort. Filters and anti-reflection coatings and miscellaneous special purpose coatings were designed and manufactured as needed.

David retired to Tucson, AZ in 2004 where he was a thin film consultant in the optical coating field. He was a Visiting Scientist at the University of Arizona and authored papers on a variety of filter types. He held seven U.S. patents and a number of world patents.

#### *John Reading 1931 – 2009*

SVC is saddened to learn of the death in October 2009 of John Reading, a long-time supporter and friend of the association.

Born and educated in the United Kingdom, John emigrated to the United States in 1956. Retired since 1993, he continued serving as a consultant to Tico Titanium Inc., in Michigan, where he worked for 20 years, representing the company at Trade Shows, Technical Conferences, and serving on various technical committees.



An avid fan of scotch, his collection includes more than 500 bottles, plus another 50 to 60 bottles earmarked for drinking. As a director of The Scotch Malt Whisky Society of America in Sunrise, FL, he oversaw many Scotch Tastings, including those held in conjunction with the annual SVC Technical Conference. John particularly enjoyed collaborating with chefs at restaurants and private clubs to present Scotch Tasting/Dinners.



## Corporate Sponsor News

### SHAPAL™-M soft Now Available from Goodfellow

SHAPAL™-M soft (aluminum nitride), a high-purity, high-strength machinable ceramic with thermal conductivity that is five times greater than alumina, is now available from Goodfellow Corporation through their affiliate, The Technical Glass Company. The ceramic is valued in a wide range of applications, particularly in the vacuum and nuclear industries, where its zero porosity, good ability to seal under vacuum, and low thermal expansion are especially important. SHAPAL™-M soft also finds application in heat sinks, electronically insulating components for the high-power electronic industry, and crucibles for vacuum deposition. Unlike ordinary ceramics, SHAPAL™-M soft can be machined into complex shapes with high precision using conventional carbide tools. This makes it possible to produce SHAPAL™-M soft components without the delay and expense of conventional ceramic manufacturing processes.



SHAPAL™-M soft is available from Goodfellow as machinable rods and plates in a range of sizes, as well as finished machined components. Visit [www.goodfellow.com](http://www.goodfellow.com) for more information.

### Mustang Solar Completes Installations of CIGS Equipment Package; Moves Line into Production

The 2009 inaugural year for Mustang Solar closed with the company reporting completed installations of their CIGS solar cell line, which are currently in successful PV production. Mustang is now discussing their solutions with solar cell production customers worldwide, as they ramp up production for 2010.

## Corporate Sponsor Profile

### HENZE Boron Nitride Products GmbH

Since 1993, Henze Boron Nitride Products GmbH (Henze BNP), has concentrated exclusively on hexagonal Boron Nitride, marketing this solid ceramic material under the trade name HeBoSint®.

HeBoSint® is both an excellent electrical insulator and a very good heat conductor. It maintains these characteristics within a wide range of temperatures and will withstand temperatures to 900°C under oxidizing conditions, and temperatures as high as 2,200°C in vacuum or in a protective atmosphere. In addition, HeBoSint® has a very low coefficient of thermal expansion and an outstanding thermal shock resistance. Last, but not least, it is not wetted by most molten metals.

This exceptional combination of properties makes HeBoSint® an ideal material for PVD and PVD ARC cathode shielings and insulators. HENZE Boron manufactures these parts in a wide range of geometries for plasma equipment used in the production of hard coatings on cutting and forming tools, as well as tribological, decorative and high quality optical surfaces.

HeBoSint® machined-to-precision parts are used and respected by renowned OEMs and vacuum coaters worldwide. For more information on HENZE Boron Nitride Product GmbH, visit [www.henze-bnp.de](http://www.henze-bnp.de).

In late 2008, Mustang Solar was spun out from parent company, Mustang Vacuum Systems, which supplies large format PVD and evaporation equipment for industrial applications, including automotive, lighting, and diamond-like coatings, as well as contract manufacturing and design of custom vacuum systems. Mustang's background in high volume industrial deposition equipment has enabled Mustang Solar to deliver production line solutions for PV, focused on the CIGS and CdTe solar processes.

"We are very excited about our achievements in our first full year of operation," said Richard Greenwell, President of Mustang Solar. "We've been able to draw upon our core competencies of thin film deposition and industrial design, along with our diverse custom tool building experience and technology, to successfully scale customers' processes to production level, and build equipment that works. We look forward to supplying a proven industrial solution to PV production customers."

Mustang Vacuum Systems ([www.mustangvac.com](http://www.mustangvac.com)) is a leading manufacturer of vacuum coating / metalizing equipment, featuring world-class deposition technology. Mustang Solar is a wholly-owned subsidiary, offering industrial production equipment, specifically designed for the photovoltaic solar market. For further information, send inquiries to [www.mustangsolar.com](http://www.mustangsolar.com)

### SINGULUS TECHNOLOGIES AG Sells HamaTech APE

SINGULUS TECHNOLOGIES (SINGULUS) announced the completion of negotiations regarding the sale of the HamaTech APE GmbH & Co. KG (APE), a 100% subsidiary of SINGULUS, to the SÜSS MicroTec AG (SÜSS).

A purchase price in the amount of € 4.5 million for the APE enterprise as well as additional € 4.5 million for the acquisition of the land and buildings at the site in Sternenfels were agreed. The completion of the transaction ("Closing date") is scheduled for January 2010. The purchase price of € 4.5 million for APE is split into fixed and variable components. The fixed component amounts to € 3.5 million and will be paid in cash. The variable purchase price ("Earn-out component") amounts to € 1.0 million and is tied to the sales performance of HamaTech APE in 2010.

An extensive letter of intent regarding the acquisition of the HamaTech APE had already been signed on December 6, 2009 by the contractual parties SINGULUS and SÜSS.

HamaTech APE has established itself in the semiconductor sector as the world's leading supplier for the cleaning of photo masks and employs approximately 80 people at the site in Sternenfels and at foreign subsidiaries. In the business year 2009, the company realized estimated sales in the amount of € 11 million.

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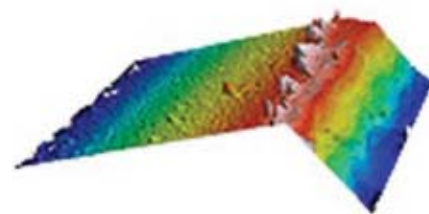
### Nanometer Online Inspection with Nanovea 3D Non-Contact Profilometer

Nanovea 3D Non-Contact Profilometer will now have optional online capability for automated inspection and report generation. With this advancement Nanovea's Profilometer can now effortlessly integrate into large or small quality control environments. Crucial applications throughout all industries, which were once inspected with vision and or touch-probe, will now be inspected with the assurance of high speed noncontact nanometer measurement. This is especially critical to batch production with tight tolerance levels which can now be easily monitored to insure quality control via online communication.

With this new feature applications can be automatically scanned and analyzed based on instructions found on a server database. The online inspection feature allows automatic product ID scan with a bar code reader (could also be manually entered in); the product ID is then checked against pre-defined pass/fail and measurement requirements stored on a company database. The part is automatically measured, and upon

completion a report is automatically generated. The report and the pass/fail information is automatically sent back to the server and stored with that part number. Measurement speeds range from 1m/s and 31,000 points/sec with nanometer accuracies. There are various scan types, analysis functions and size options that can be customized to fit applications throughout all industries.

"This is a very exciting capability for Nanovea. Our Profilometers can best utilize online inspection at this time, but it is also a new option for our Mechanical Testers when hardness could be used for quality control," commented Craig Liesing, Product Manager.



3D cutting tool edge

## New Product

### Lesker's New MEMS Pirani Gauge

Kurt J. Lesker's new MEMS Pirani gauge offers a cost effective, yet rugged and reliable solution to vacuum measurement from atmosphere down to  $1 \times 10^{-4}$  Torr. The MEMS Pirani gauge uses advanced MEMS technology and lock-in AC signal processing in its integrated electronics which results in reliable and precise measurement. Digital field calibration, any orientation mounting, and optional rear sensor port also add to the flexibility of this gauge. Visit [www.lesker.com](http://www.lesker.com) for more information on our MEMS Pirani gauge and all the vacuum gauges that we offer.



MEMS Pirani Gauge

## New Product Announcements

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## Corporate Sponsor News

### Pfeiffer Vacuum Acquires Vacuum Component Manufacturer – Trinos

Pfeiffer Vacuum, one of the world's leading producers of vacuum products and services, has acquired Trinos Vakuum-Systeme GmbH of Göttingen, Germany. Under the terms of the agreement, Pfeiffer Vacuum has acquired 100 percent of the shares in Trinos effective January 1, 2010. The purchase price will be financed in cash. Confidentiality has been agreed regarding the total volume of the transaction.

By expanding the Pfeiffer Vacuum portfolio to include the high-quality vacuum components, chambers and systems from Trinos Vakuum-Systeme, the company can now offer its customers throughout the world even more comprehensive solutions for their vacuum needs. The expertise possessed by the two companies in developing and engineering new technologies is also complementary. All regions and market segments will benefit from this acquisition, in particular the North America region and the analytical, coating and research & development segments.

Pfeiffer Vacuum Chief Executive Officer Manfred Bender explains: "Of all of the potential acquisitions that we have recently reviewed, Trinos Vakuum-Systeme makes for the best fit with us. The company is young, fast growing, profitable and active in the same markets we are. Trinos has a very good name in the marketplace. With this move, Pfeiffer Vacuum is taking a further step along the road to becoming a full-line provider of vacuum applications. We are convinced that Trinos' integration into our worldwide sales and service network will be swift, and we intend to work together to generate further growth."



### Goodfellow Corporation Becomes Autonomous Company

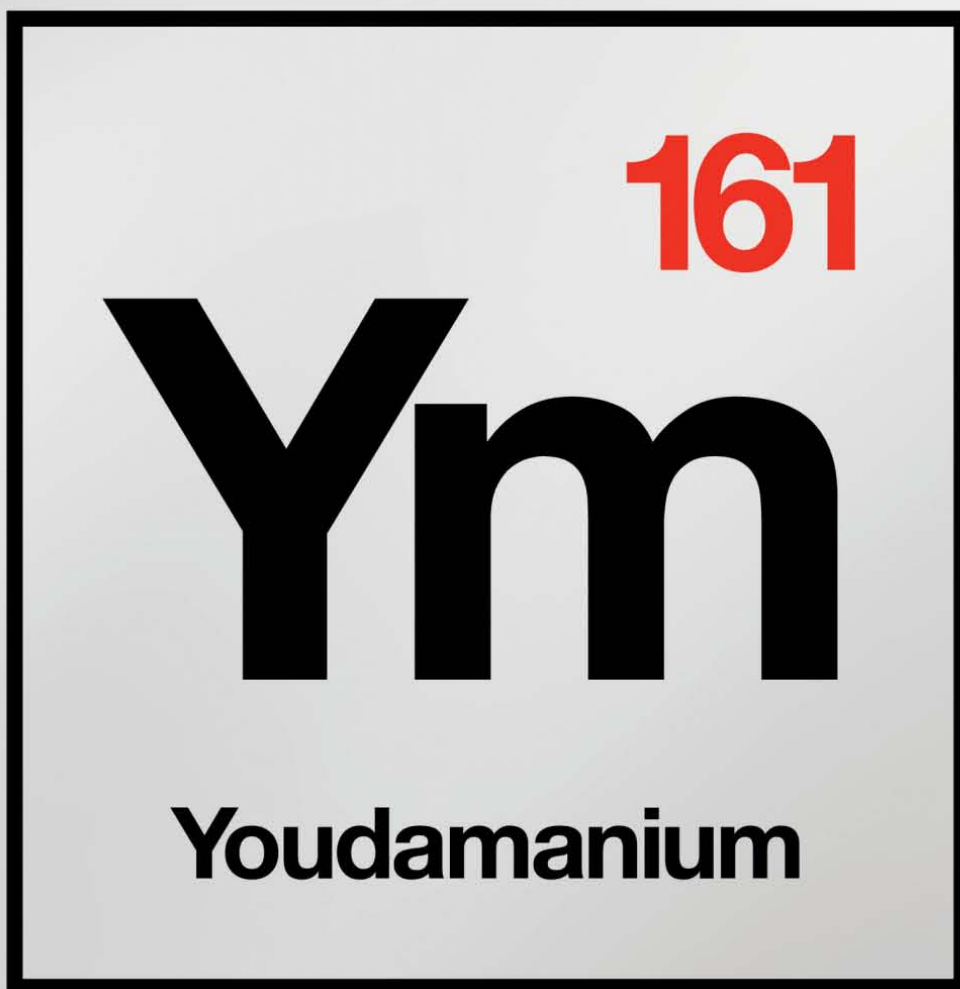
Goodfellow Corporation of Oakdale, PA, formerly a subsidiary of Goodfellow Cambridge Ltd., is now a fully autonomous U.S. company within the Goodfellow Group of Companies. In announcing the news, Stephen Aldersley, president of Goodfellow Corporation, noted that a dedicated website – [www.goodfellowusa.com](http://www.goodfellowusa.com) – has also been created exclusively for the U.S. market.

"An autonomous Goodfellow Corporation will have an even keener focus on the specific materials requirements of

U.S. scientific research and manufacturing," states Aldersley. The company will also be providing a more timely service, with many orders shipped directly from Goodfellow Corporation's Pennsylvania warehouse. "As the Goodfellow Group of Companies assumes a more global presence, the need to be nearer the customers we serve in each market increases," continues Aldersley. "We're confident that our U.S. customers will enjoy the benefits our new autonomy brings."

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