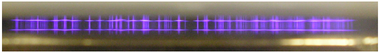
Atmospheric Pressure DBD (AP-DBD)

Two forms of dielectric barrier discharges (DBDs) with parallel plate electrodes:

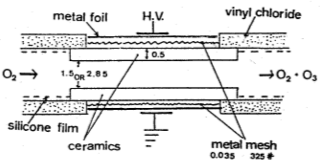
- filamentary



- homogeneous

Stabilization of **homogeneous DBDs requires suppression of filament formation**.

Important role of

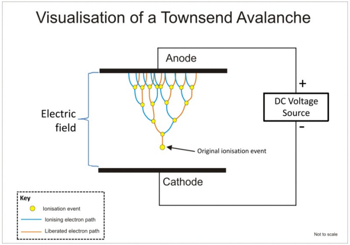


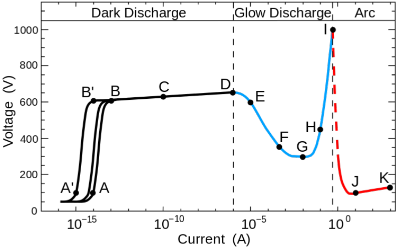
- **structure and material of electrodes**
  e.g. M. Kogoma, S. Okazaki, JPD (1994) 27 1985
- **higher frequencies of power supply**
  T. Nozaki et al., Plasma Process. Polym. (2008) 5 300)
- **gas mixture** (He, Ne, N_2, Ar + NH_3 etc.):
  - homogeneous DBD in He, Ar/NH_3 and N_2
    F. Massines et al. Surf. Coat. Technol. 174–175, 8 (2003); Plasma Phys. Controlled Fusion 47, B577 (2005).
  - PECVD in HMDSO/N_2 and HMDSO/N_2/synthetic air mixtures
    D. Trunec et al. J. Phys. D: Appl. Phys. 37 (2004) 2112; J. Phys. D: Appl. Phys. 43 (2010) 225403
  - PECVD in Ar/C_2H_2
    M. Eliáš et al. J. Appl. Phys. 117(10) (2015) 103301

Homogeneous Dielectric Barrier Discharges

Two different forms of homogeneous discharges were classified by Massines et al. Both start with Townsend breakdown initiating a Townsend discharge but

- in He, during the current increase, the discharge transits to a glow discharge ($n_\mathrm{e} \approx 10^{11}$) having a cathode fall and a positive column if gas gap is > 2 mm - **atmospheric pressure glow discharge (APGD)**
- in N_2, the ionization level is too low ($n_\mathrm{e} \approx 10^8$) to allow formation of cathode fall and the glow regime cannot be achieved - **atm. pressure Townsend discharge (APTD).**



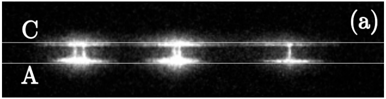


- C: avalanche Townsend discharge

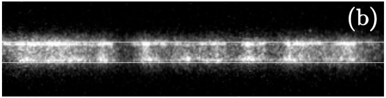
- D: self-sustained Townsend discharges
- F: sub-normal glow discharge
- G: normal glow discharge

Homogeneous DBD (APGD) in Ar/acetylene

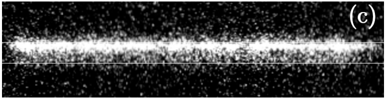
filamentary DBD in Ar



filamentary DBD in Ar/CH_4



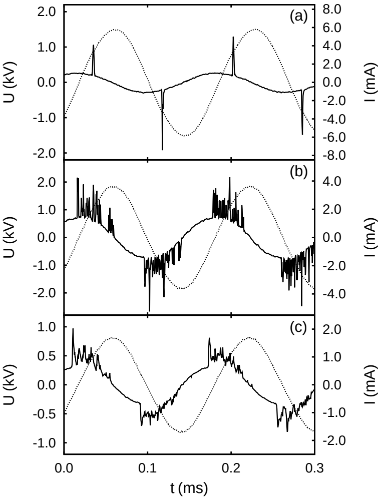
homogeneous DBD in Ar/C_2H_2



(80 μs (one half-period) exposure time)

- difference caused by possibility of Penning ionization of C_2H_2 in Ar
- Ar $1s^5$ metastable - 11.55 eV,
- C_2H_2 ionization potential 11.40 eV but CH_4 12.61 eV

M. Eliáš et al., J. Appl. Phys. 117(10) (2015) 103301



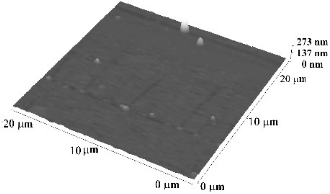
(a) DBD in pure Ar, (b) DBD in Ar/CH_4, (c) APGD in Ar/C_2H_2

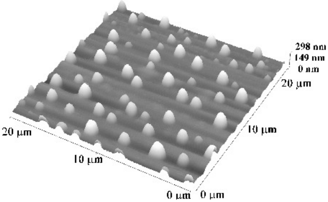
Why to Use Homogeneous DBD for Deposition?

. . . **to eliminate unwanted surface structures and non-uniformities**

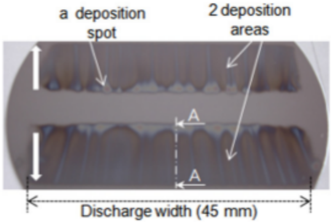
D. Trunec, Z. Navrátil, P. Sťahel et al. J. Phys. D: Appl. Phys. 37 (2004) 2112:

deposition in APTD (HMDSO/N_2) and in filamentary discharge





H. Caquineau et. al J. Phys. D: Appl. Phys. 42 (2009) 125201:



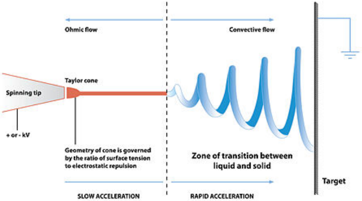
Local increased of the deposition rate, “deposition spots”, due to non-uniform power dissipation in micro-filaments.

Why to Use Homogeneous DBD for Deposition?

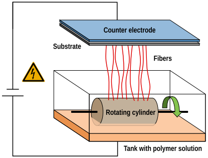
. . . modification of temperature sensitive and porous polymer nanofibers

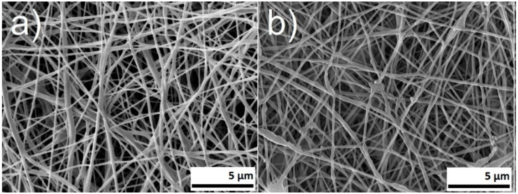
Interesting novel material, polymer nanofibers, can be prepared by electrospinning but it requires further modification of surface properties (as usually with polymers)

Classical nozzle electrospinning:



Nozzle-less electrospinning by Nanospider$^{\text{TM}}$ from ELMARCO:





a) polycaprolactone electrospun nanofibers b) coated by plasma polymerization in homogeneous DBD

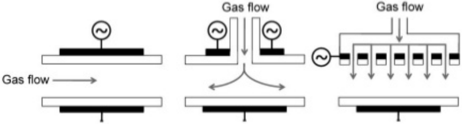
Problem of Film Uniformity

Amospheric-pressure plasmas are characterized by high collision frequencies of particles (several orders of magnitude higher compared to low pressure)

⇒ Delivery of active species to the substrate is much more advection than diffusion-driven (opposed to low-pressure).

⇒ High electron-neutral collision frequency ⇒ fast monomer conversion

Basic gas delivery set-ups



are **modified for optimization of flow patterns by gas dynamics simulations**

P. Cools et al., Plasma Process. Polym. 2015, 12, 1153–1163

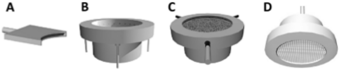
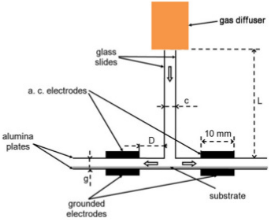


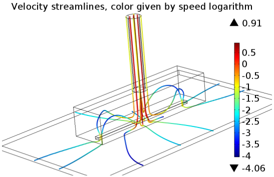
Figure 2. Schematic representation of the four different inlet set-ups: a) Sideway inlet, b) ring inlet, c) porous glass inlet, and d) microplasma-electrode.

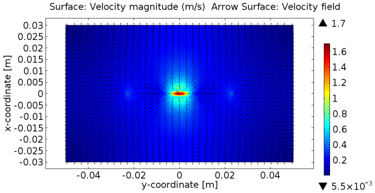
H. Caquineau et al. J. Phys. D: Appl. Phys. 42 (2009) 125201

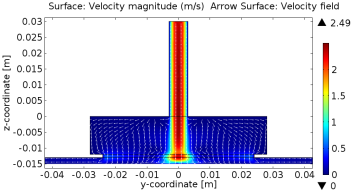


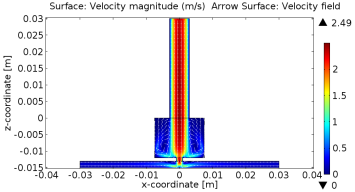
Gas Dynamics Simulations in Our Set-up

Solving the Navier-Stokes equations (laminar flow) in full 3D geometry for pure Ar (results are shown for 1550 sccm):


Velocity streamlines, color given by speed logarithm


Surface: Velocity magnitude (m/s) Arrow Surface: Velocity field

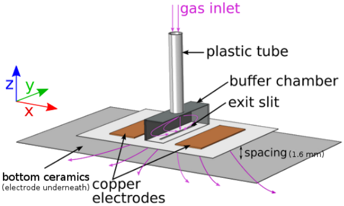

Surface: Velocity magnitude (m/s) Arrow Surface: Velocity field

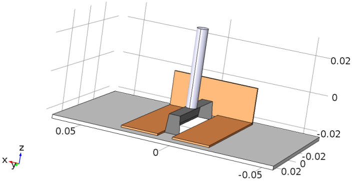

Surface: Velocity magnitude (m/s) Arrow Surface: Velocity field

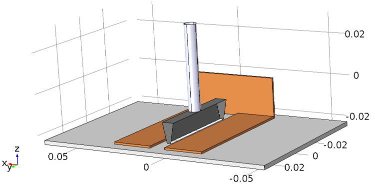
⇒ Complex flow patterns inside the buffer chamber make **the flow through the slit relatively even but better designs of the buffer chamber can be found!**

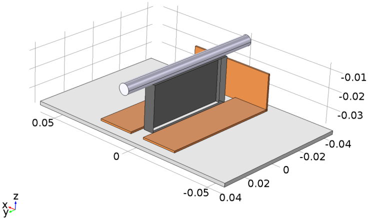
Gas Supply Optimization Using CFD Model

Variations of four different geometries tested





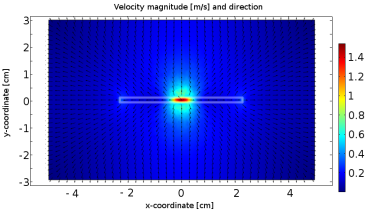


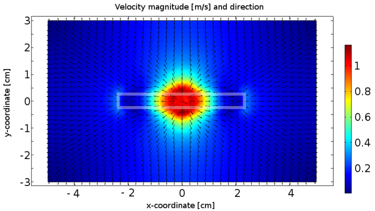


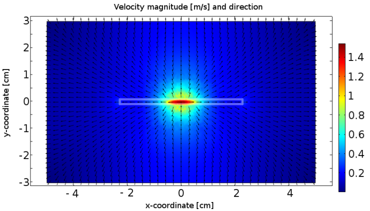
L. Zajíčková et al. Plasma Physics and Controlled Fusion, submitted

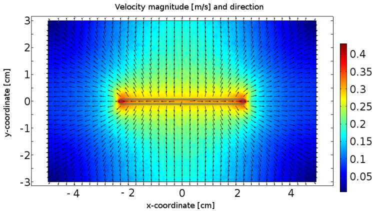
Gas Supply Optimization Using CFD Model

Variations of four different geometries tested



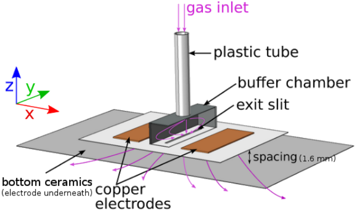


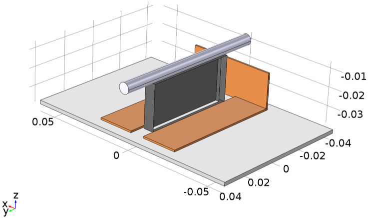


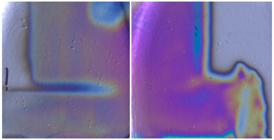


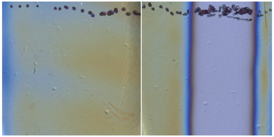
Does It Work in Real Life?

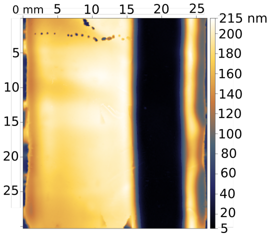
(case study for DBD co-polymerization of MA and C_2H_2 in Ar, no electrode movement)











Interference colours are measured by imaging spectroscopy refractometry ⇒ fitting of optical data provides spatially resolved film thickness