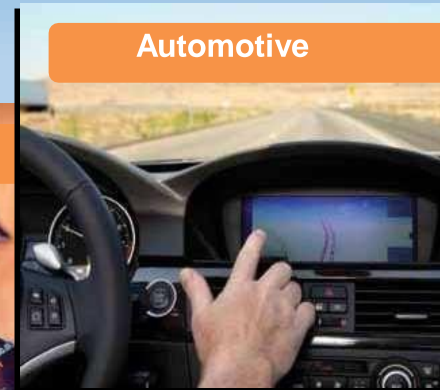
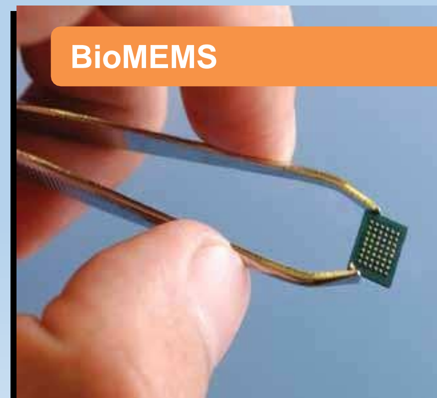
Deep reactive ion etching

Deep silicon etch

Micro-Electro-Mechanical Systems

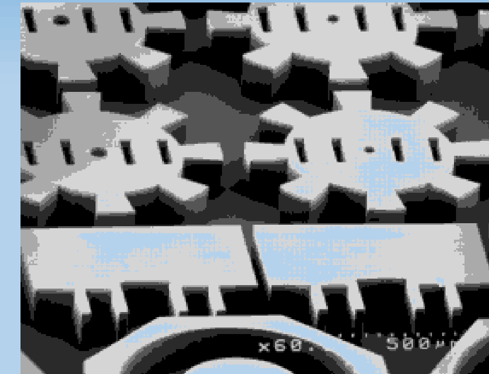
- MEMS is a solution where there is a need for a device or sensor to be miniaturised
- Trends towards increased integration and complexity

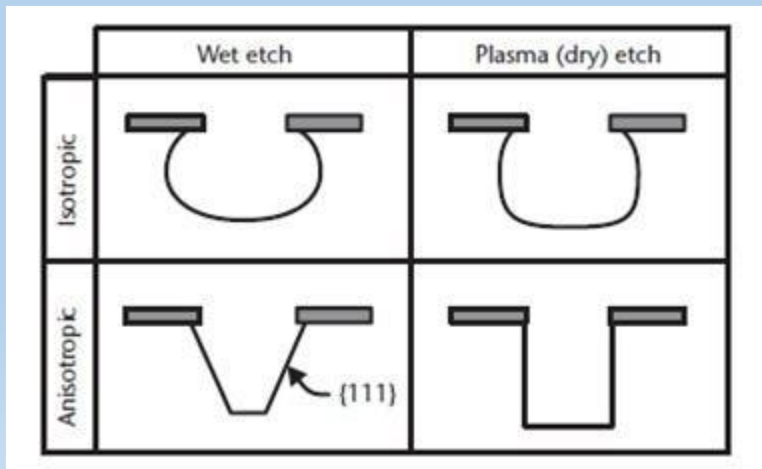


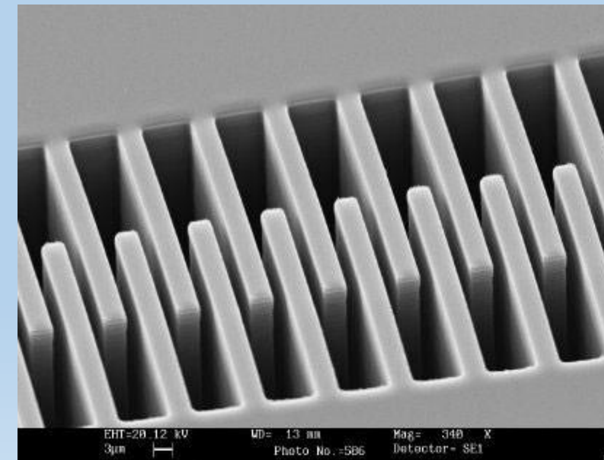


Why DSE?

- Complex structure pattern can be made by DSE
- Higher etching rates, aspect ratio
- Compatibility with photoresist masks
- **The ability to produce vertical sidewalls on silicon substrates of any crystal orientation**

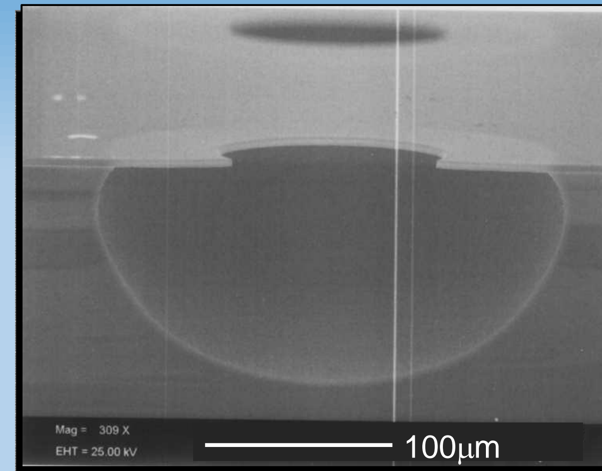




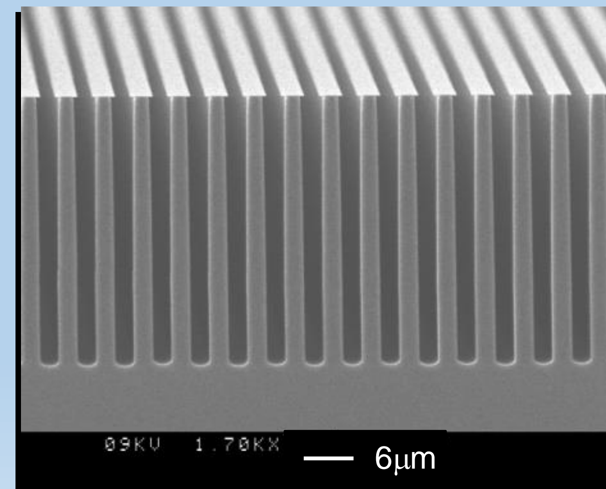


Silicon ICP Etch Using Fluorine

- Silicon can be etched by any halogen atom (Cl, Br, F, I)
- Only Fluorine reacts with silicon spontaneously
  - silicon etches isotropically (in all directions)
  - need passivation to achieve a vertical (anisotropic) profile
  - the reaction releases heat



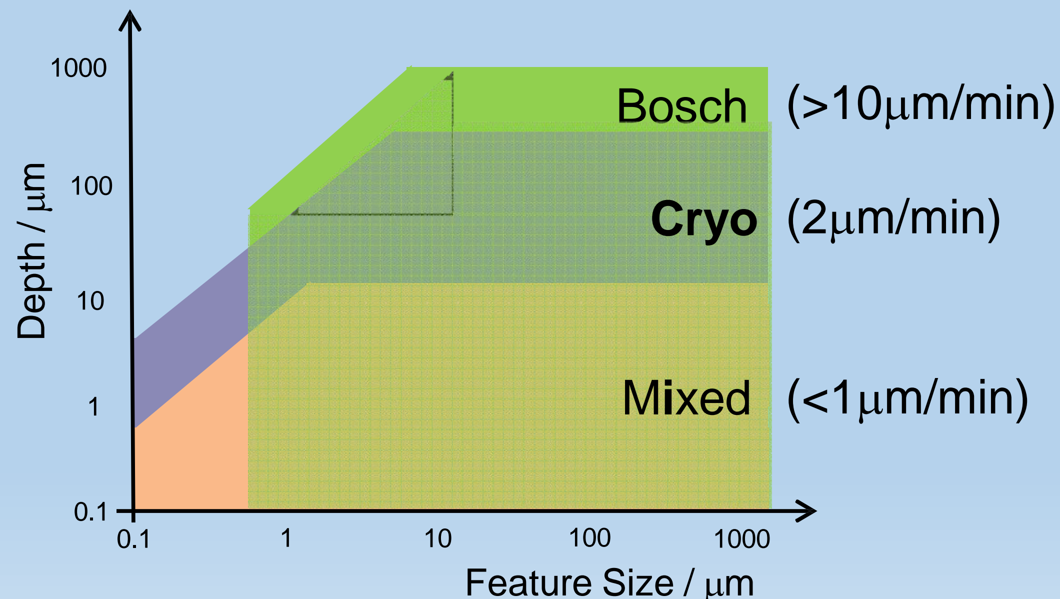
Isotropic Etch

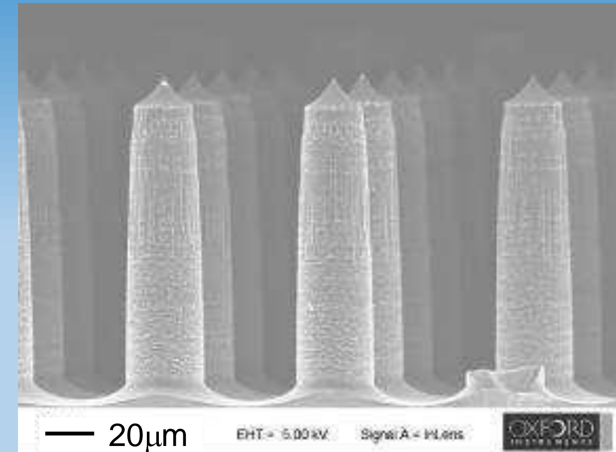


Anisotropic Etch

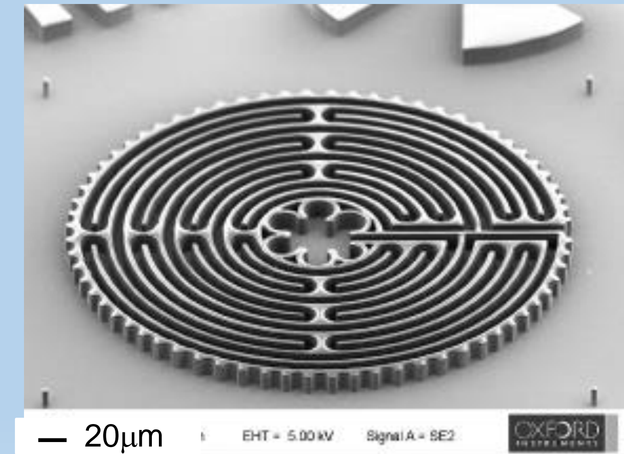
Fluorine-based silicon etch choices

- **Bosch** DSE is typically used for features >1µm and depths >10µm
- **Cryogenic** DSE is typically used for smooth sidewalls and/or nano-etching
- Mixed processes are an option for shallow, low aspect features





Microneedles (Bosch)

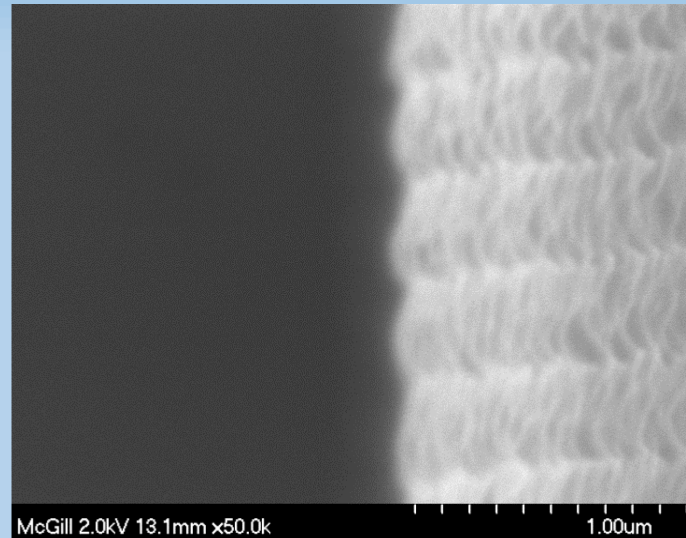


Micro-mould (Cryo)

Bosch DSE

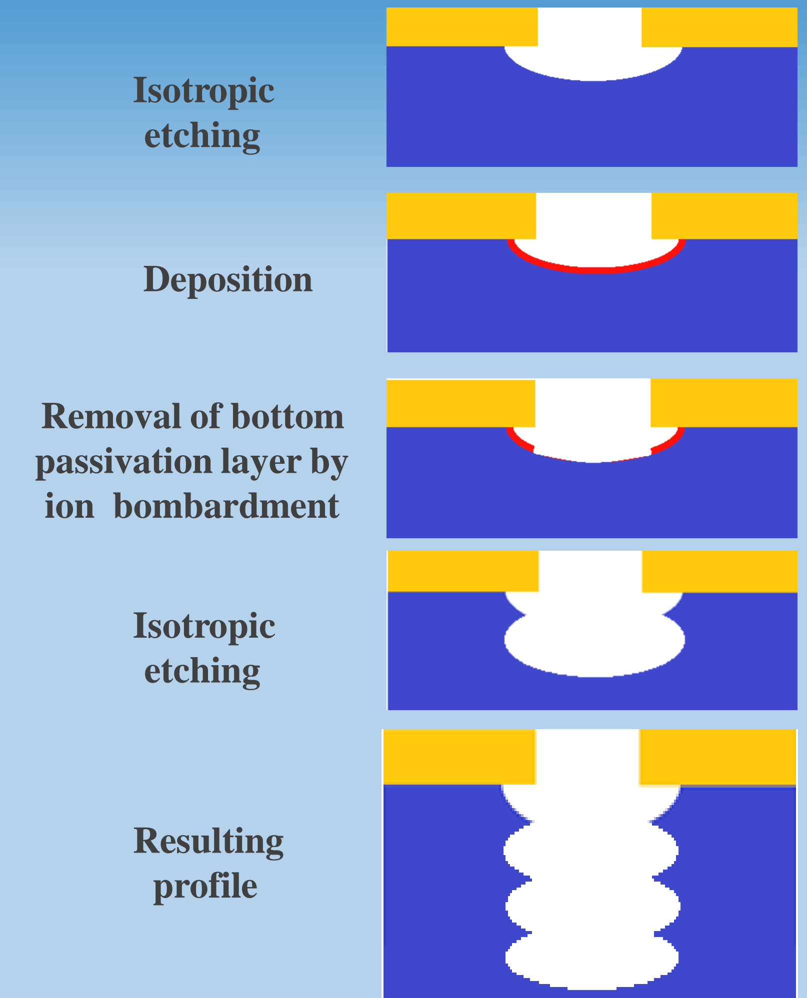
Alternating sequence of deposition and etch

- Enabling:
  - High etch rate
  - High selectivity
  - Highly anisotropic (vertical) profile



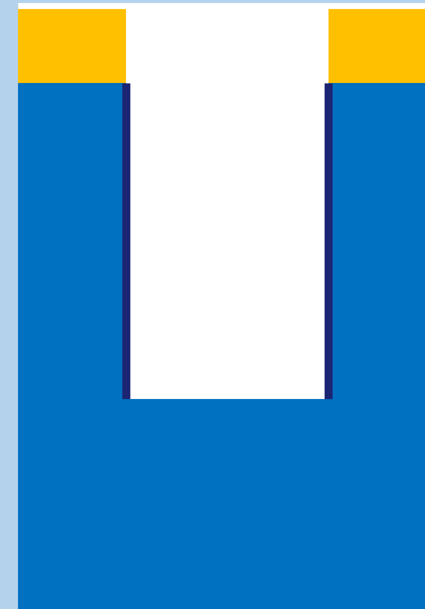
- 3 step Bosch cycle:
  - Deposition / Breakthrough / Etch
    - allows optimised breakthrough

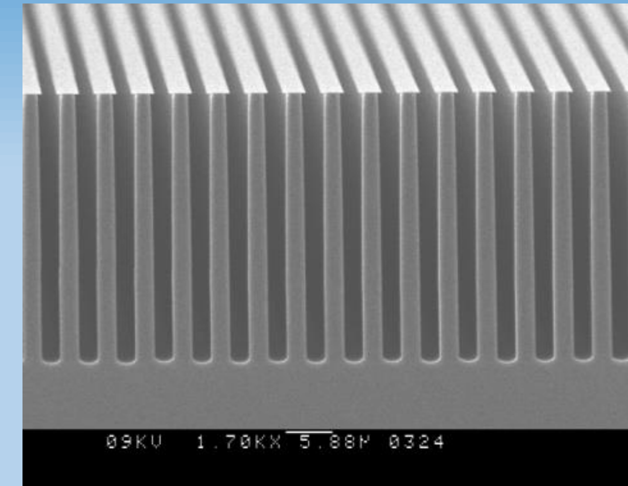
      and isotropic etch conditions

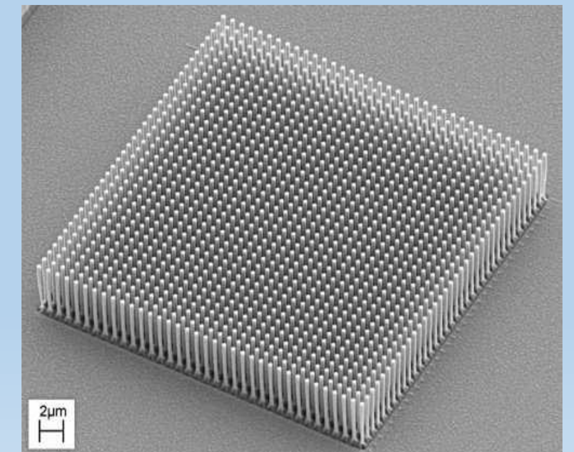


Cryogenic DSE

- Low temperature process (-110°C)
  - Particularly suited to photonic, moulding and nano applications
- Fluorine radicals etch the silicon
  - Sidewalls are continuously passivated (SiO_xF_y)
  - Ions keep the etch front passivation-free
- Moderate etch rates (>2μm/min)
- High selectivity (100:1 to PR)
- Smooth sidewalls (<10nm)



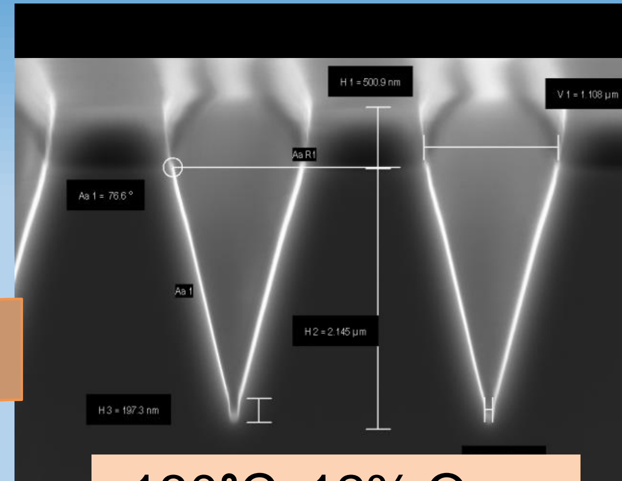




Cryo Etch Process – Profile Control

- Main control parameters are:
  - Temperature
  - O_2 flow
  - Bias

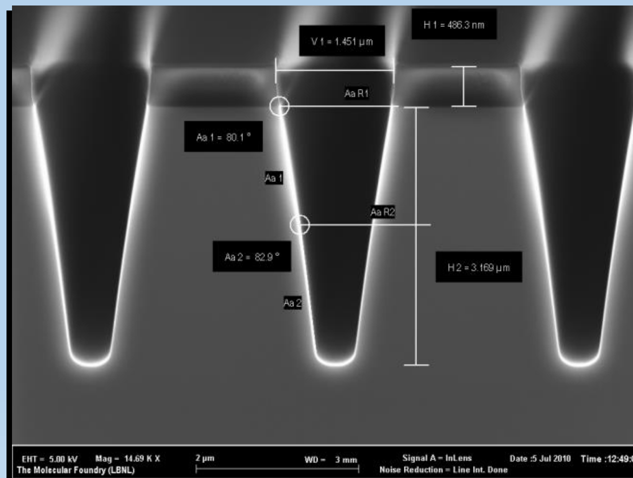
-130°C, 24% O_2



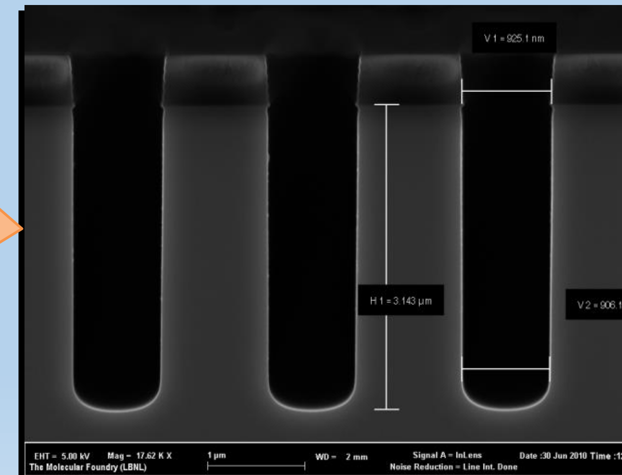
Temperature

O2 flow

-100°C, 24% O_2

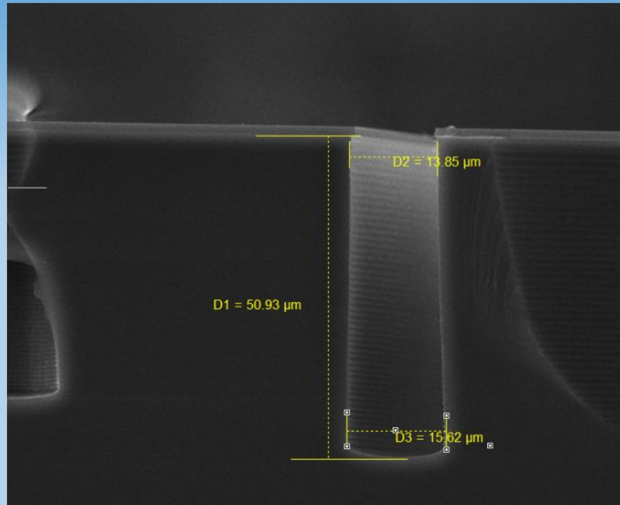


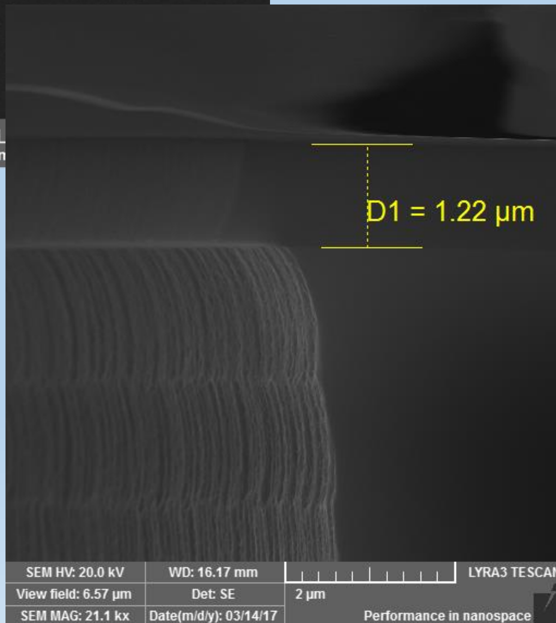
-130°C, 12% O_2

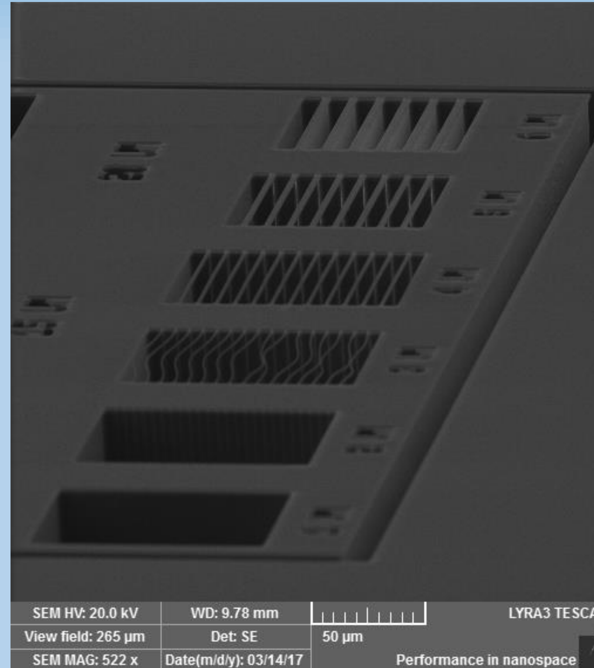


Calculation of etching parameters

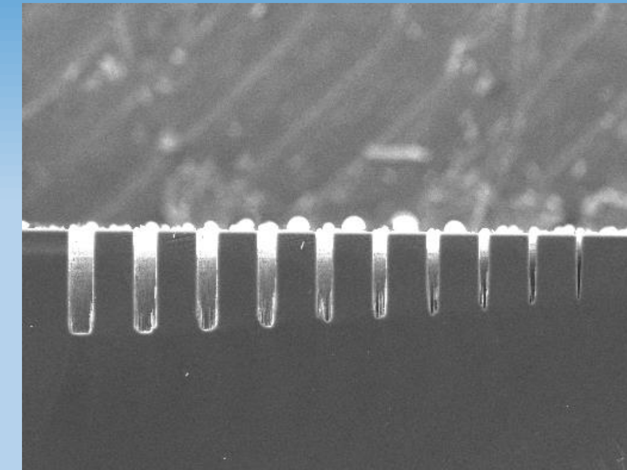
Selectivity

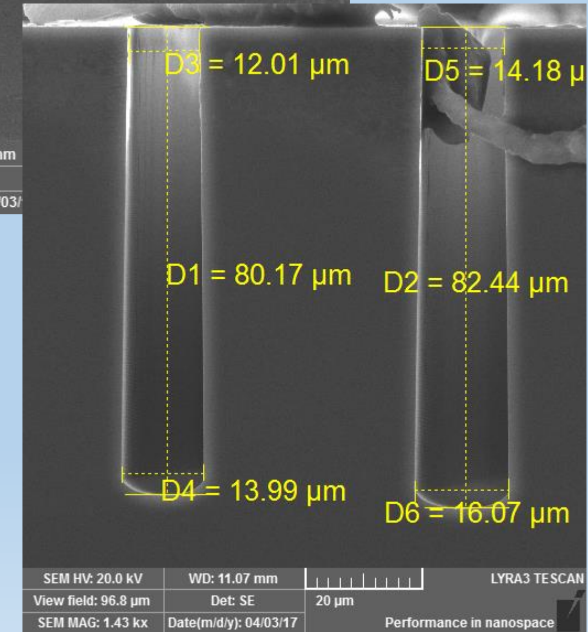






Aspect ratio (AR)



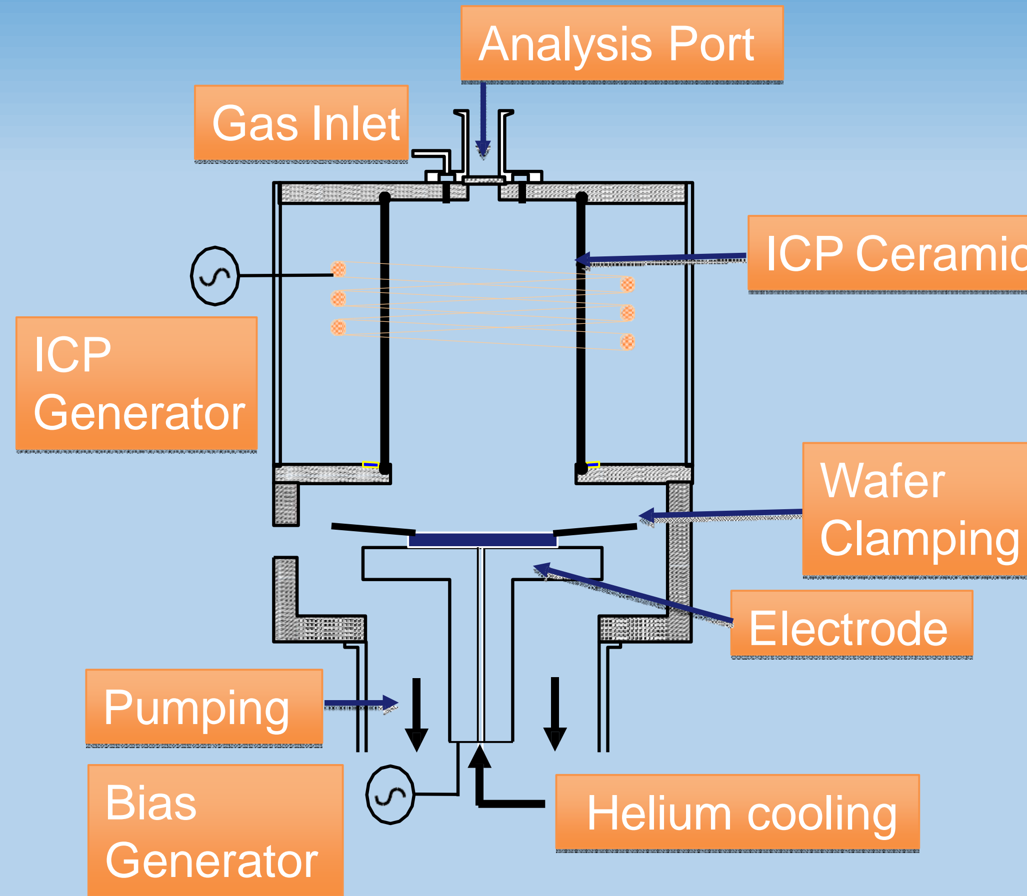


DSE Process Comparison

Parameter	Bosch	Cryo	Mixed Gas
Rate (μm/min)	High (< 20)	Moderate (< 4)	Low (< 0.5)
Selectivity to PR	Very High (< 250)	High (< 100)	Low (< 10)
Profile	Veritical	Veritical or Sloped	Veritical or Sloped
Aspect Ratio	Very High (> 70)	High (> 30)	Low (< 10)
Sidewalls	Scallops (< 15nm)	Smooth	Smooth
Cooling	Chiller or Cryo	Cryo only	Chiller or Cryo
Mask	PR / SiO_2	PR (thin) / SiO_2	PR / SiO_2
Min. feature /nm	$\approx$ 300	$\approx$ 10	$\approx$ 30

DSE Equipment Requirements

- High density ICP plasma
  - Separate control of ion density and energy
- Fast gas / pressure control
- Low chamber volume with good throughput
- Efficient cooling
  - He-assisted cooling
  - Cryo electrode

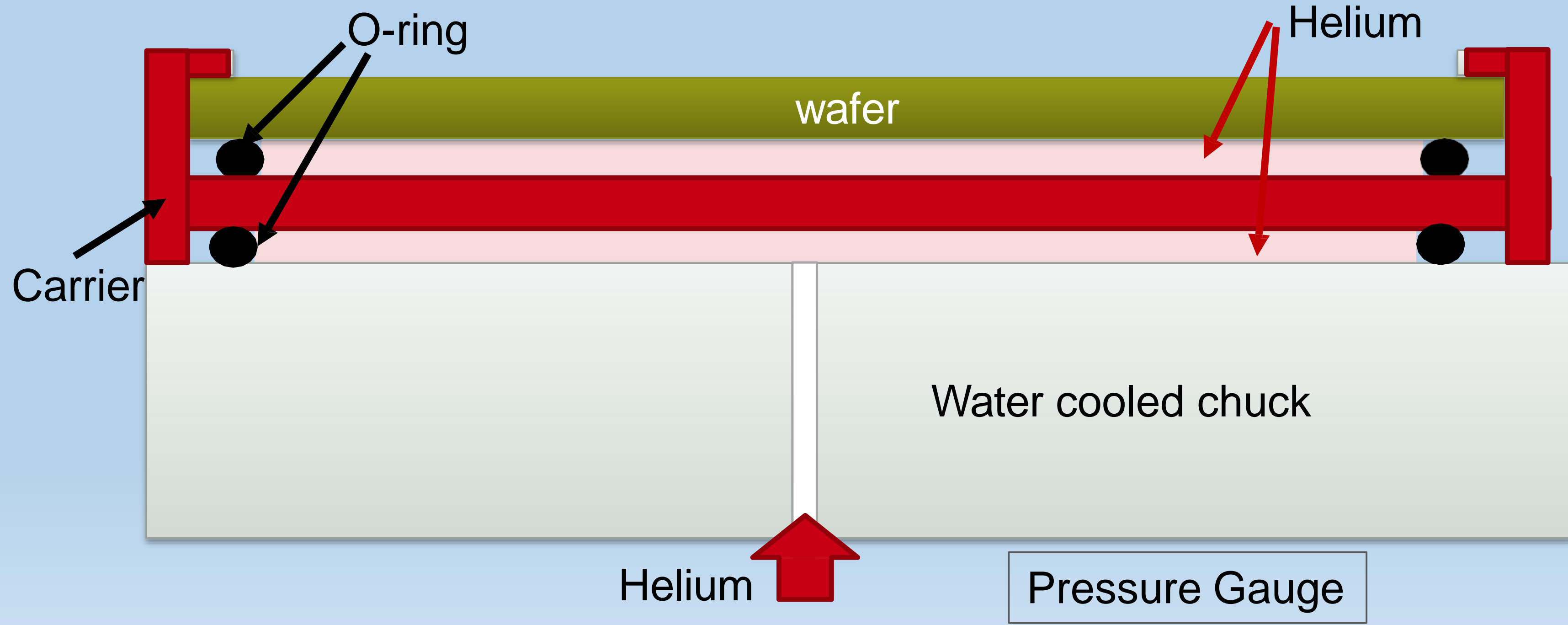


DSI Process Chamber Schematic

Helium Backside Cooling

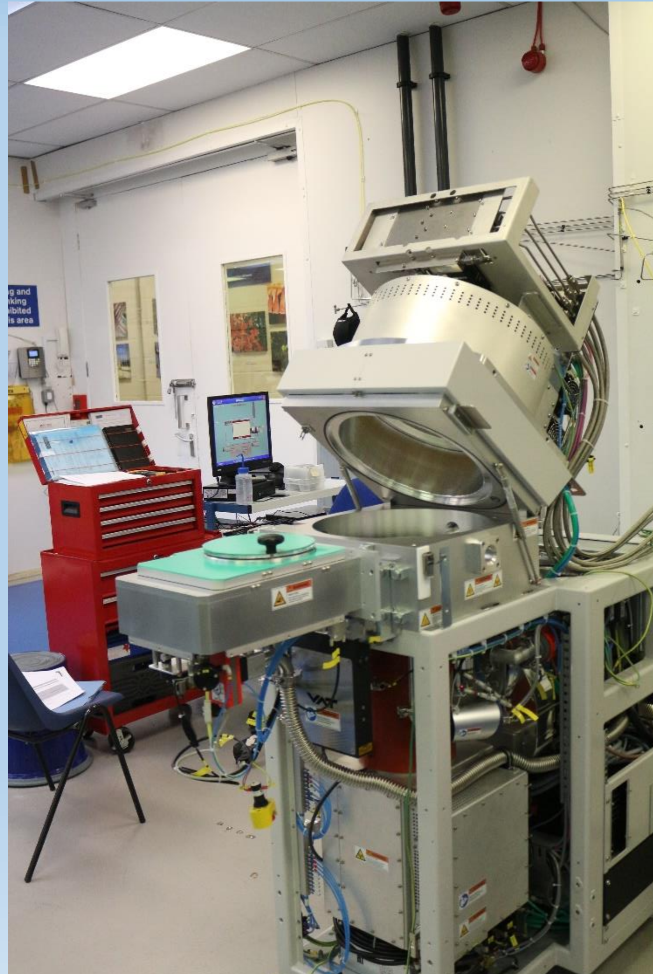
- Helium between wafer and chuck for good thermal coupling
- Small leakage into process chamber (< 1 sccm)
- Pressure < 50 mbar to avoid decrease of thermal conductivity due to collisions of He atoms

Thermal conductivity of different gases in W/(m · K)	
Hydrogen	0.186
Helium	0.157
Argon	0.018



CEITEC DRIE

- PlasmaPro 100 from Oxford Instruments
- Etching Si, SiO_2, SiN
- Bosch or cryo process
- RF ICP max. power 3000 W
- RF substrate biasing
- Substrate temperature -150 – 80^{0}C
- wafer max. 6'', mechanical clamping
- Loadlock
- Metal free reactor
- Gases: SF_6,CHF_3,C_4F_8,Ar, O_2



Vědci a využití

Sadílek Jakub, Gablech Imrich, Zahradníček Radim, Svatoš, Vojtěch Feng, Jianguo Pekárek, Jan Fecko, Peter Kurdík, Stanislav

- 275 hodin
  - školení 9 hodin (1 %)
  - Údržba 54 hodin (21 %)
  - vědci 212 hodin (75 %)

HV	curr	mag	HFW	WD	det	mode	tilt	
5.00 kV	50 pA	450 x	460 µm	6.2 mm	ETD	SE	30 °	CEITEC Nano

100 µm

HODNE STESTI
PAVLI