Surfaces and Films

Session 5B:
Physical Vapor Deposition PVD

Jari Koskinen

Aalto University

Contents

- Plasma
- Different PVD methods
- PVD Systems
- Commercial PVD coatings
- Scale up

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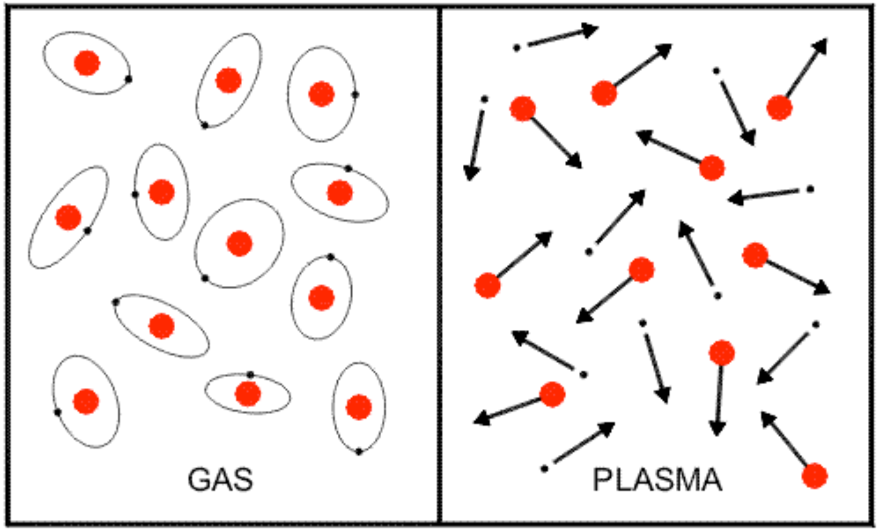
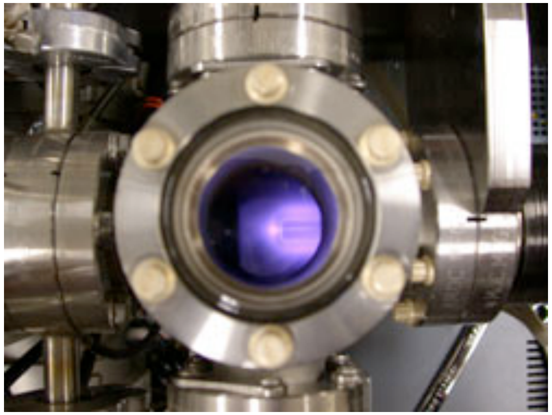
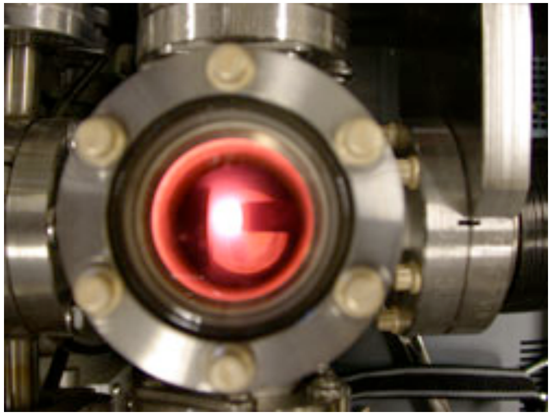
PVD Plasma

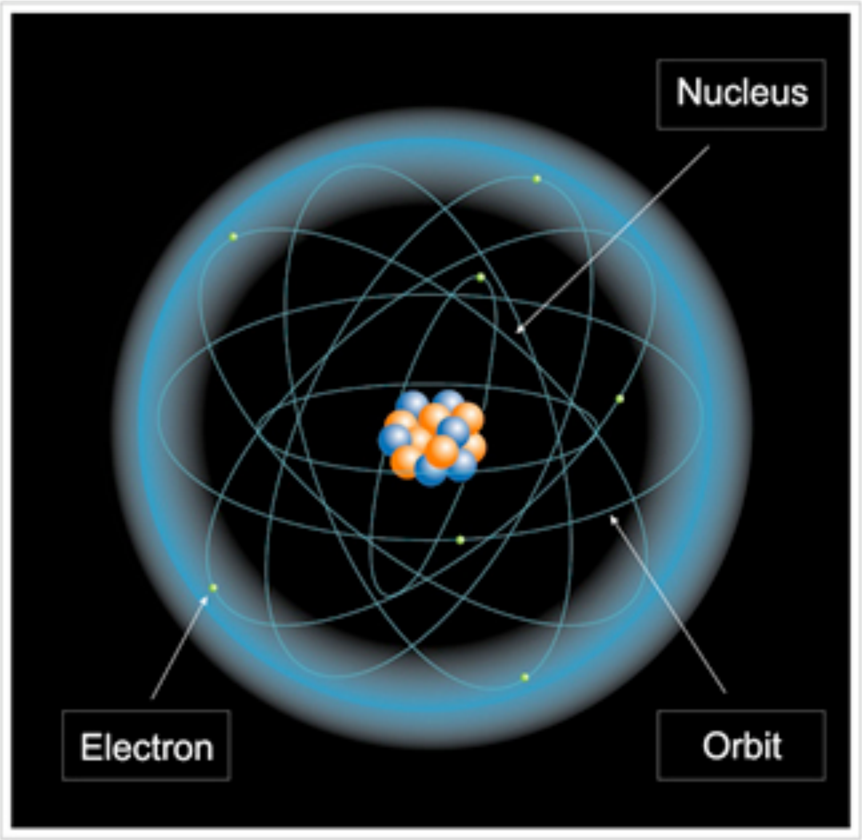
- Plasma
  - Colliding electrons ionise atoms
  - Ions and electrons accelerate in electric field
  - collisions excite atoms
  - de-excitation creates photons – visible light





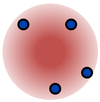


Glow discharge

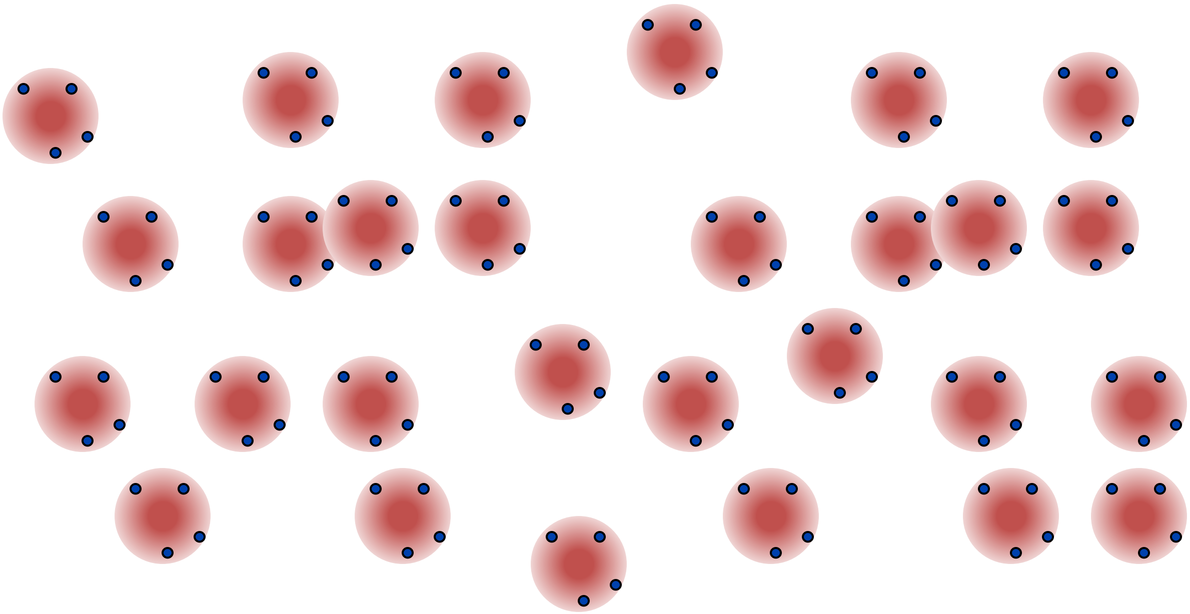


http://astro-canada.ca

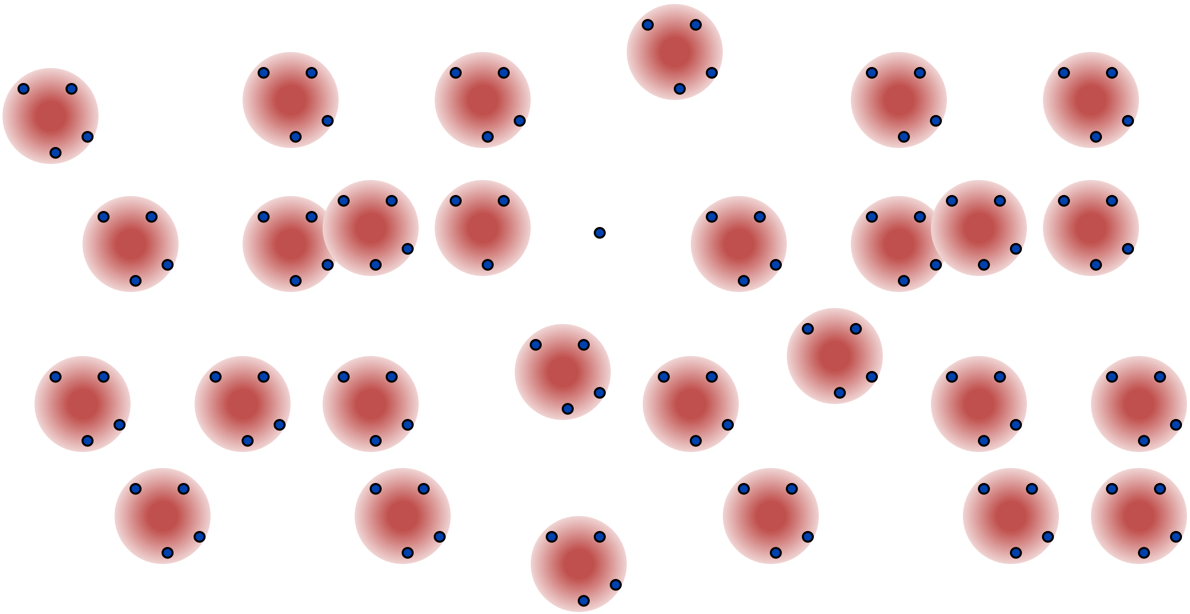
Glow discharge



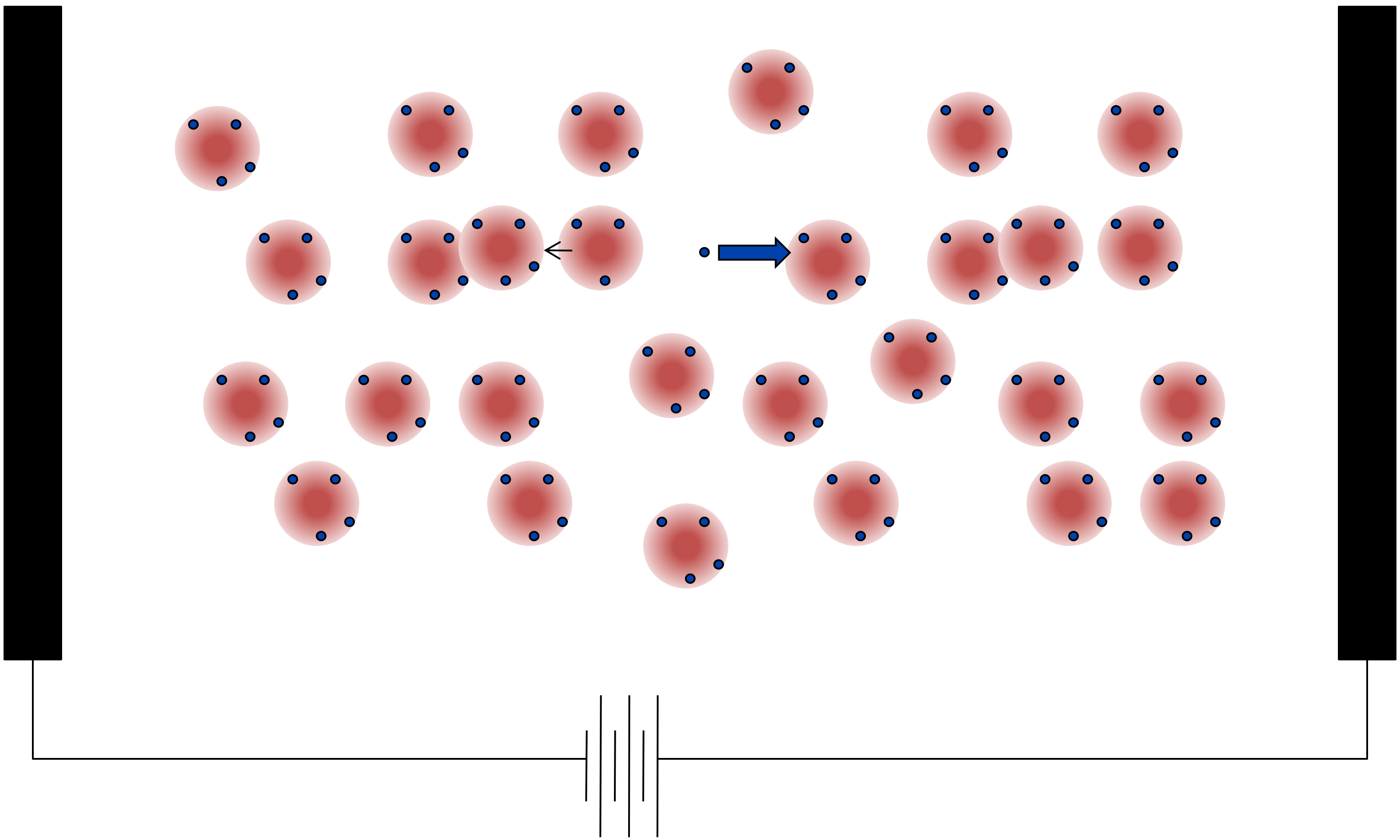
Glow discharge



Glow discharge



Glow discharge



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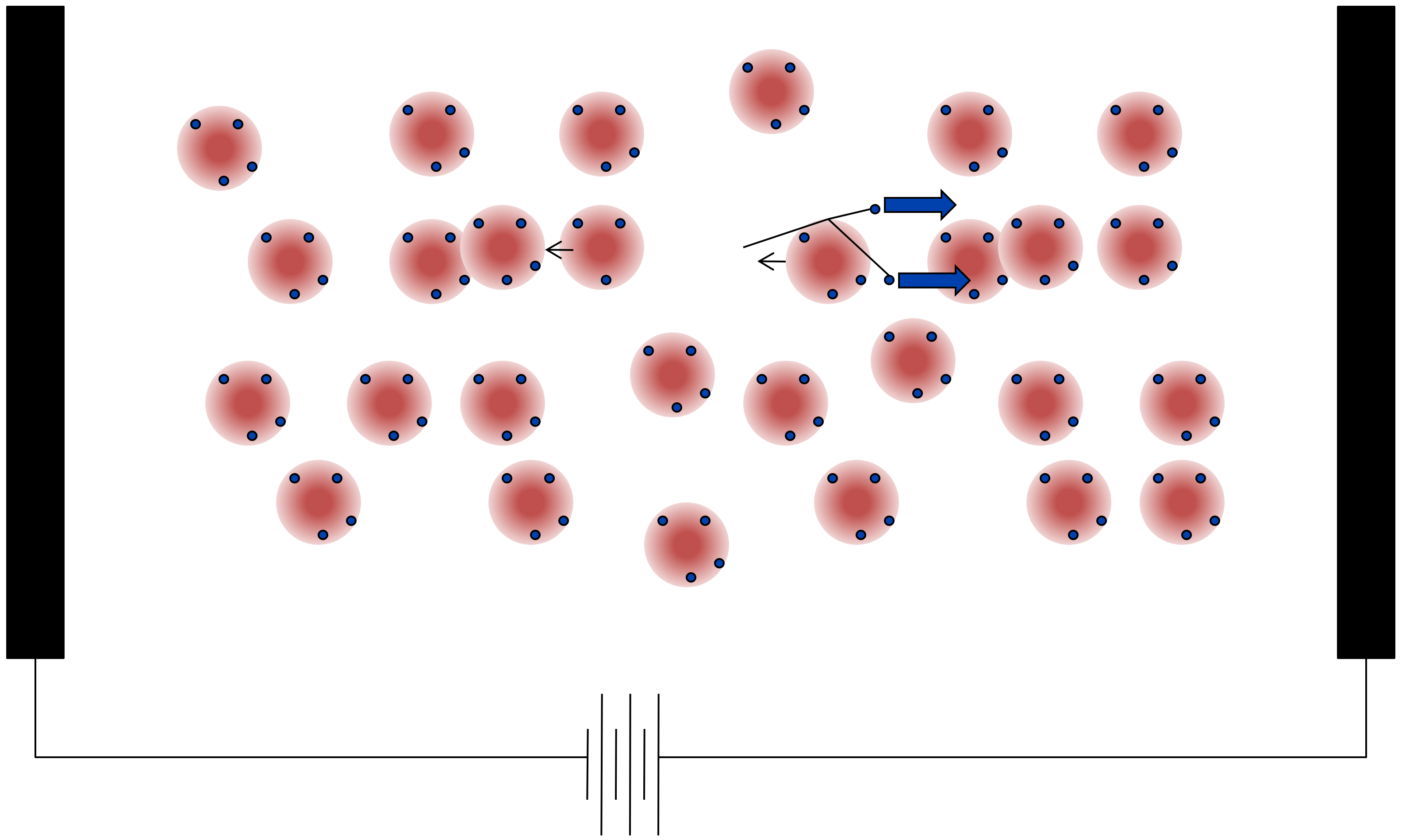
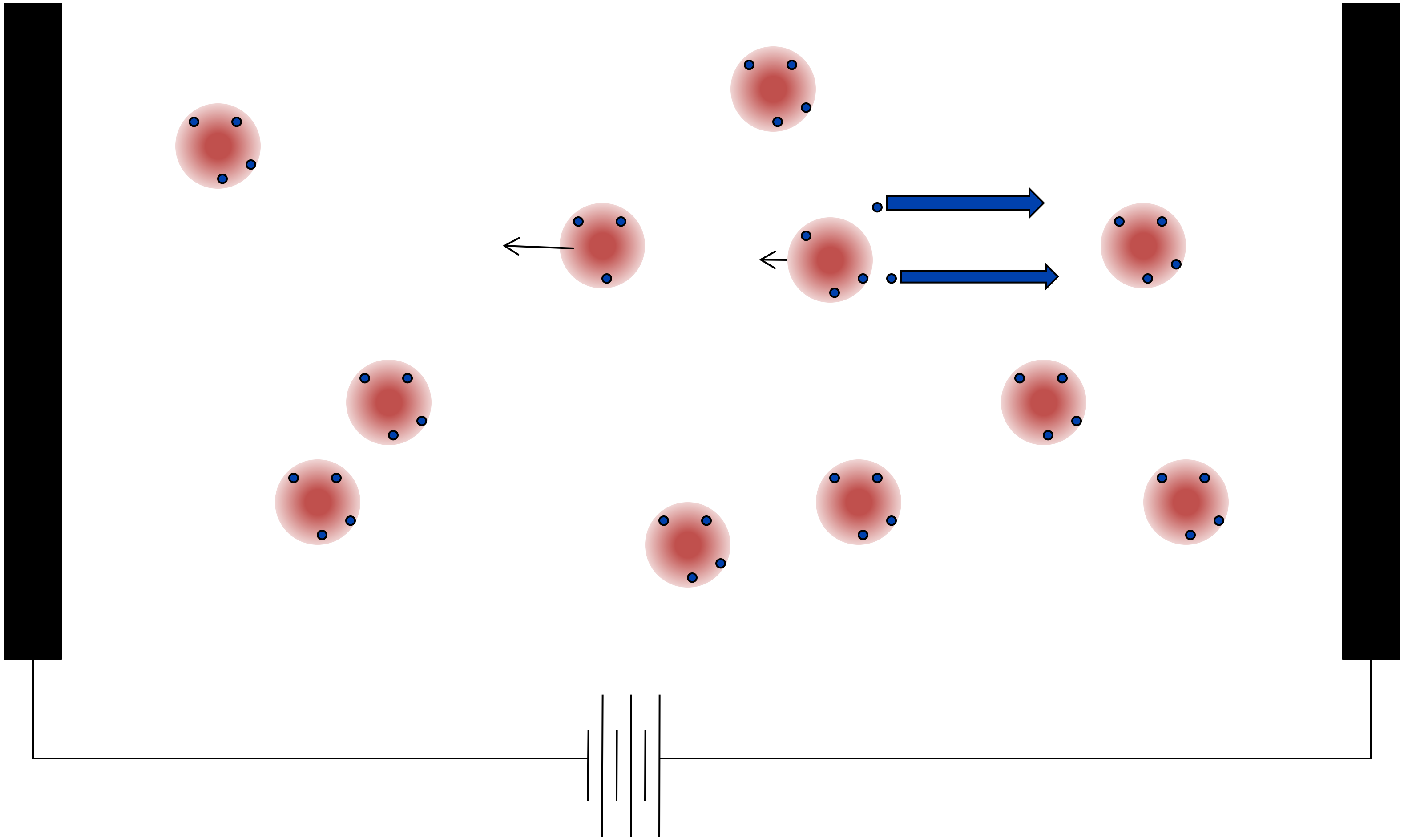
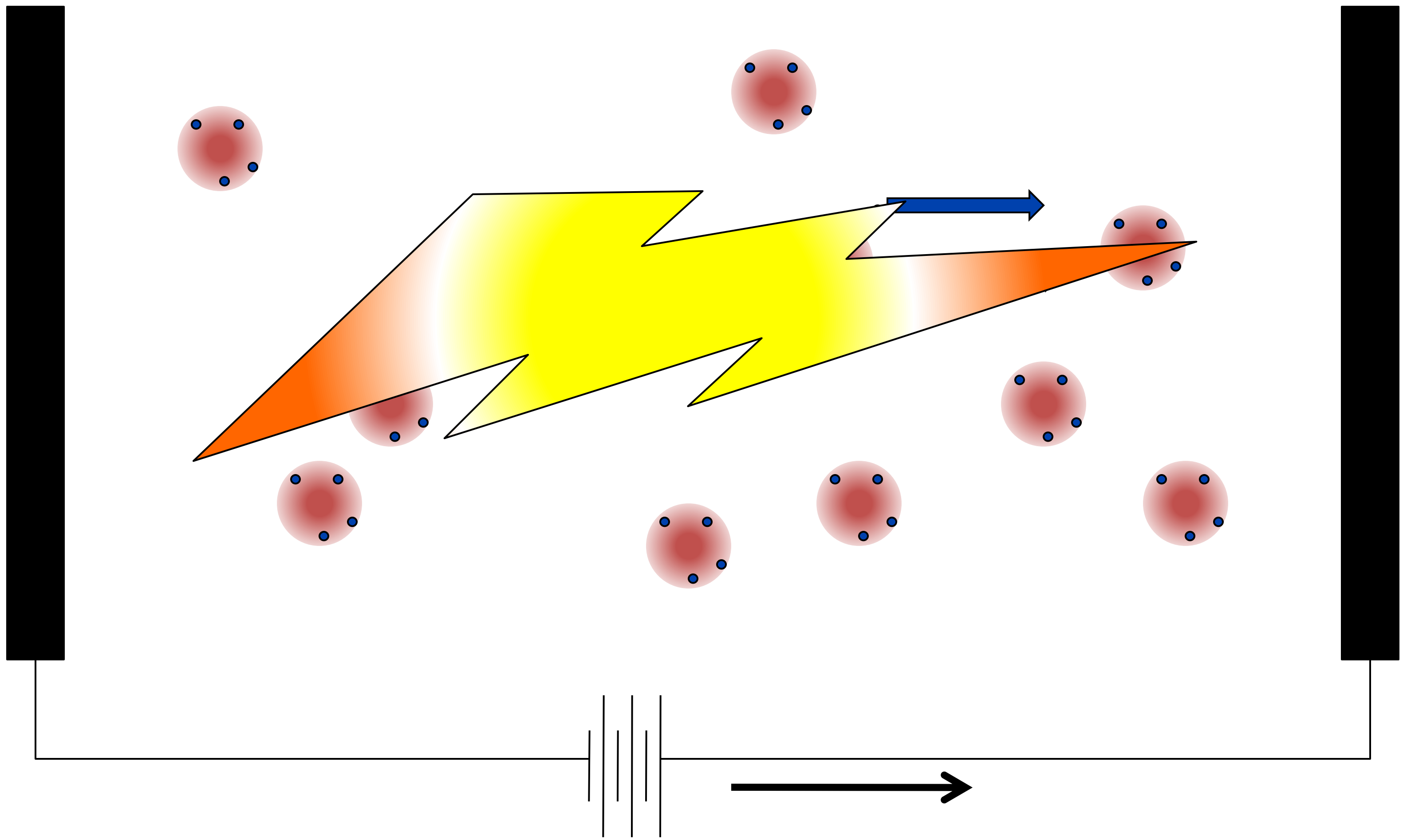
Glow discharge



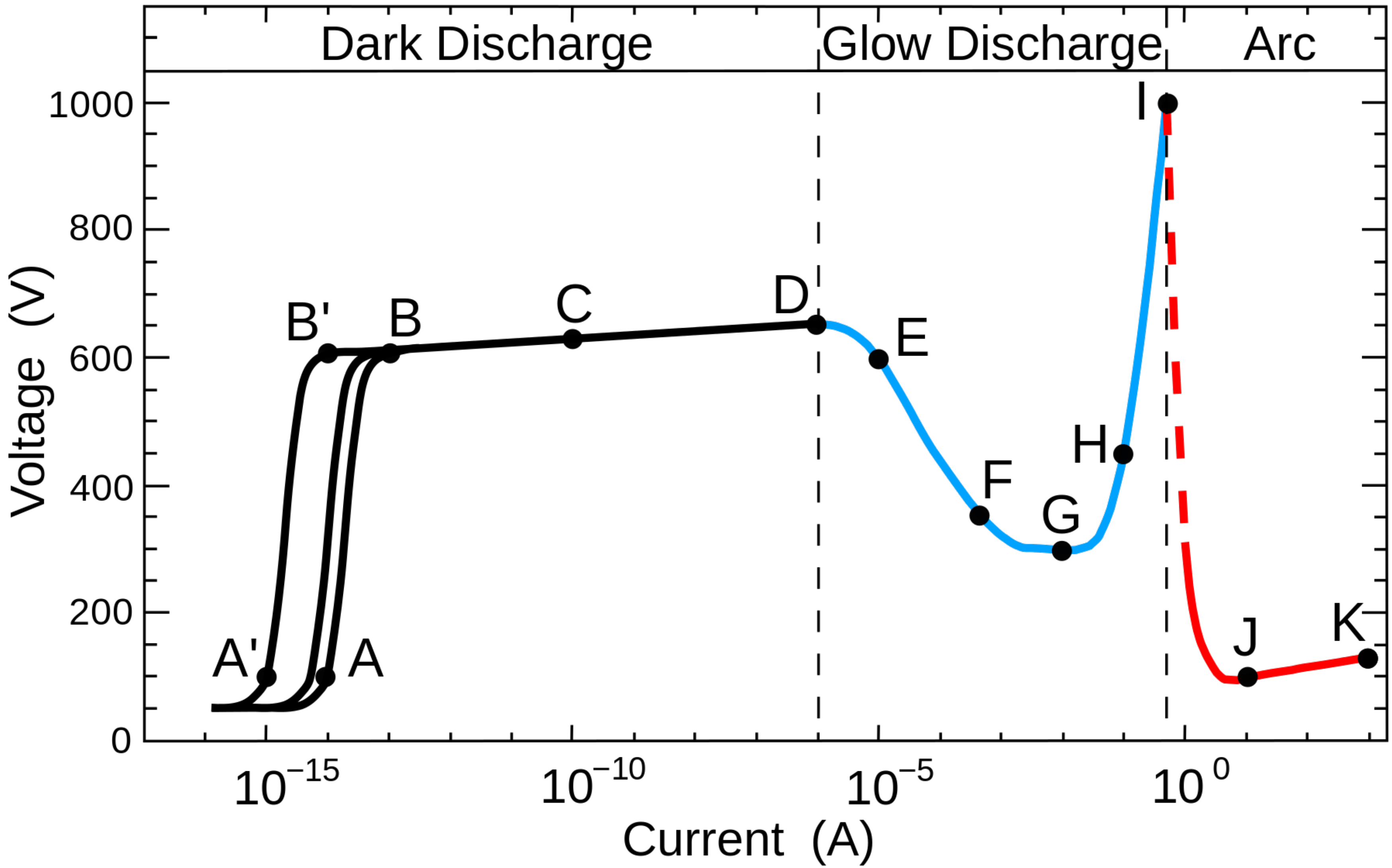
Glow discharge



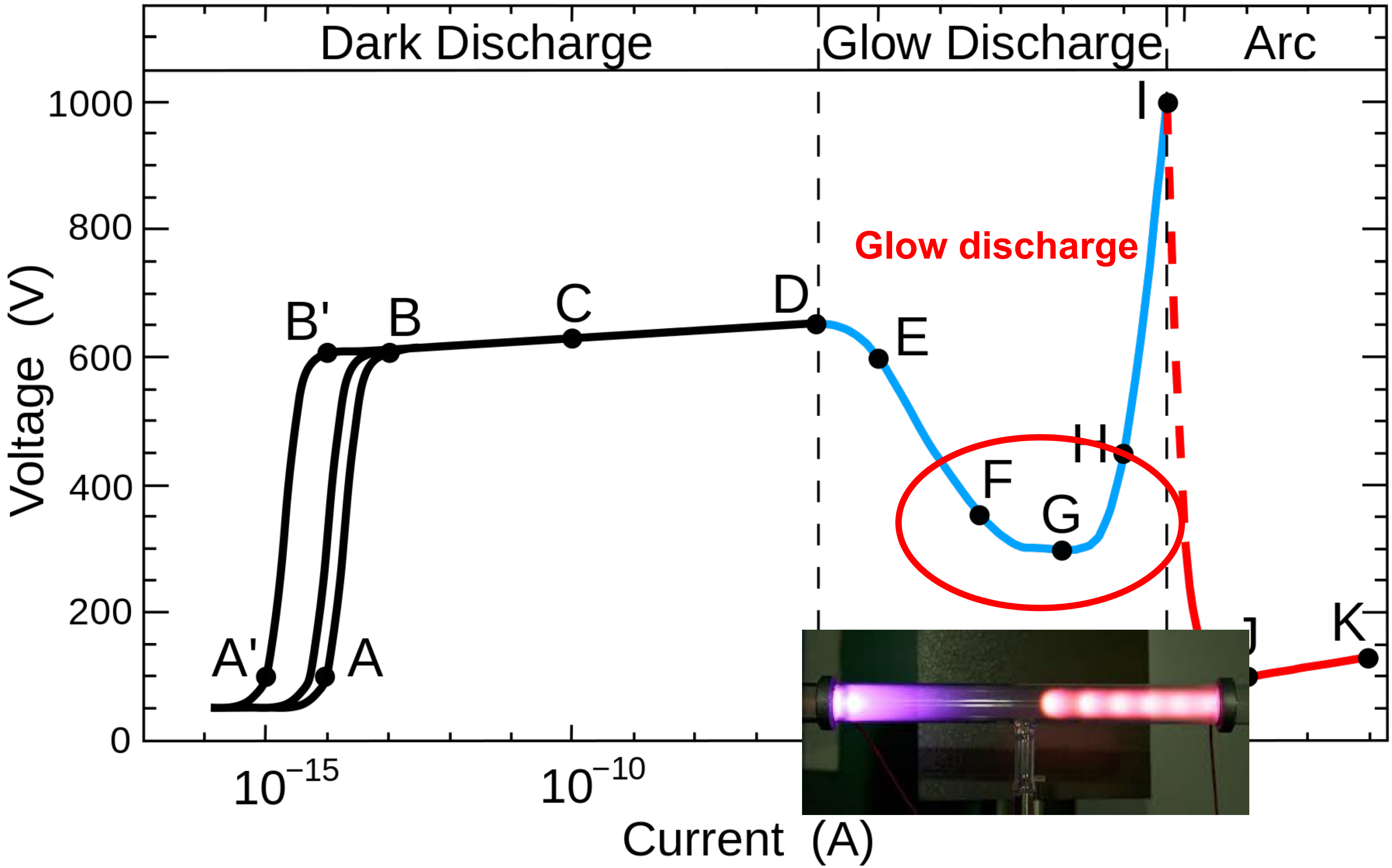
Glow discharge



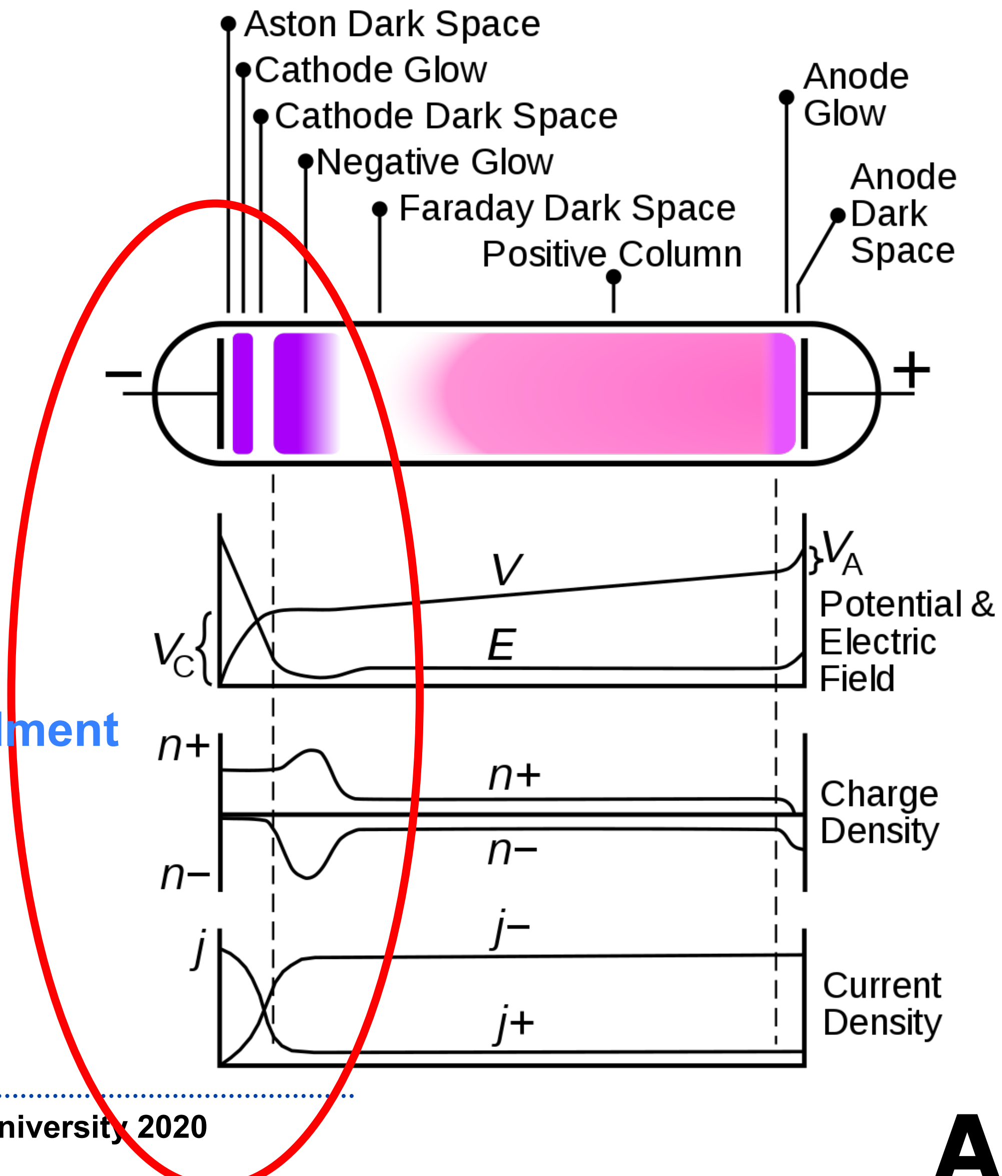
DC Plasma glow discharge and arc



DC Plasma glow discharge and arc



Glow discharge plasma



In PVD
Interesting things happen at cathode:

Positive ion bombardment

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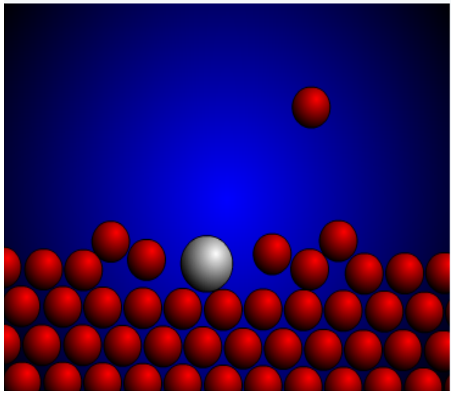
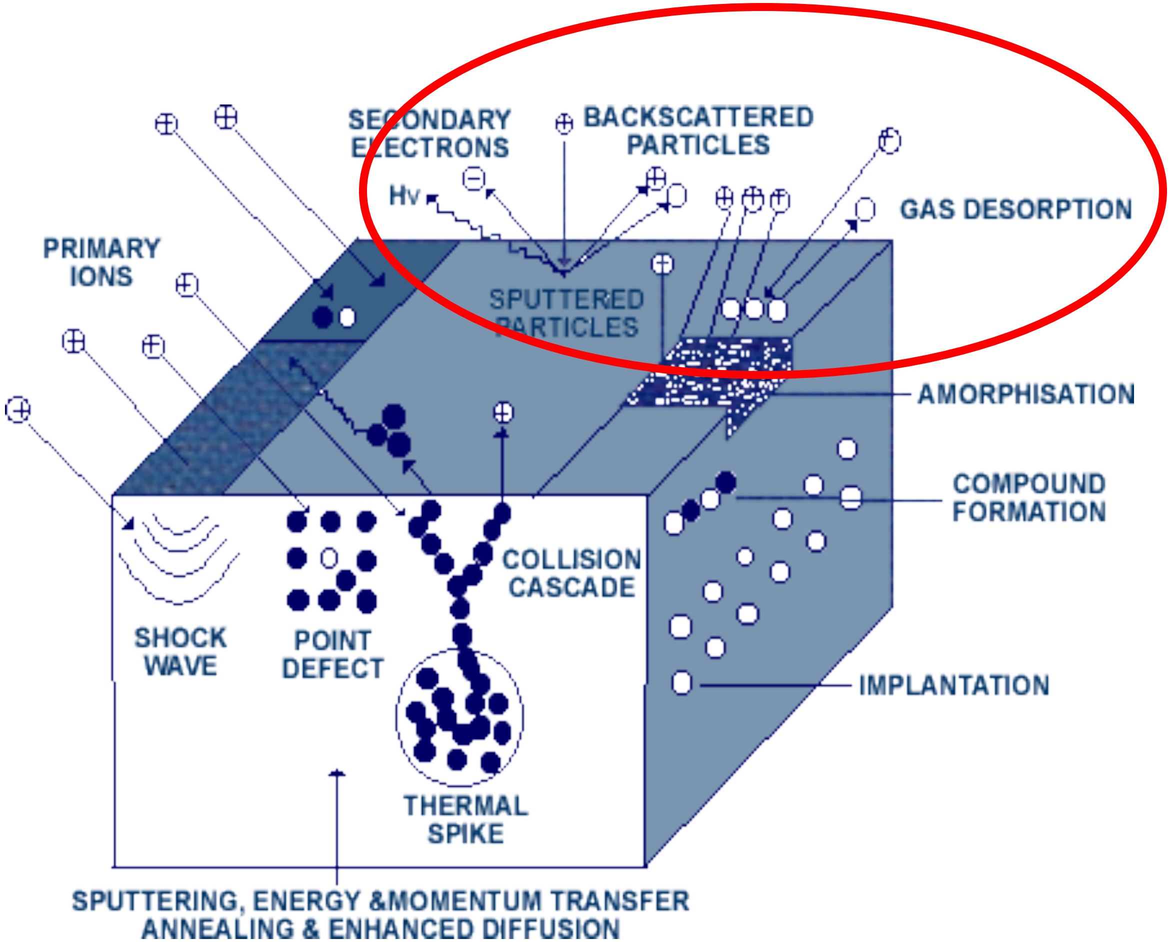
Source materials

- **Coating material from solid target or gas**



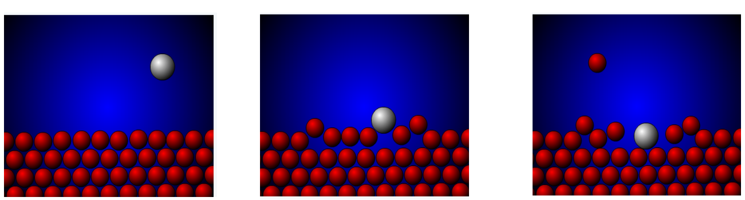
http://sunnygreater.com/products/sputtering_targets

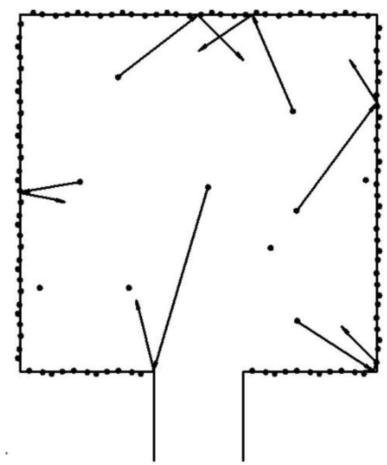
Energetic ion surface interactions

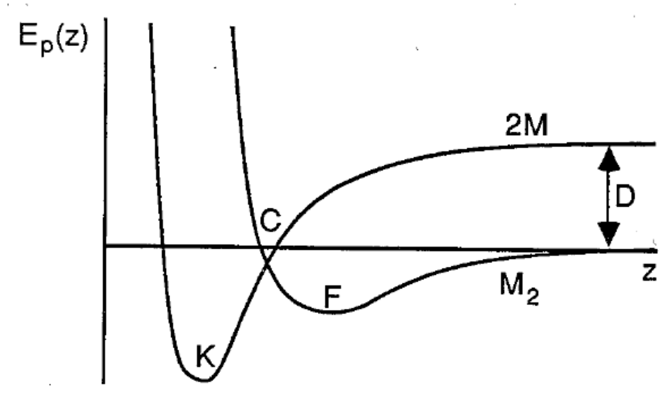


PVD coating process

- (High) vacuum
  - long mean free path of ions
    - high ion energy
  - cleaning of surface
    - desorption of gas
    - sputtering of surface
      - removal of
        - oils
        - water
        - oxides

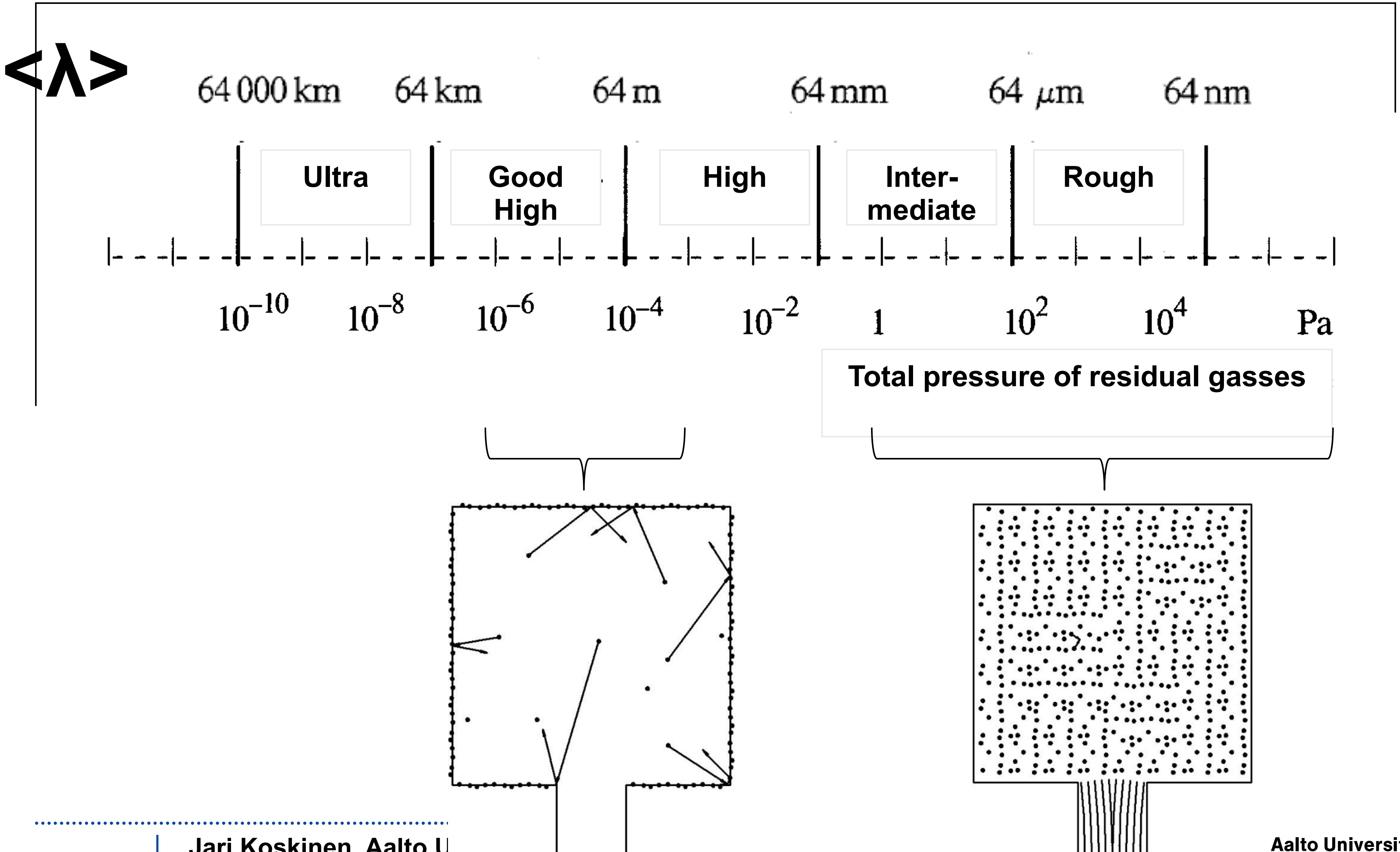




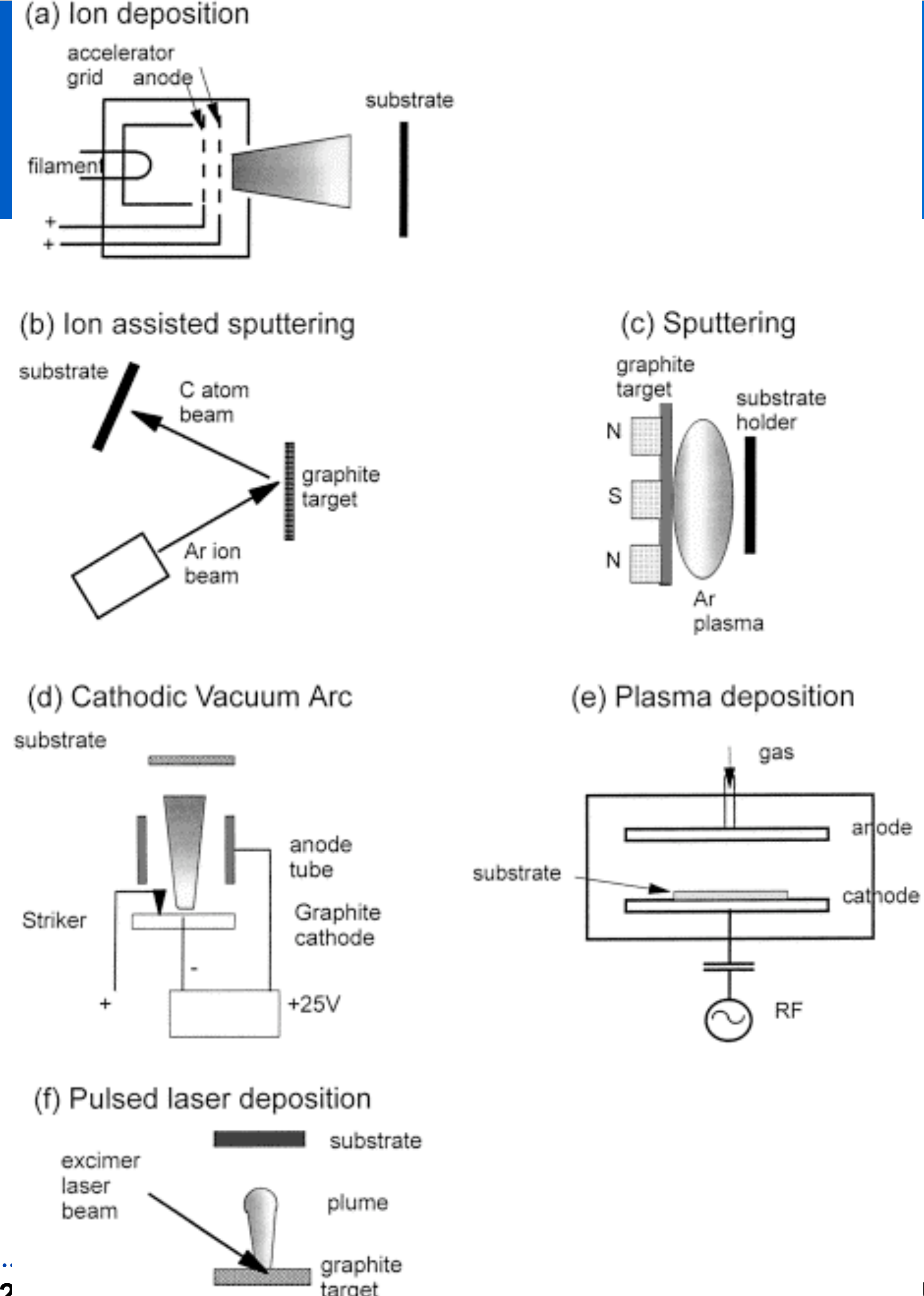


Kuva 12.1. *Lennard-Jones-diagrammi.*

Average mean free path (distance between collission) in nitrogen residual gas



PVD methods


(a) Ion deposition
accelerator grid
anode
substrate
filament
+
+
(b) Ion assisted sputtering
substrate
C atom beam
graphite target
Ar ion beam
(c) Sputtering
graphite target
substrate holder
N
S
N
Ar plasma
(d) Cathodic Vacuum Arc
substrate
anode tube
Striker
Graphite cathode
-
+
+25V
(e) Plasma deposition
gas
anode
substrate
cathode
RF
(f) Pulsed laser deposition
substrate
excimer laser beam
plume
graphite target

PVD methods

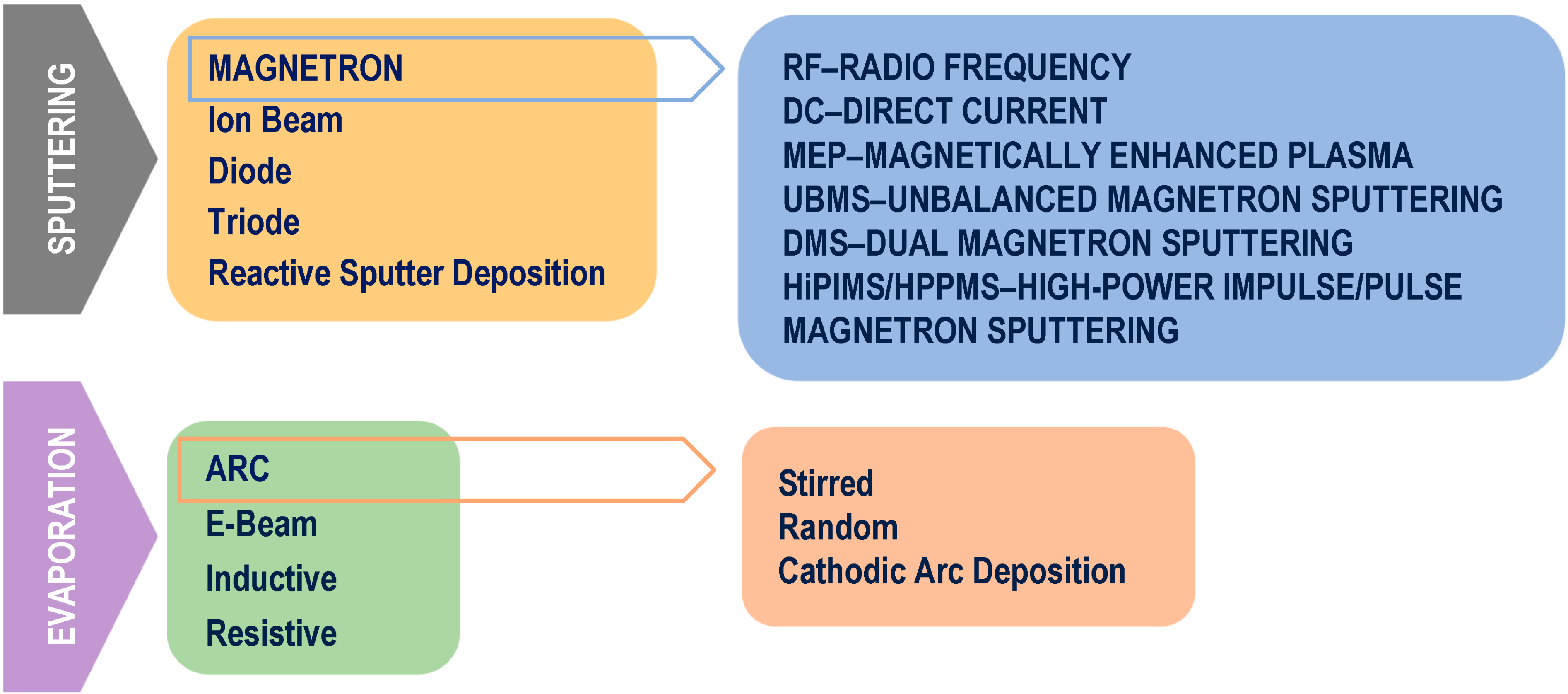


Figure 1. Segmentation of the current physical vapour deposition (PVD) techniques for advanced coatings.

Andresa Baptista et al., *Coatings* **2018**, *8*(11), 402; https://doi.org/10.3390/coatings8110402

Selected PVD methods

Particle energy

Growth rate

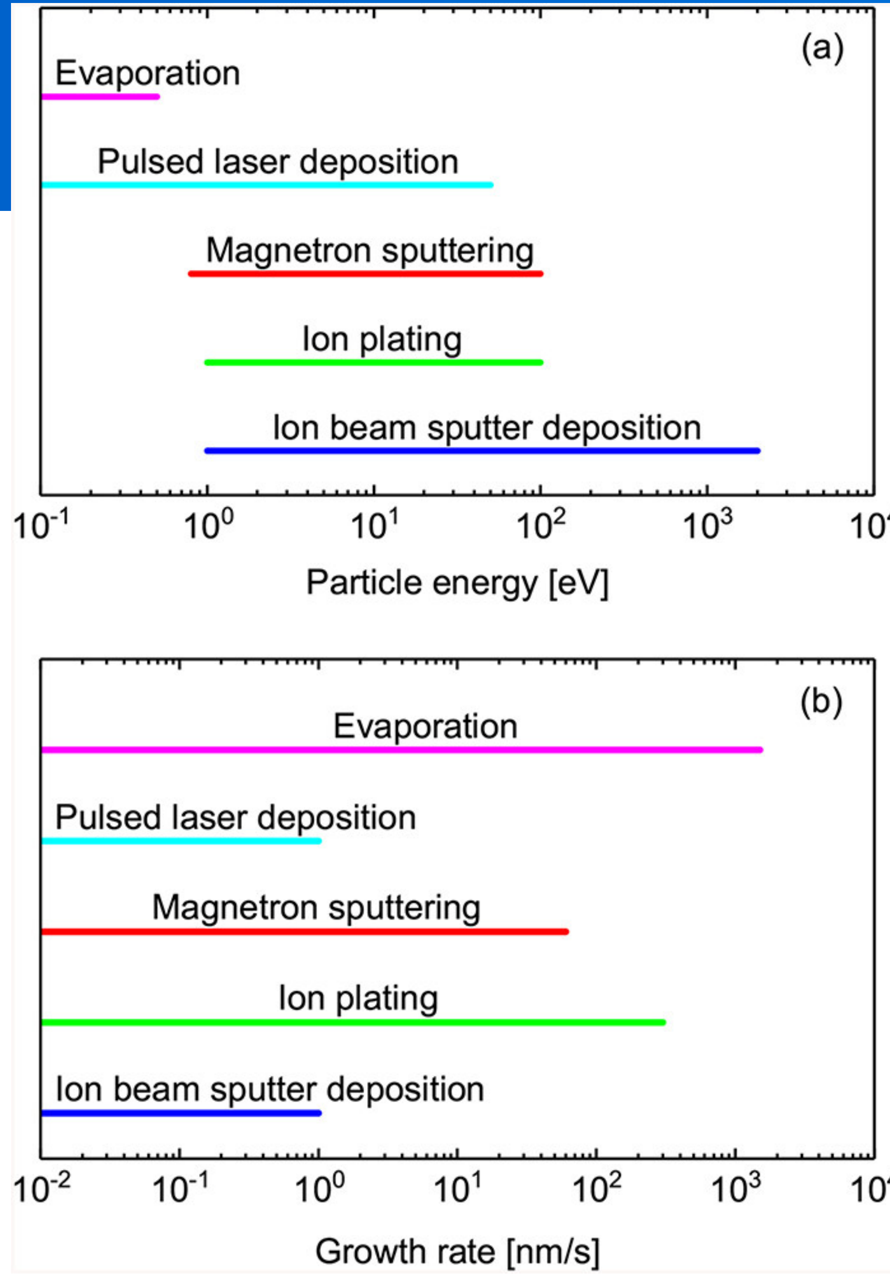
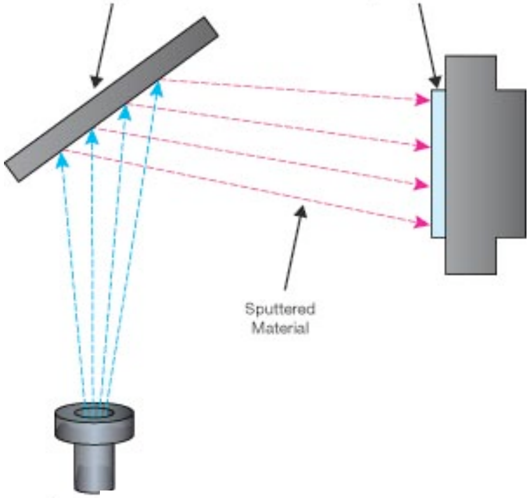


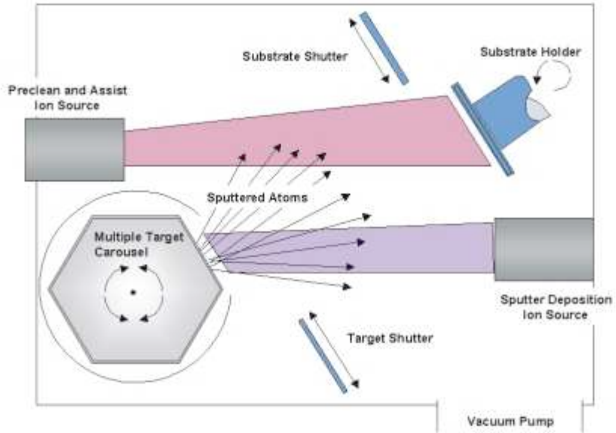
FIG. 1. Typical range of particle energy [panel (a)] and growth rate [panel (b)] of selected PVD techniques.[2,6]

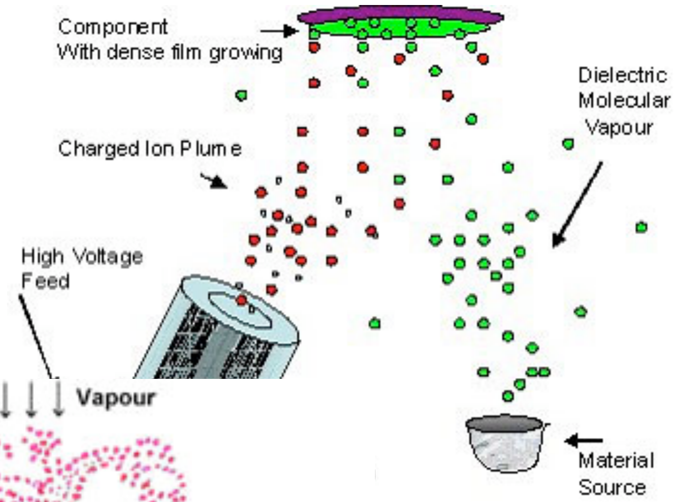
Published in: Carsten Bundesmann; Horst Neumann; *Journal of Applied Physics* 124, 231102 (2018)
DOI: 10.1063/1.5054046

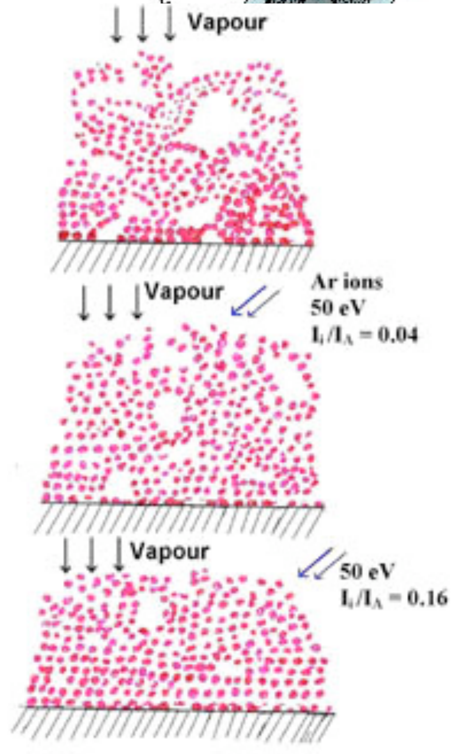
Ion beam sputtering



Kaufman
http://www.youtube.com/watch?v=lbcr-B258J8&NR=1







Magnetron sputtering - evaporation

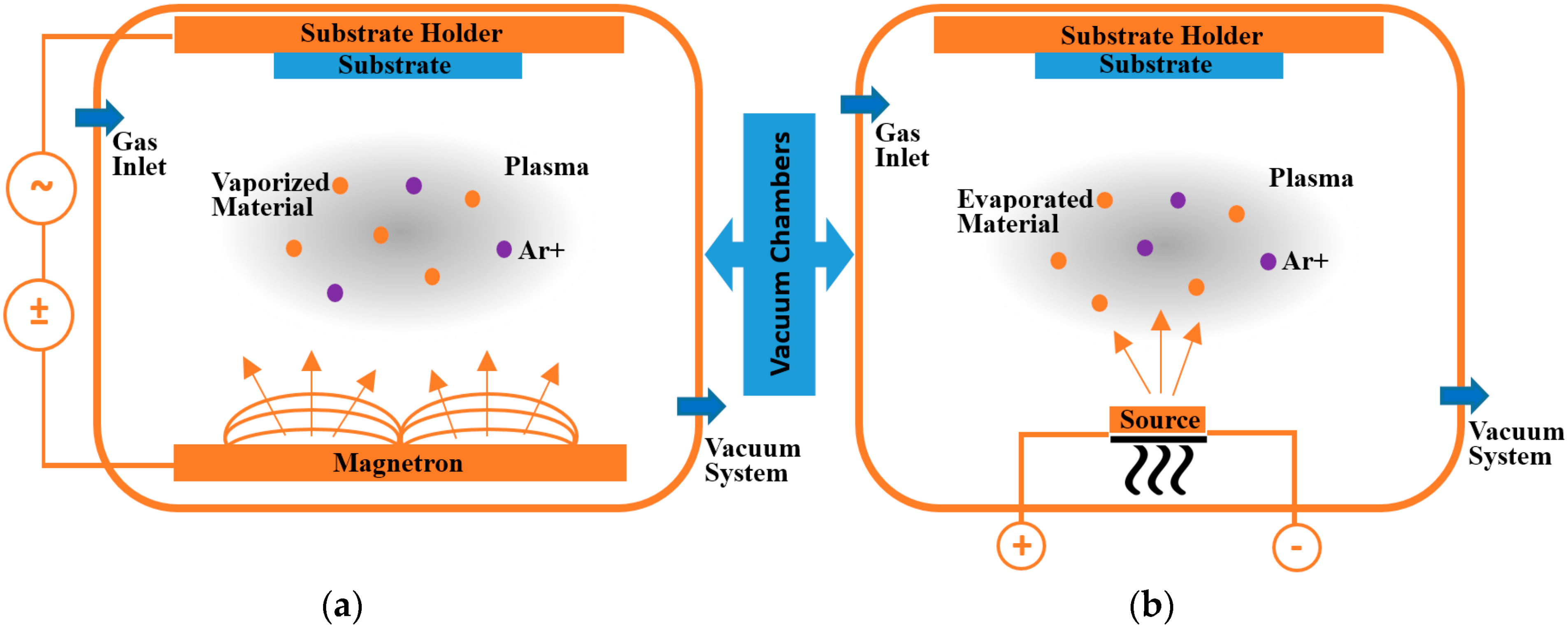
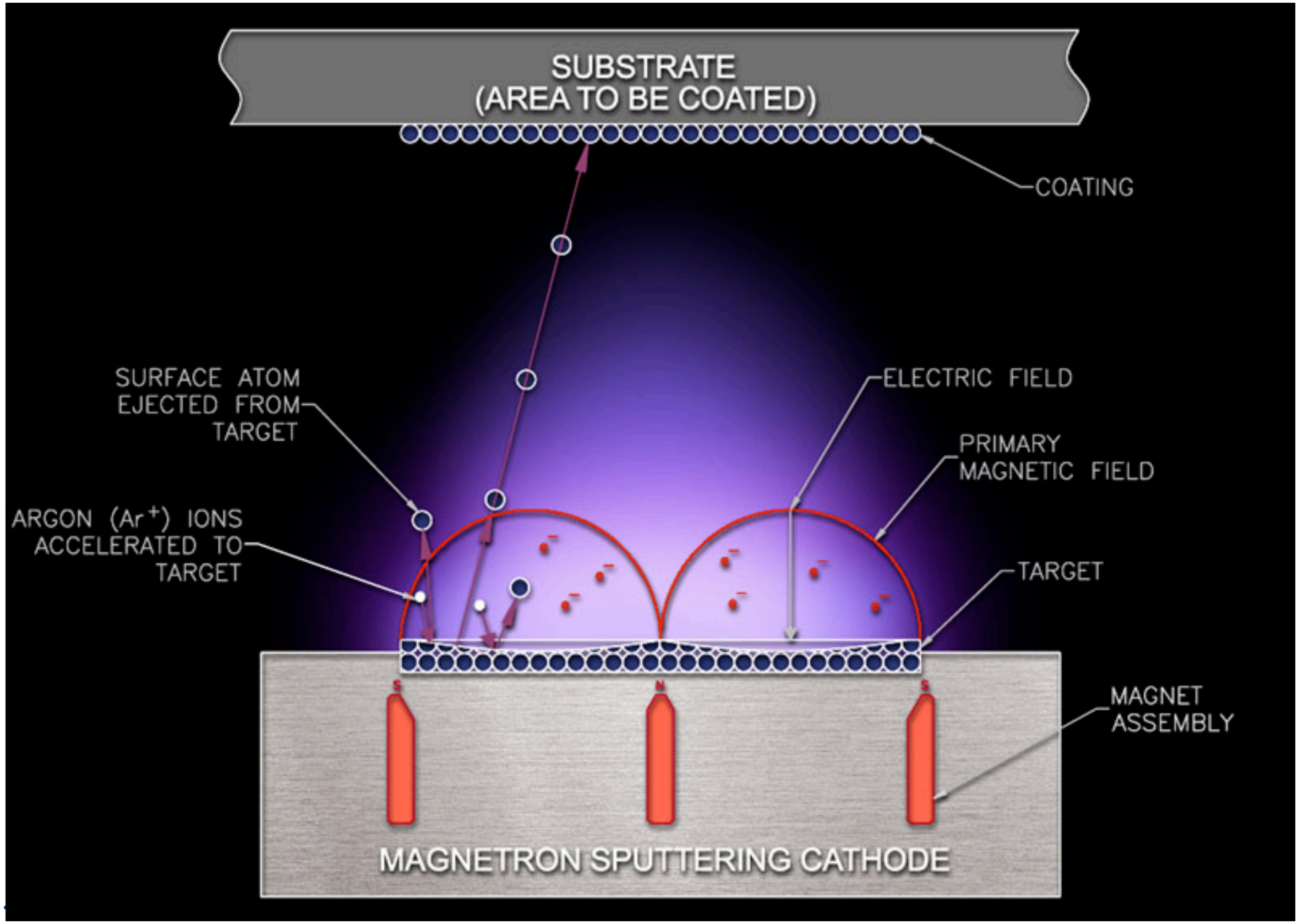


Figure 2. Schematic drawing of two conventional PVD processes: (**a**) sputtering and (**b**) evaporating using ionized Argon (Ar+) gas.

Andresa Baptista et al., *Coatings* **2018**, *8*(11), 402; https://doi.org/10.3390/coatings8110402

Magnetron-sputtering



Lande / Angstrom Sciences, Inc.

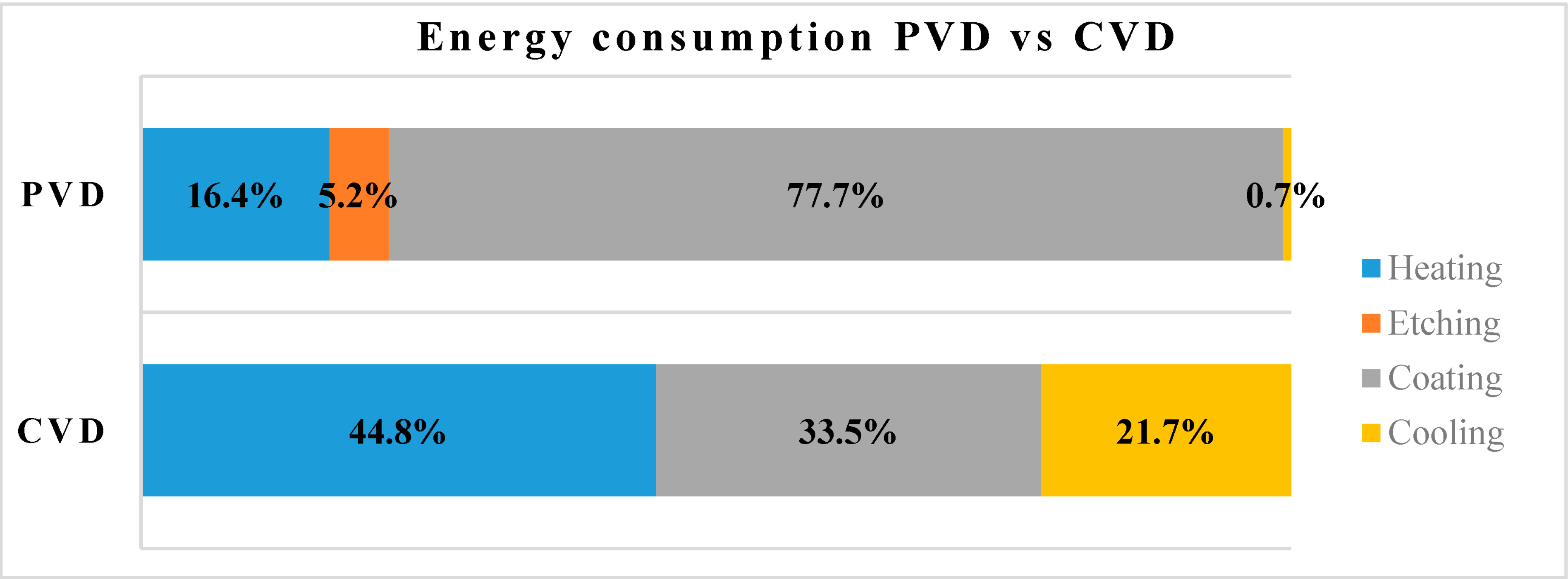
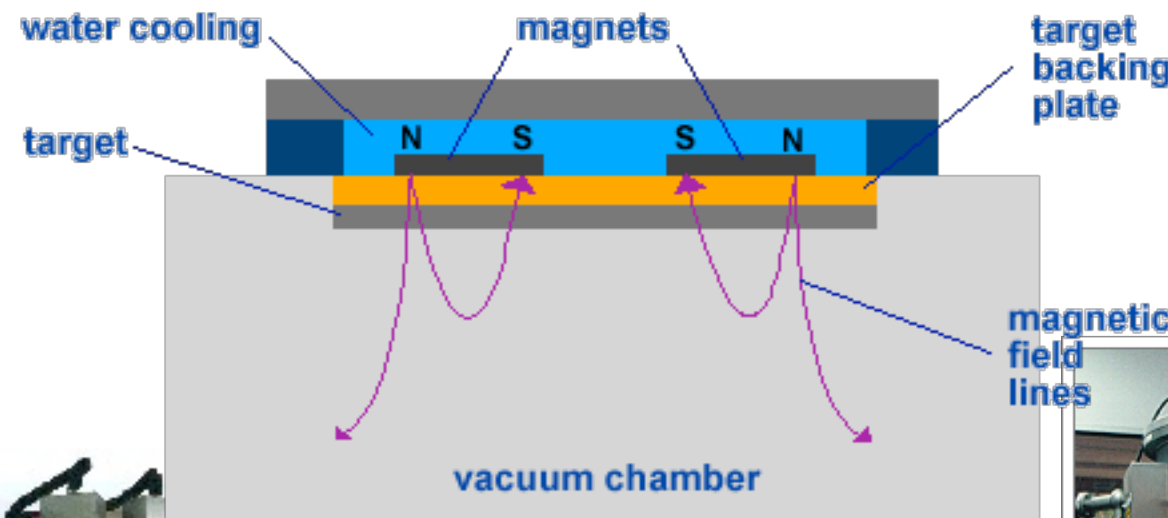


Figure 4. Energy consumption in the different steps of the PVD process: Heating, Etching, Coating, and Cooling. Energy consumption in the steps of the CVD process: Heating, Coating, and Cooling.

Andresa Baptista et al., *Coatings* **2018**, *8*(11), 402; https://doi.org/10.3390/coatings8110402

Unballaced magnetron sputtering



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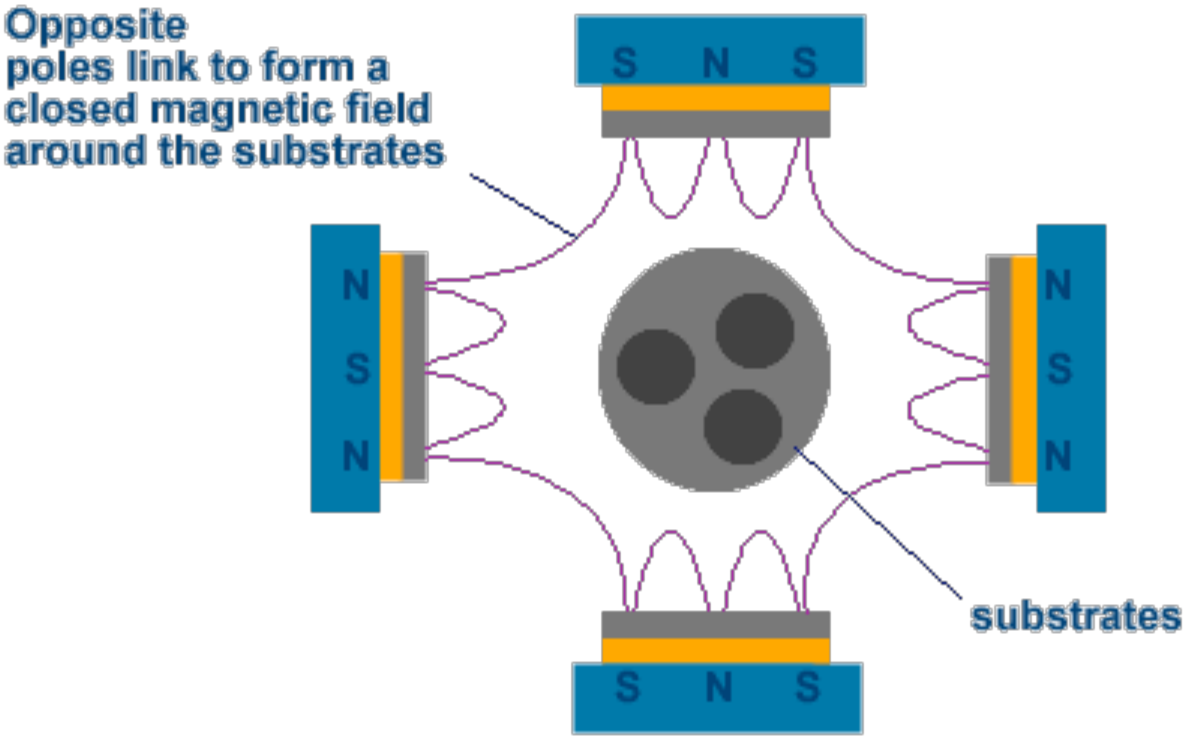
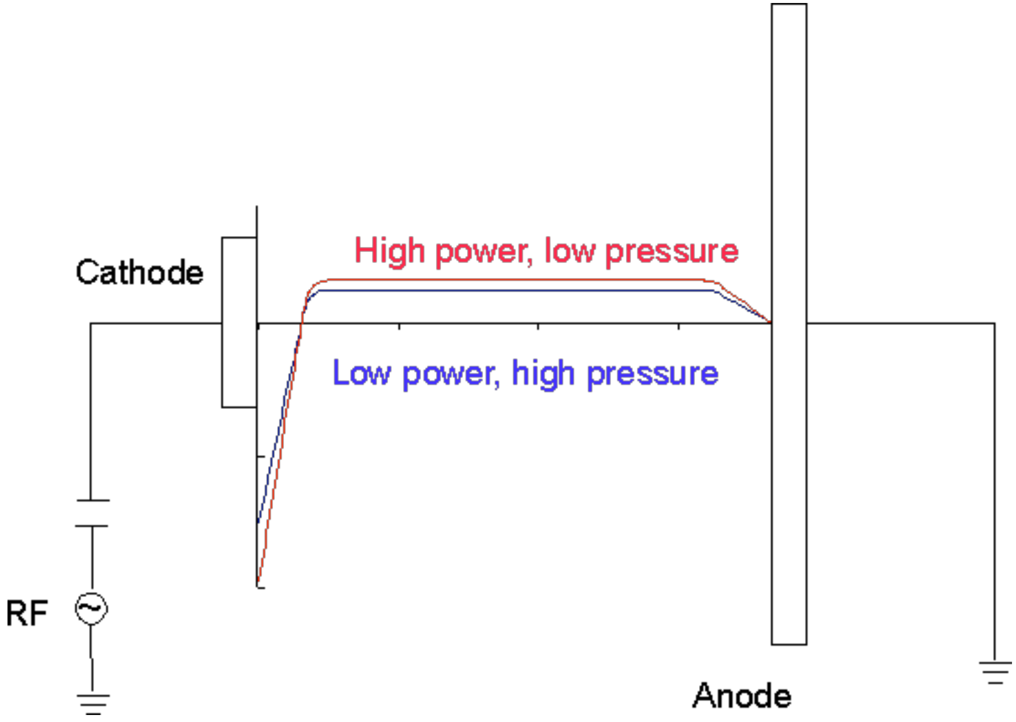
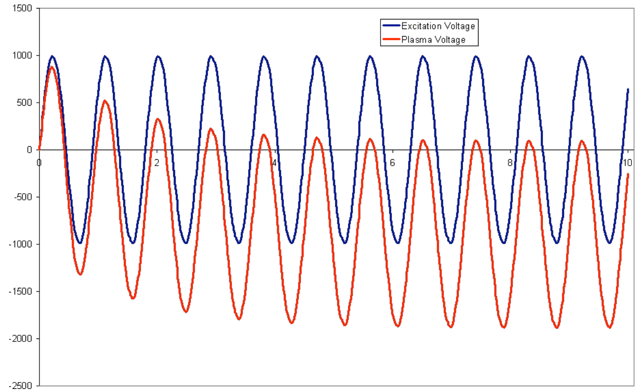
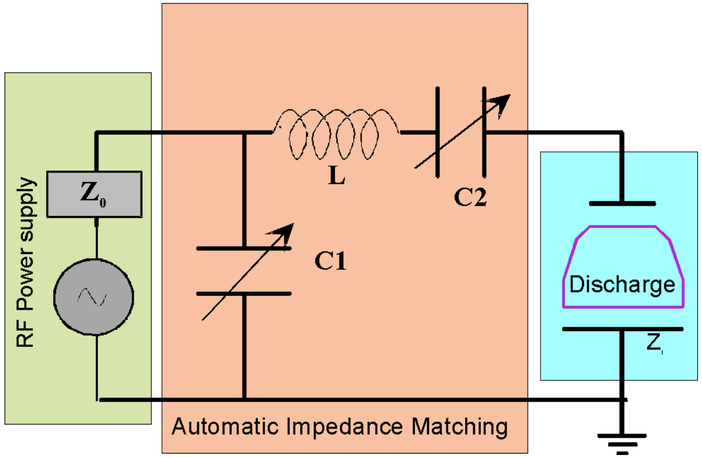
Closed field magnetron sputtering



RF Plasma glow discharge

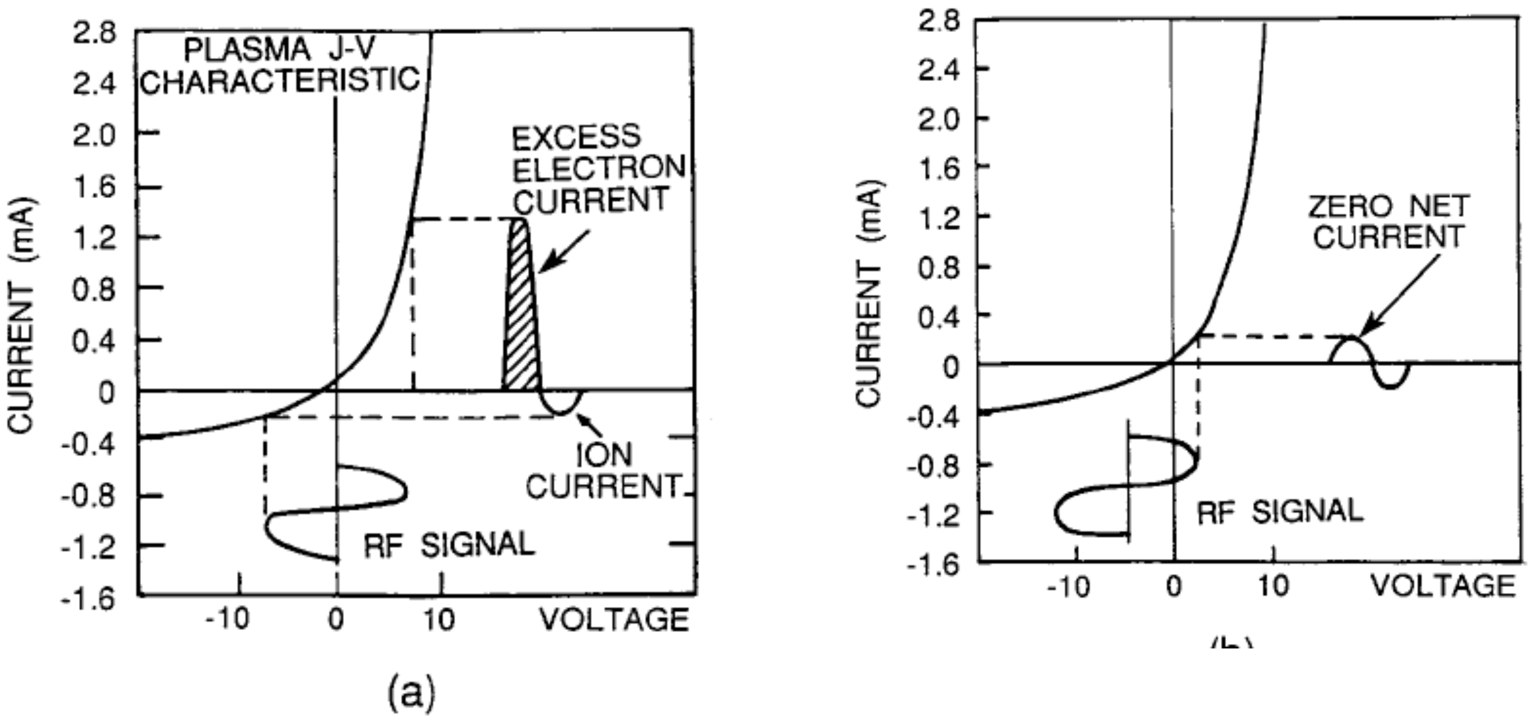






http://www.spectruma.de

RF Plasma glow discharge self bias



M. Ohring

Self bias at electrodes

$$\frac{V_1}{V_2} = \left(\frac{A_2}{A_1}\right)^4$$

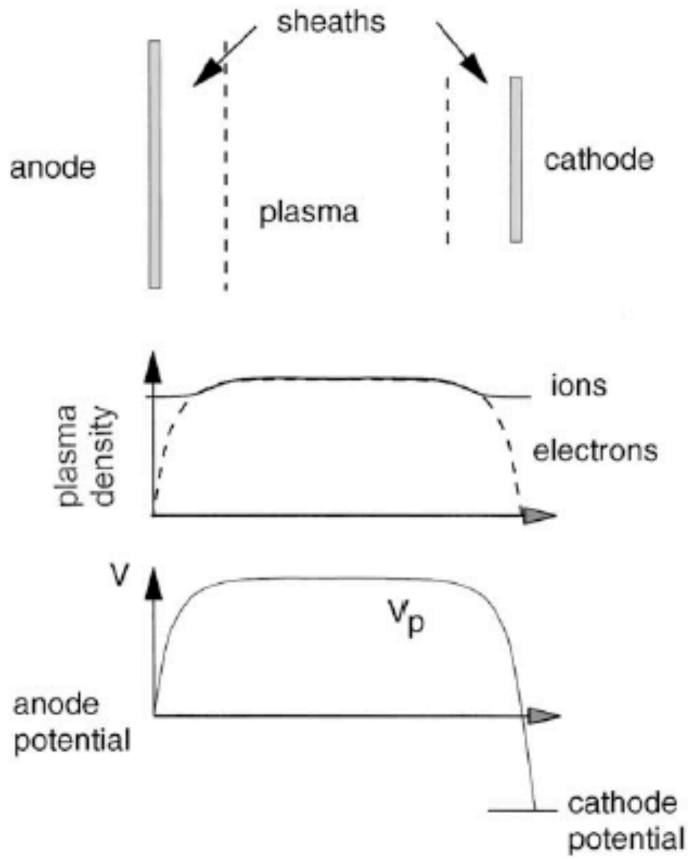
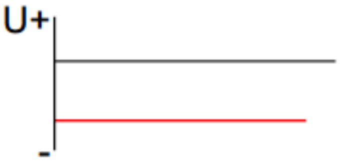


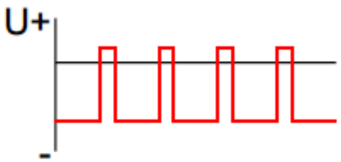
Fig. 7. Electron and ion distributions which create sheaths between the neutral plasma and the walls.

PULSED SPUTTERING
Definitions

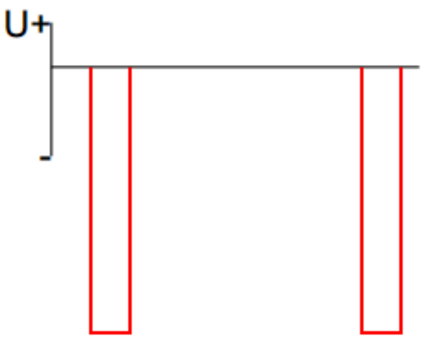
- DC-sputtering



- Pulsed DC



- HiPIMS



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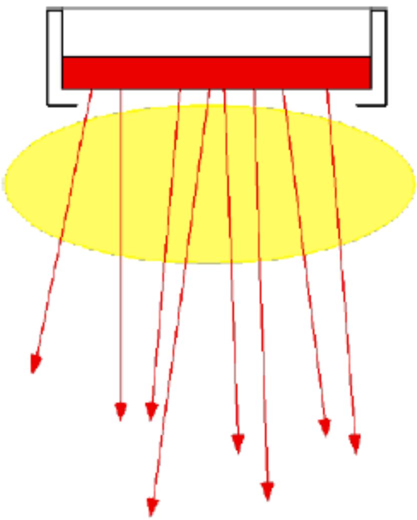
III. High power pulsing

- High Power Impulse Magnetron Sputtering – HiPIMS
- High Power Pulsed Magnetron Sputtering – HPPMS
- Modulated Pulsed Power - MPP

What is HiPIMS?

High peak powers (500-2000 W/cm^2)
Reasonable average powers
Low duty factors (0.5 – 5 %)

Plasma densities in the range of 10^{19} m^{-3}
(Normal magnetron sputtering 10^{16} m^{-3})

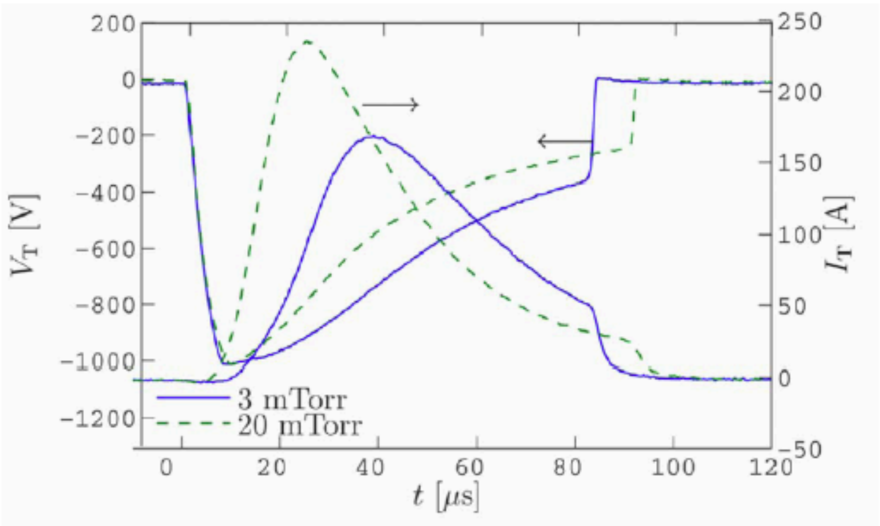


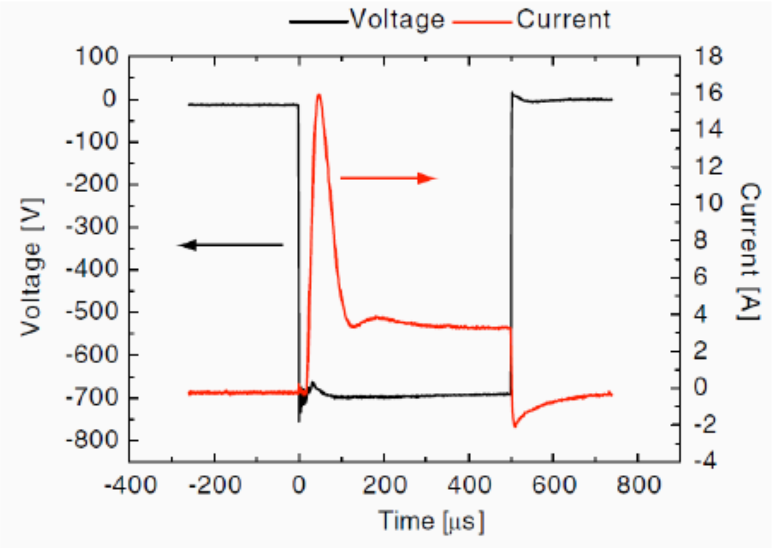
D.V. Mozgrin, I.K. Fetisov, and G.V. Khodachenko, Plasma Phys. Rep. **21**, 400 (1995)

S.P. Bugaev, N.N. Koval, N.S. Sochugov, and A.N. Zakharov, Proceedings of the XVIIth International Symposium on Discharges and Electrical Insulation in Vacuum, July 21-26, 1996, Berkeley, CA, USA, vol., p.1074

V. Kouznetsov, K. Macák, J.M. Schneider, U. Helmersson, and I. Petrov, Surf. Coat. Technol. **122**, 290 (1999)

Typical HiPIMS pulses

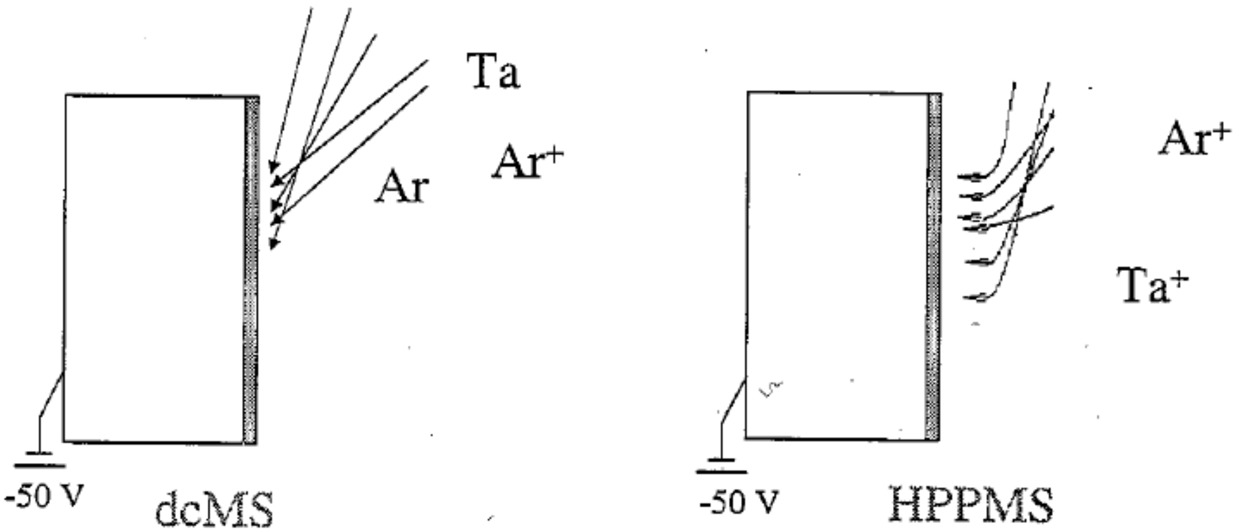




J.T. Gudmundsson, P. Sigurjonsson, P. Larsson, D. Lundin, U. Helmersson, J. Appl. Phys. **105**, 123302 (2009)

D. Lundin, N. Brenning, D. Jädernäs, P. Larsson, E. Wallin, M. Lattemann, M.A. Raadu and U. Helmersson, Plasma Sources Sci. Technol. **18**, 045008 (2009).

DC-MS and HPPMS Deposition*



- Shadowing effect
- Bombardment of surface with Ar ions

- Efficient momentum transfer (Metal ion bombardment)
- Enhanced surface diffusion

*J. Alami, P. O. A. Persson, D. Music, J. T. Gudmundsson, J. Bohlmark, and U. Helmersson, "Ion-assisted physical vapor deposition for enhanced film properties on nonflat surfaces," J. Vac. Sci. Technol. A 23(2) (2005) 278.

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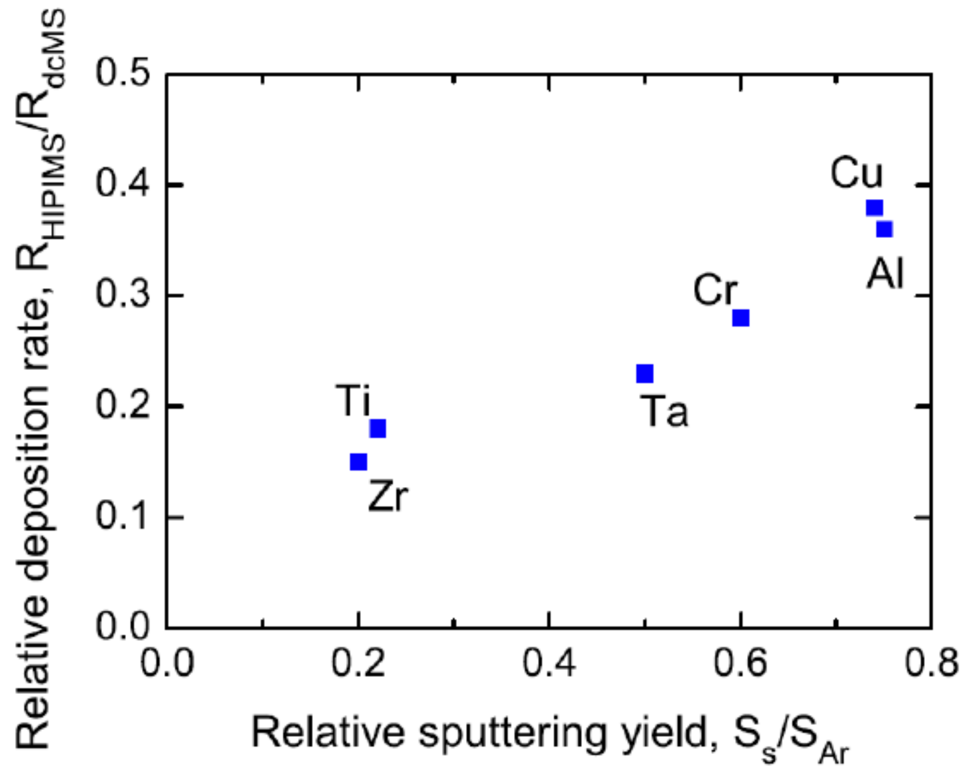
Deposition rate

The deposition rate in HiPIMS is in general lower compared to DC sputtering at the same average power



U. Helmersson, M. Lattemann, J. Bohlmark, A.P. Ehiasarian, and J.T. Gudmundsson, Thin Solid Films **513**, 1 (2006)

HIPIMS denser films

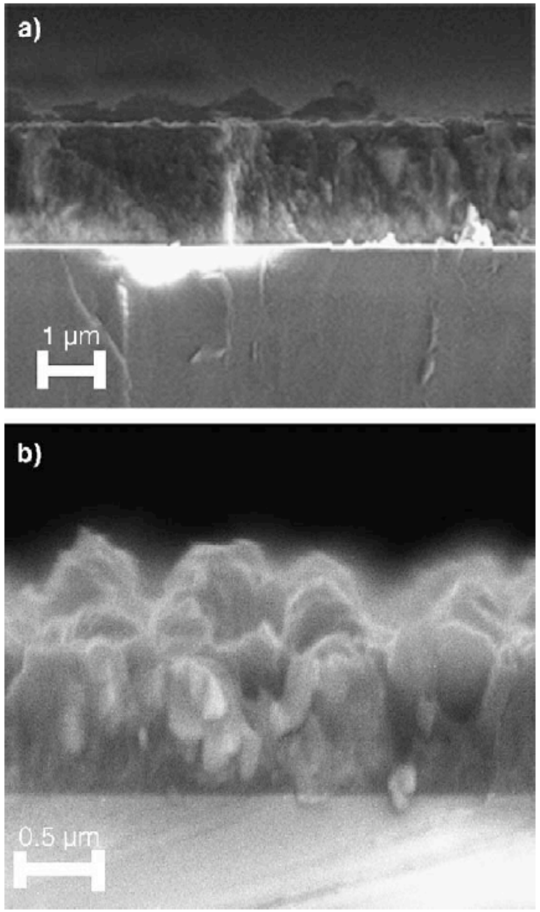


Fig. 2. SEM micrographs from Ti–Si–C films grown facing the target surface by HIPIMS (a) and dcMS (b), using 20 mTorr Ar, a sputtering gas and a substrate bias of −20 V.

Reactive sputtering

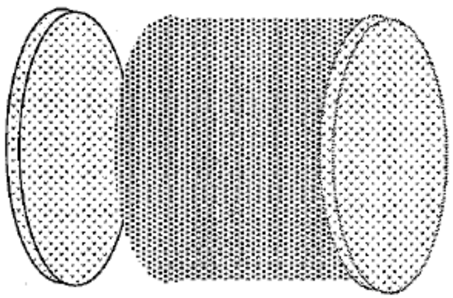
Reactive Sputtering

- Sputtering of an elemental target in the presence of a gas (in addition to the inert gas) that will react with the element to form a compound
  - Examples:
    - $Al + O_2$ to form Al_2O_3
    - $Ti + N_2$ to form TiN
- Purposely add the reactive gas
- Outgassing can be a factor

RSI The Practice of Reactive Sputter Deposition Chapter 1 - 11

Reactive sputtering

Reactive Sputtering



Target + Reactive gas = Film

1. **Doping:** $Ta + N_2 = TaN_x$

2. **Compound formation:** $Ta + O_2 = Ta_2O_5$

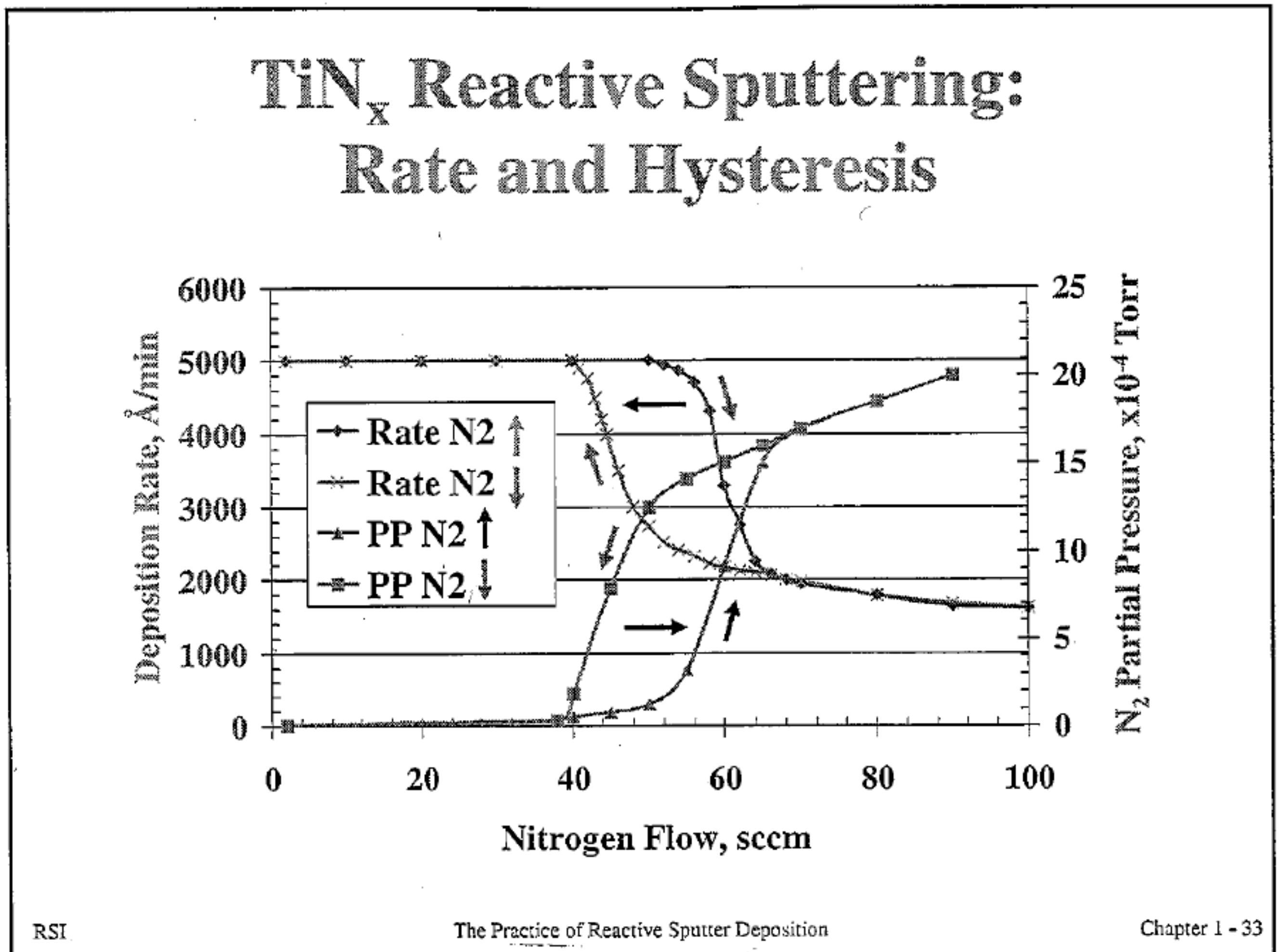
RSI The Practice of Reactive Sputter Deposition Chapter 1 - 14

Reactive sputtering

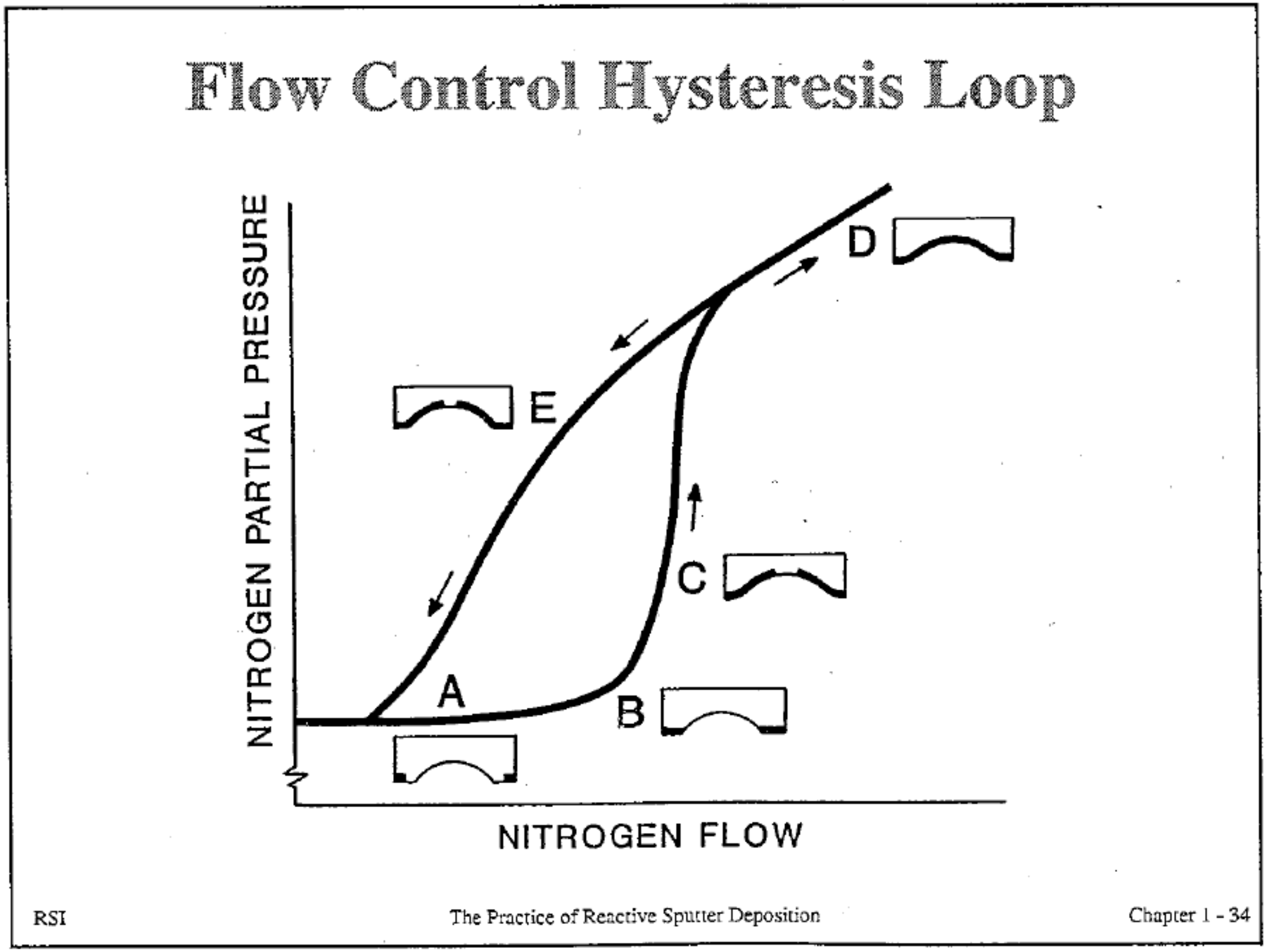
Metal vs. Poisoned Mode

- Metal mode
  - Sputtering metal
  - Reactive gas partial pressure low
- Poisoned mode
  - Target covered with compound
  - Reactive gas partial pressure high
- Target can be partially reacted
  - Takes partial pressure control

Reactive sputtering



Reactive sputtering

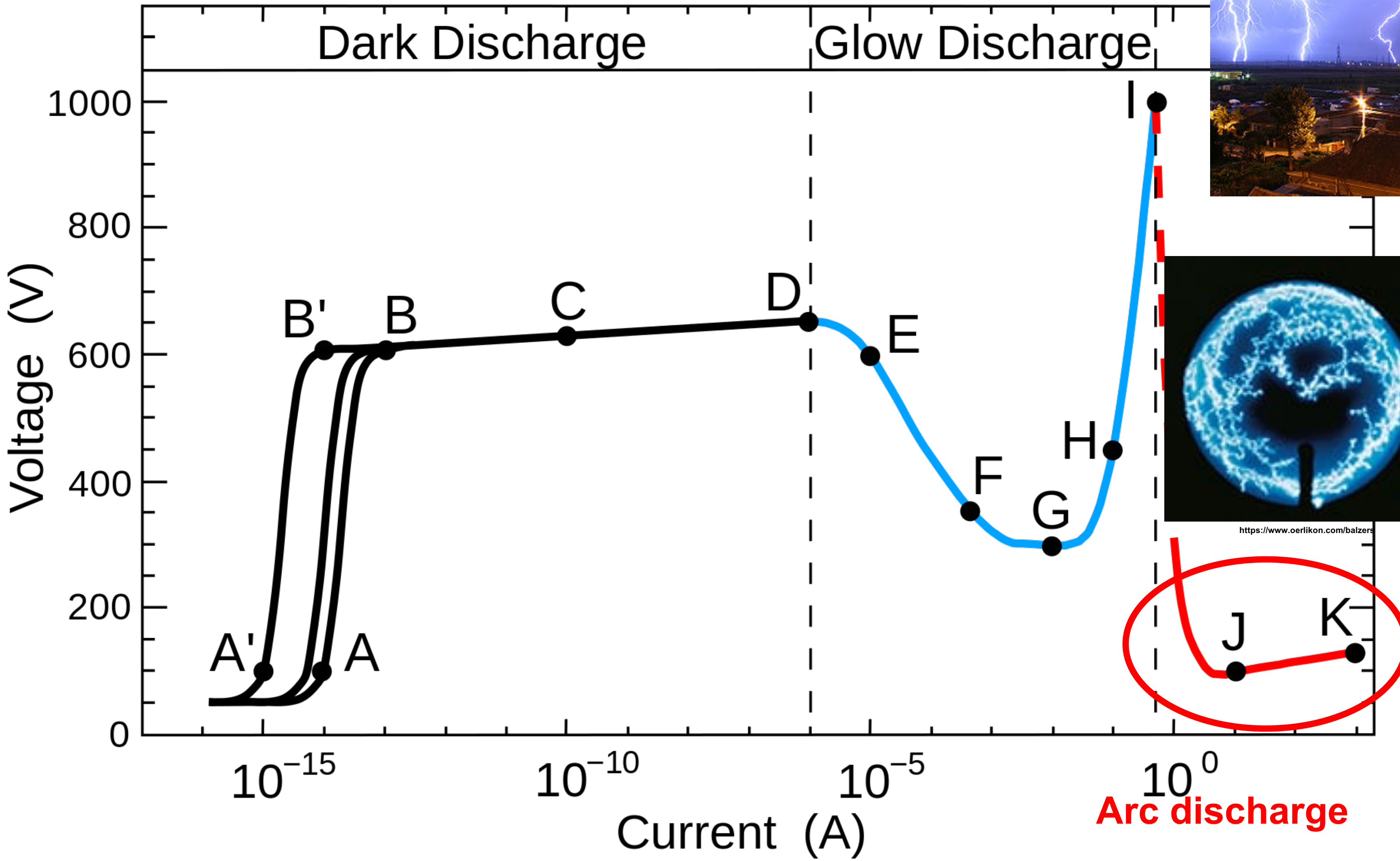


Reactive sputtering

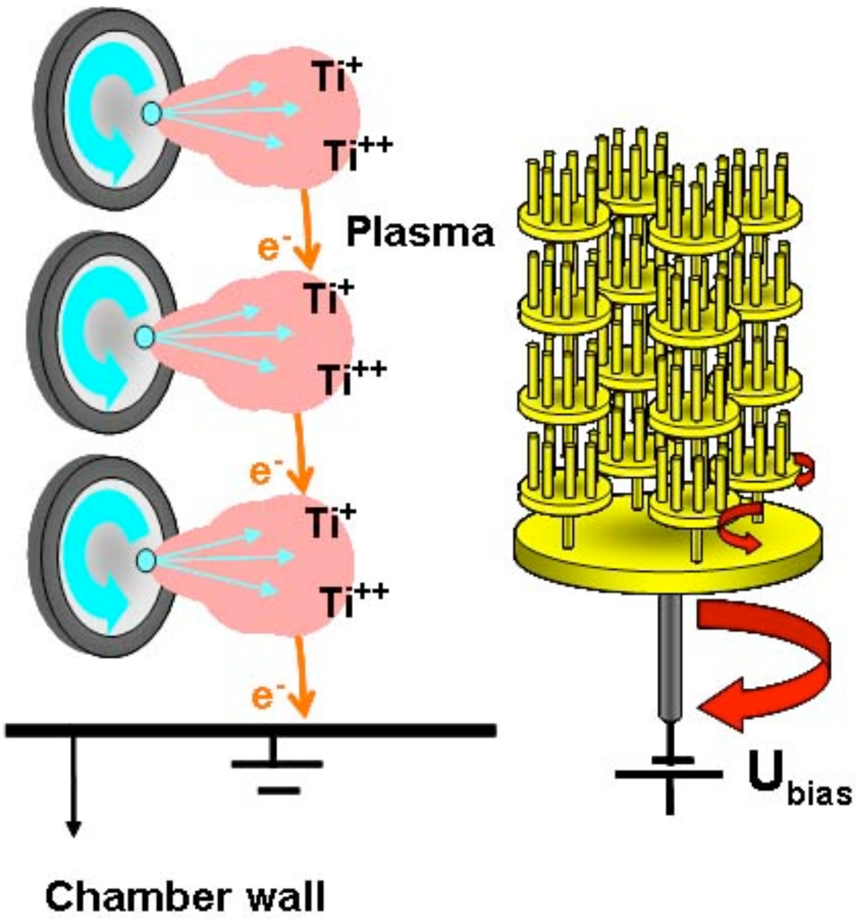
Reactive Deposition Examples

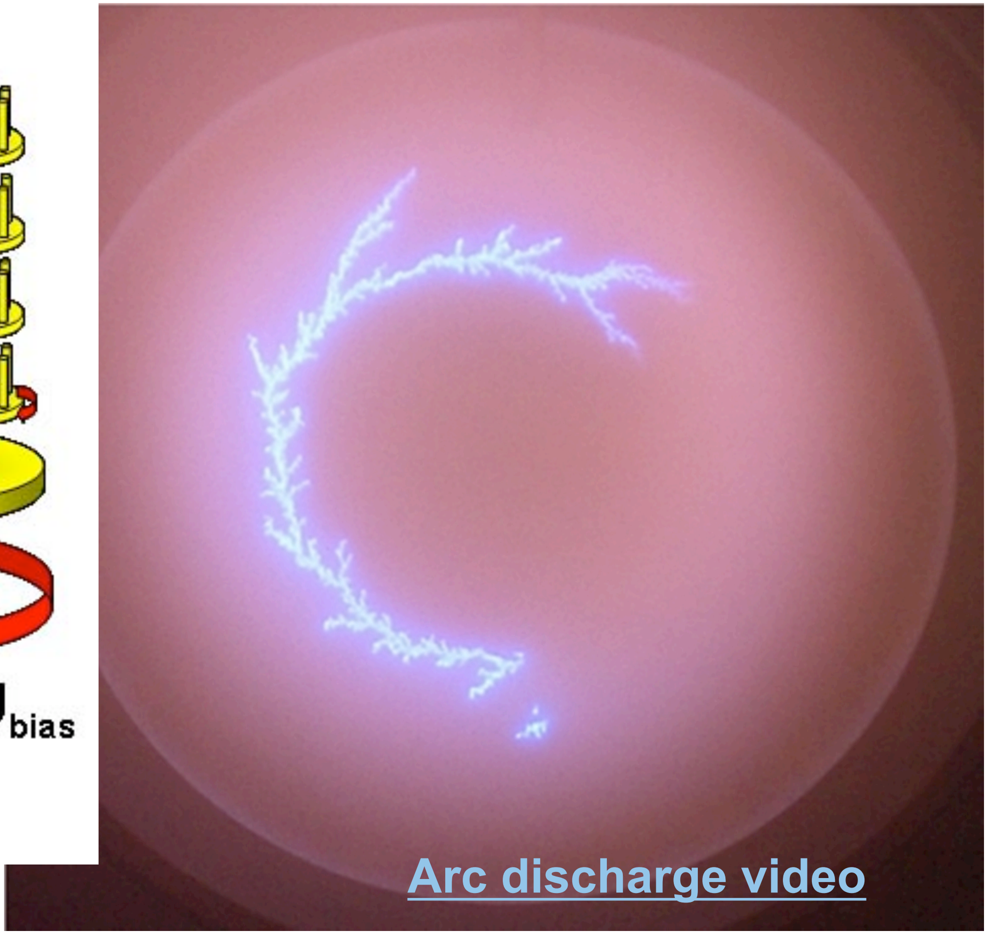
Target	H_2	N_2	O_2	H_2S	AsH_3	$Ga(CH_3)$
Al		AlN	Al_2O_3			
Ti	TiH	TiN	TiO_2			
Ta	TaH	Ta_2N, TaN	Ta_2O_5			
Cu			CuO	Cu_2S		
B		BN				
C		CN				
Si	Si:H	Si_3N_4	SiO_2			
$In_{.9}Sn_{.1}$			ITO			
Zn			ZnO			
Sb						GaSb
$LiNbO_3$			$LiNbO_3$			
GaAs					GaAs	
ZnO	ZnO_{1-x}		ZnO			

DC Plasma glow discharge and arc

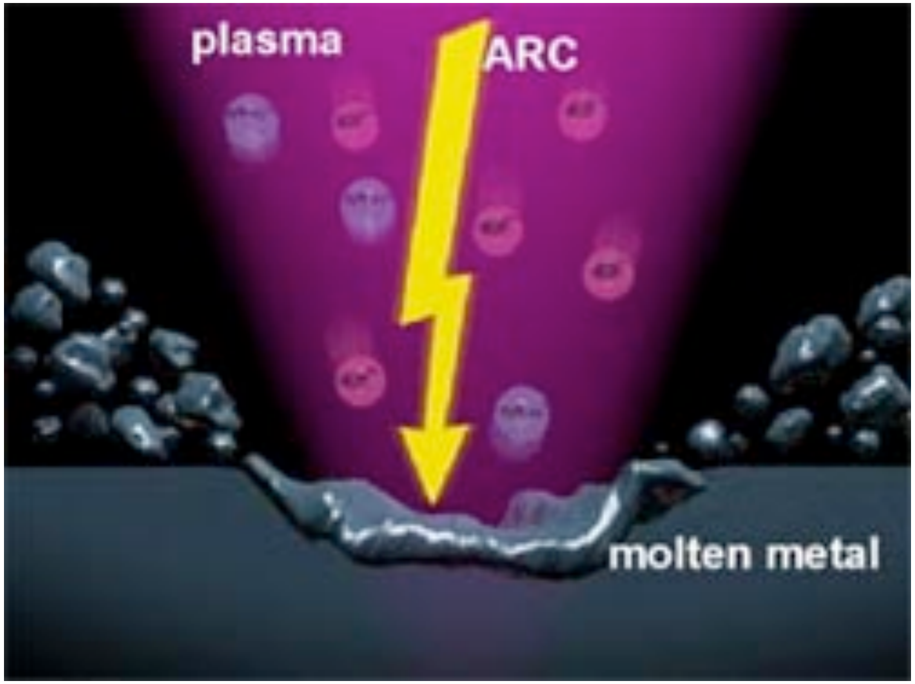


Arc discharge deposition



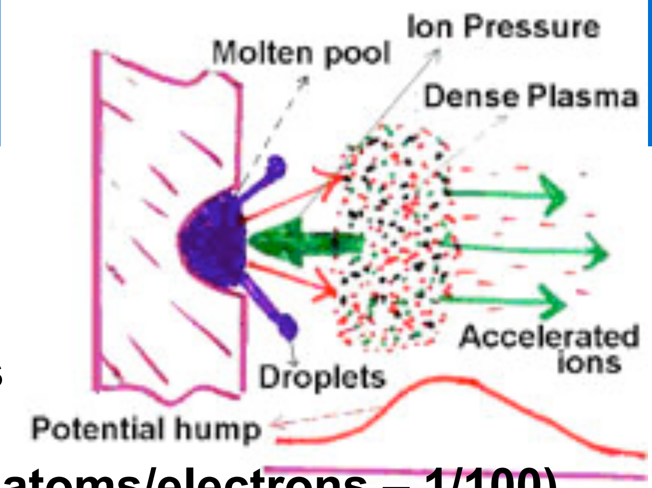


Arc disharge - cathode spot



www.shm-cz.cz/files/schema01.jpg

Arc discharge process



• arc current concentrated into filaments – arcs
• intense electron emission
•intense ion emission due to electron current (atoms/electrons – 1/100)
•ionization of atoms – formation of plasma
•flow of ions to cathode – intense sputtering of atoms
• 10^6 - 10^8 A/m^2
• overlapping thermal spikes
• materials is melted and sublimated in cathode spots
• cathode spots move randomly or could be steered by using magnets
• electons ionize vapor and create more electrons – increase of current
• ions accelerate
  • due to potential difference in plasma
  • due to multiple collisions with fast electrons
• macro particles (up to 10 μm diam.l are formed

Timko, Nordlund simulations
http://prb.aps.org/supplemental/PRB/v81/i18/e184109

Filtered arc

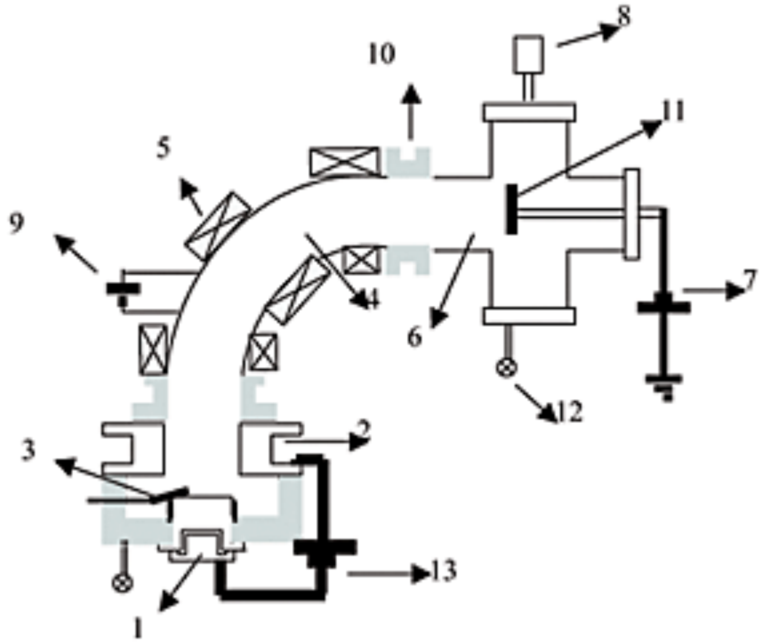
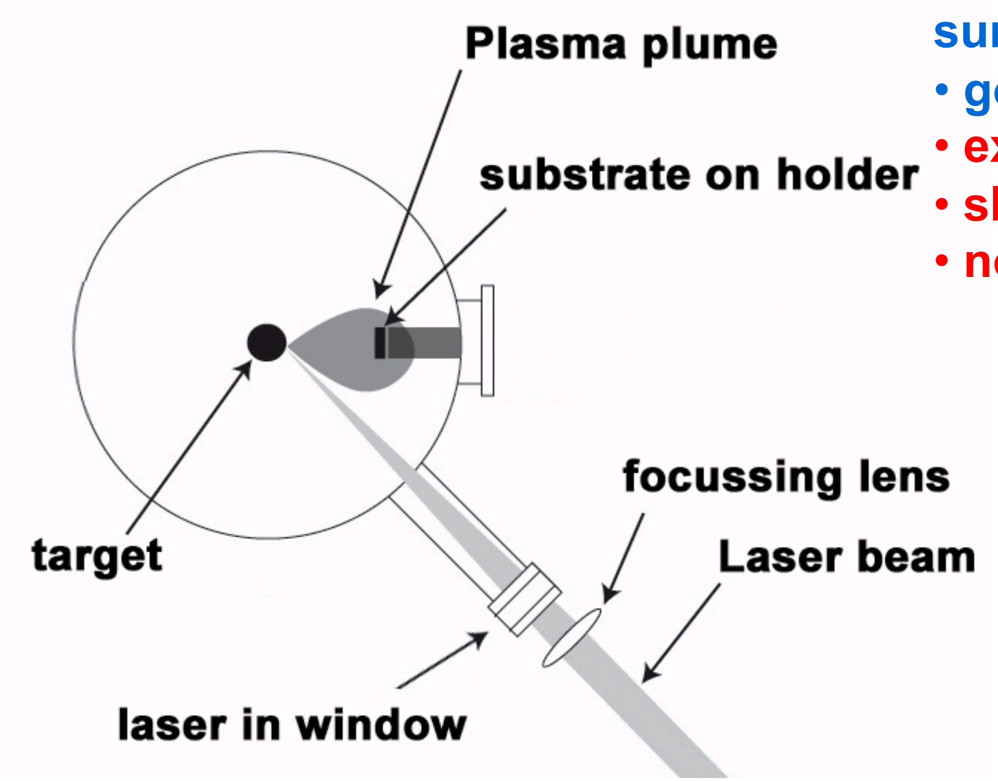
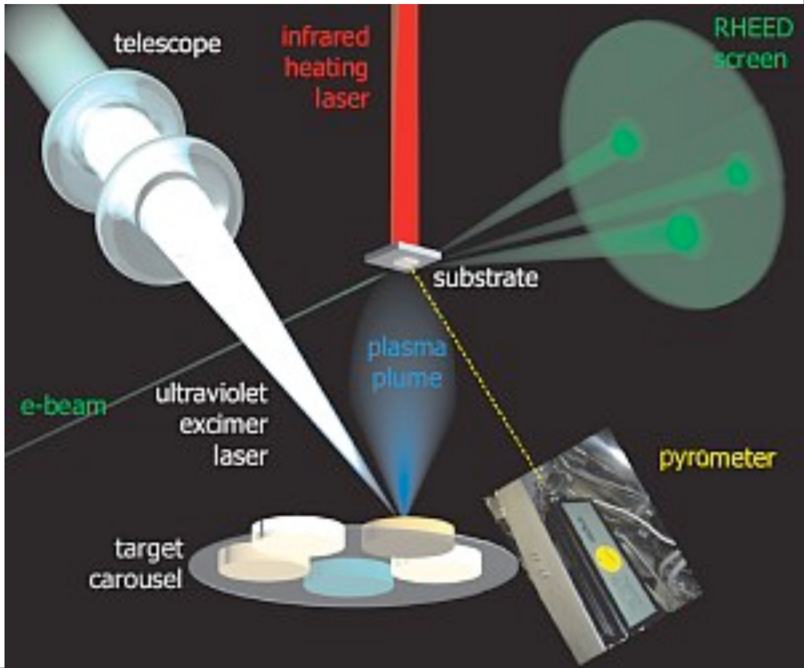


Figure 1. Scheme of the DCF2 device. (1) cathode; (2) anode; (3) trigger; (4) quarter torus magnetic filter; (5) torus coil; (6) deposition chamber; (7) probe bias source; (8) diagnostic port; (9) filter bias source; (10) insulators; (11) collecting probe; (12) vacuum pumping systems; (13) arc source.

Pulsed laser deposition PLD



- high ionization
- evaporation of any material also in reactive gas
- stoichimetry of target to the surbstrate
- good control of depostion rate
- expensive lasers
- slow depostion rate
- not yet in industrial level



http://www.youtube.com/watch_popup?v=g9RM4QhBnL0&vq=medium#t=19

E_i as a function of laser pulse energy

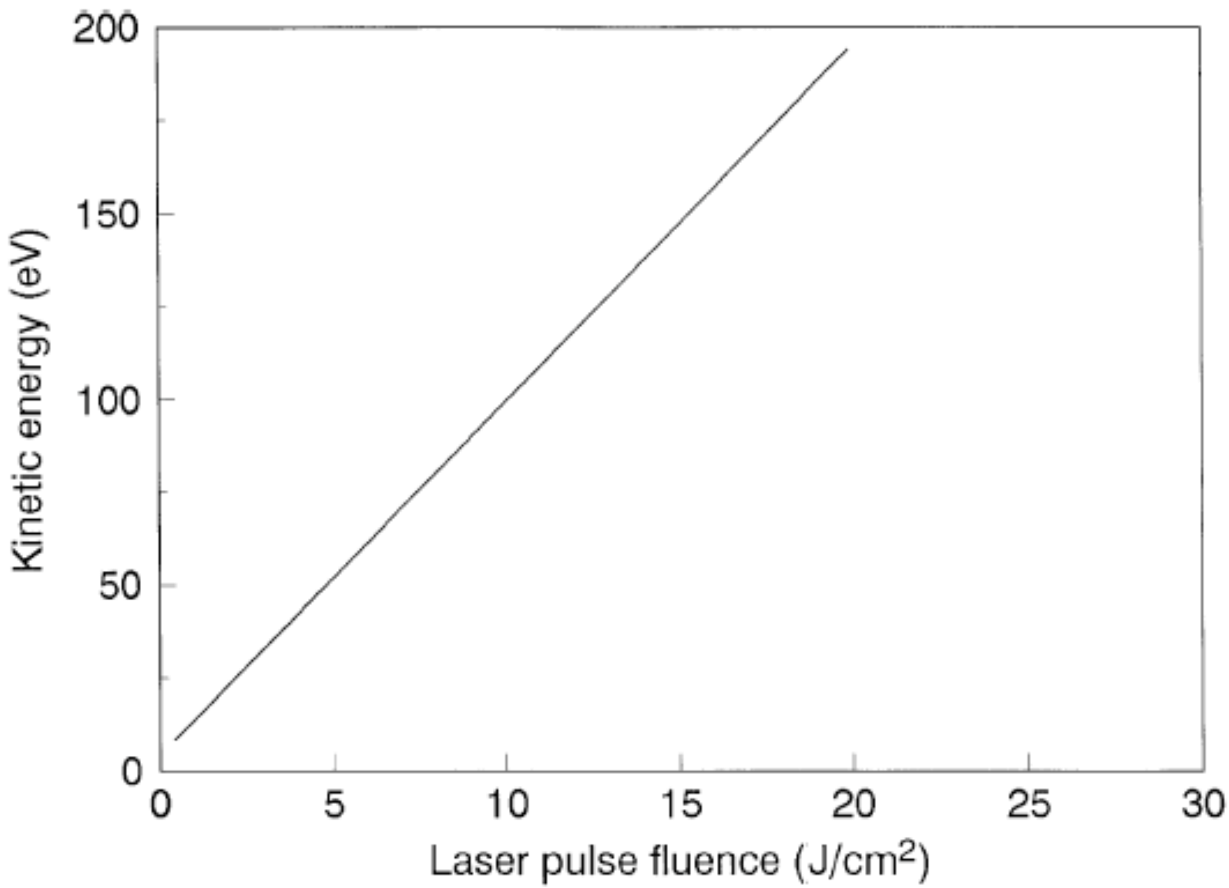


Fig. 6. Average ion energy vs. laser pulse fluence [9].

J. Robertson / Materials Science and Engineering R 37 (2002) 129–281

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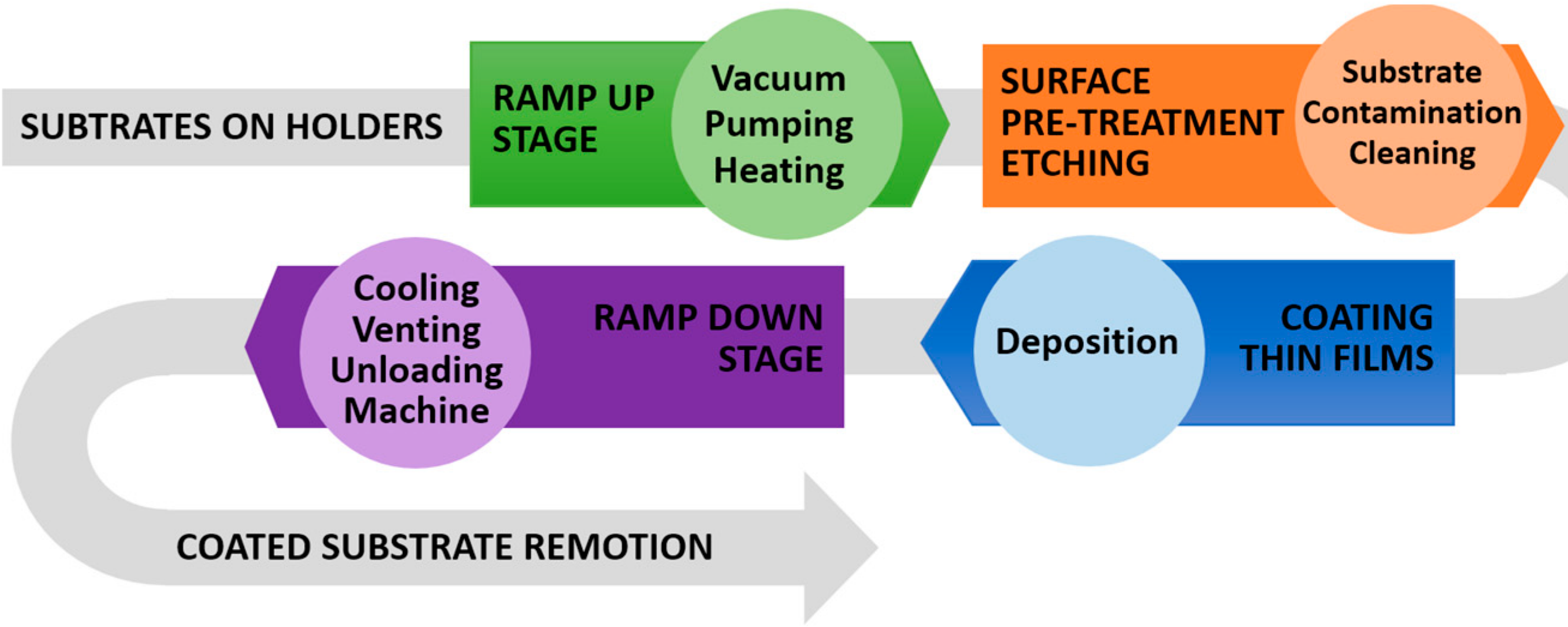


Figure 3. The processing flow for a classic PVD sputtering process.

Andresa Baptista et al., *Coatings* **2018**, *8*(11), 402; https://doi.org/10.3390/coatings8110402

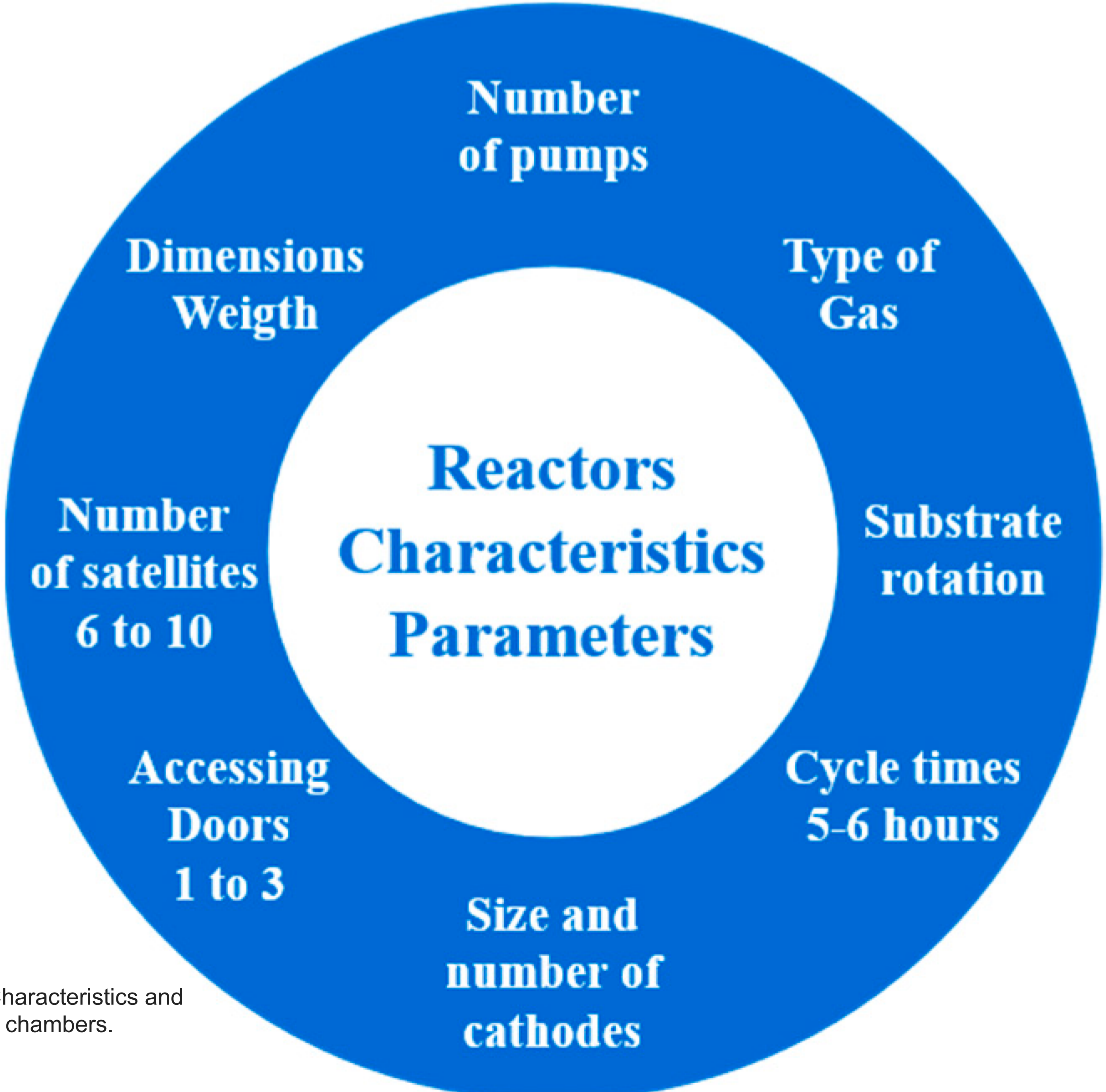
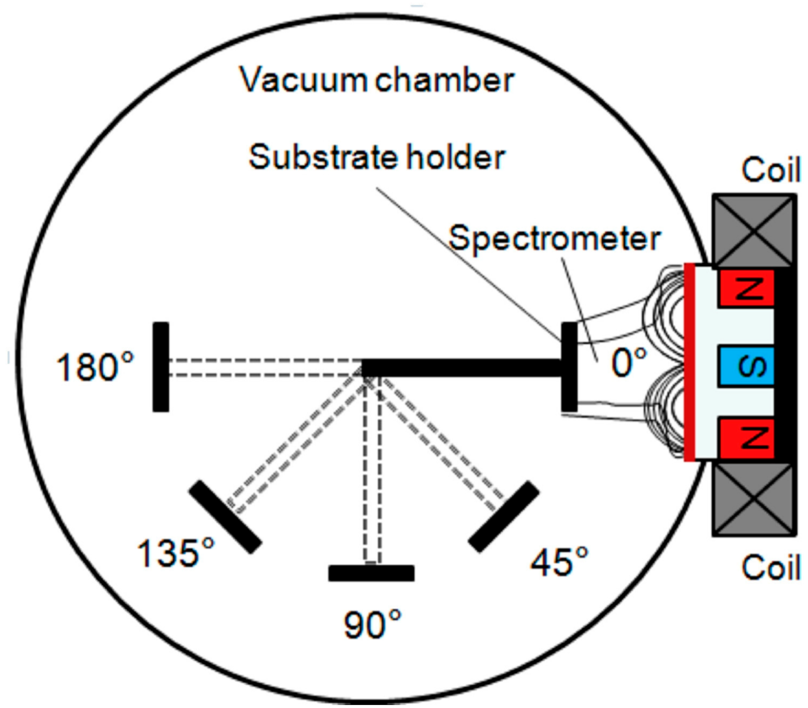


Figure 5. Characteristics and parameters chambers.

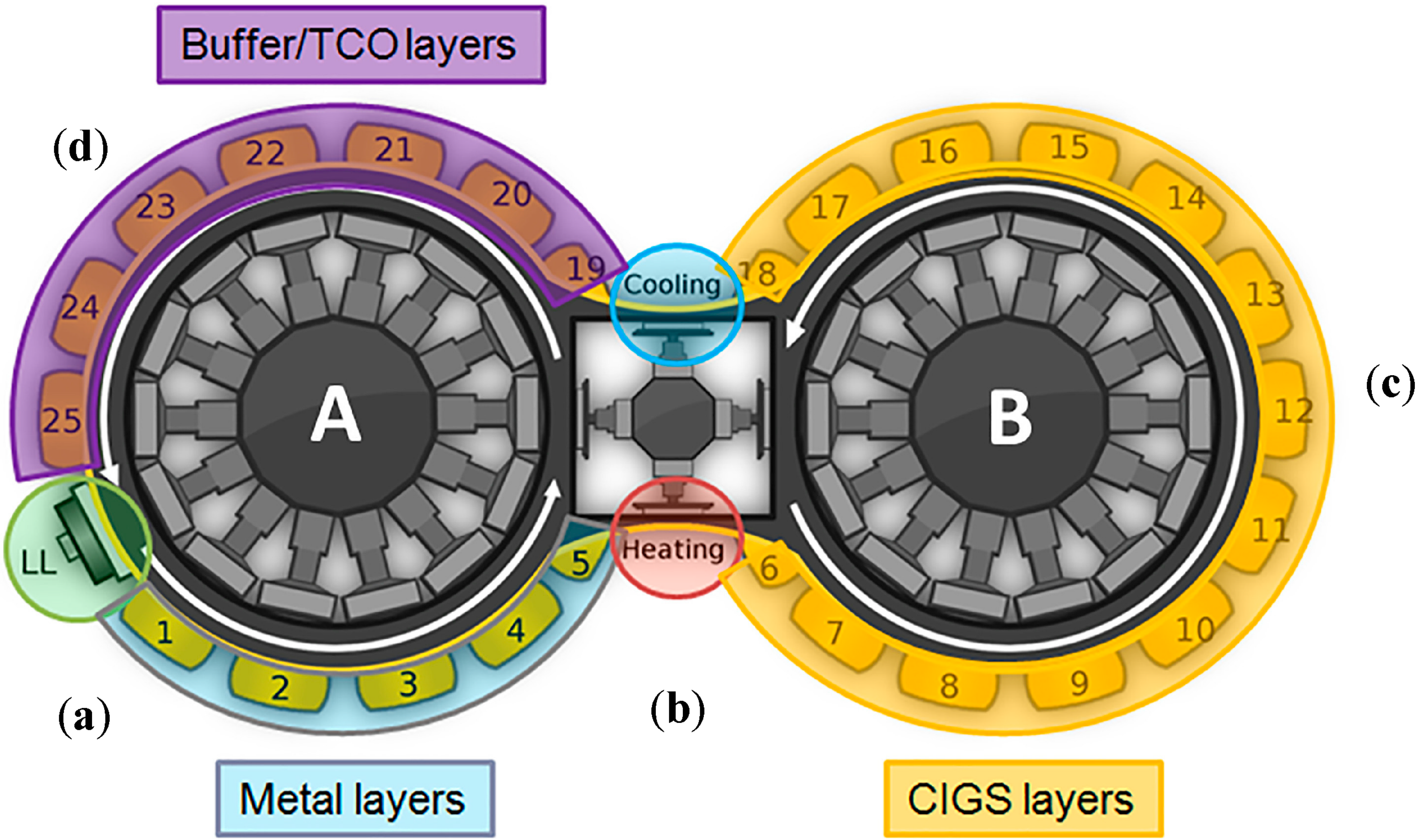
Andresa Baptista et al., *Coatings* **2018**, *8*(11), 402; https://doi.org/10.3390/coatings8110402

Vacuum system setup – unballaced magnetron



(a)

Andresa Baptista et al., *Coatings* **2018**, *8*(11), 402; https://doi.org/10.3390/coatings8110402



Andresa Baptista et al., *Coatings* **2018**, *8*(11), 402; https://doi.org/10.3390/coatings8110402

Contents

- Plasma
- Different PVD methods
- PVD Systems
- **Commercial PVD coatings**
- Scale up

PVD coatings - some commercial companies

Barlzers coatings

http://www.oerlikon.com/balzers/com/en/coating-guide-overview/

Hauzer Techno Coating

http://www.hauzertechnocoating.com/en/

Platit coatings

Coating guide

Contents

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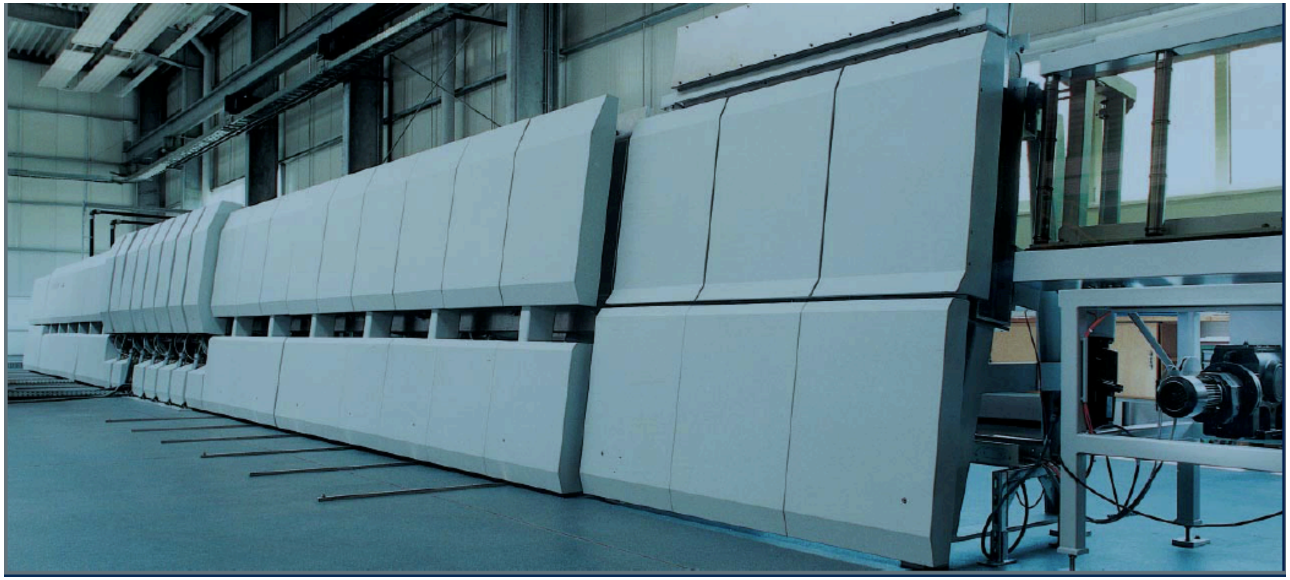
Large volumes, up scaling
Hear reflecting, self cleaning, photo voltaic



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