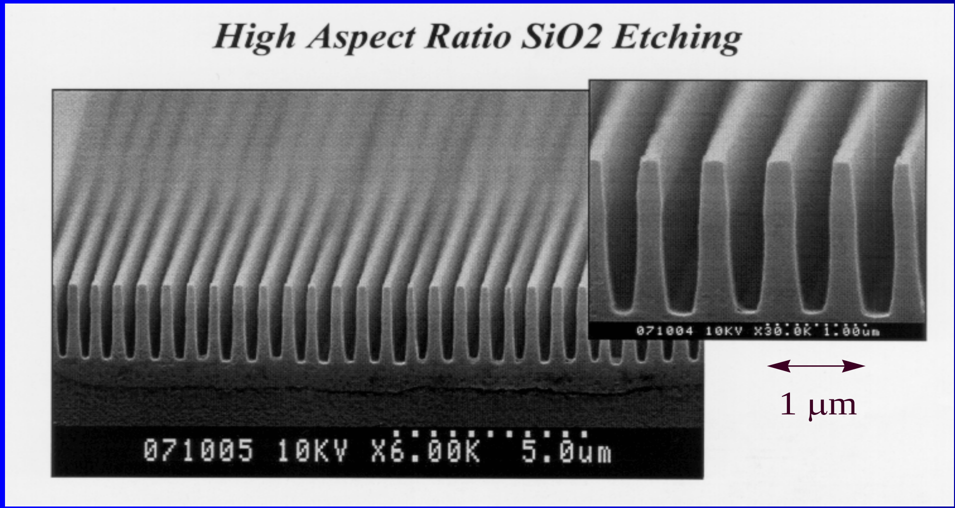
Plasma Surface Interaction

(part II: application)

- Examples for application of PSI (etching)
  - # plasma etching of GaAs
  - # plasma etching of Si in F-containing gases
  - # plasma cleaning

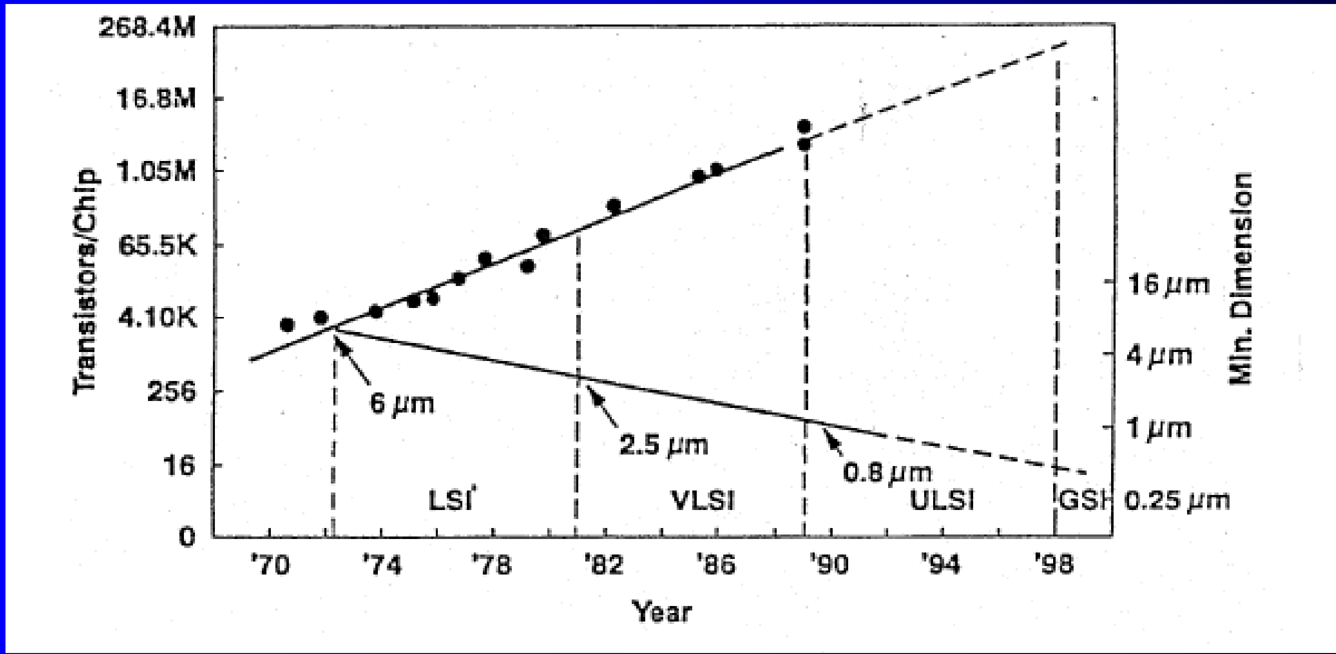
- Examples for application of PSI (deposition)
  - # plasma polymerization
  - # TiN deposition in HCAED
  - # sputtering of Al, powder modification

applications

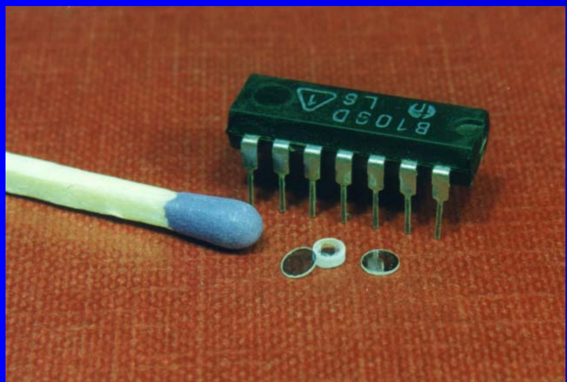


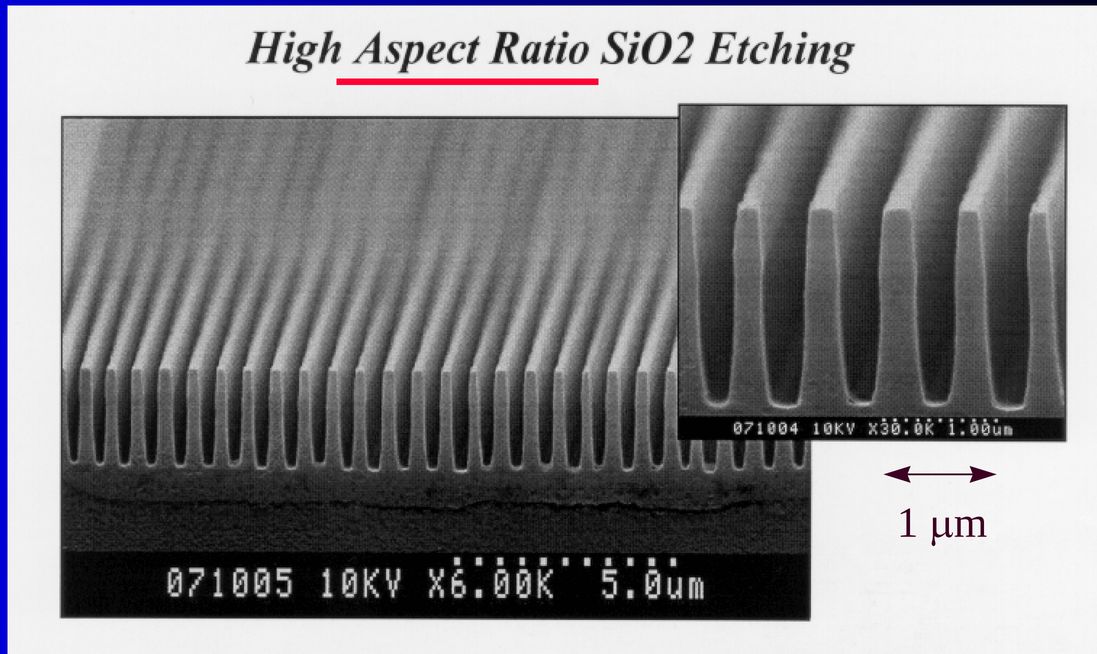
microelectronics fabrication : plasma etching of semiconductors

	1997	**2012**
transistor / µP	*~ 10^7*	*~ 10^9*
processes	*350*	*600*
wafer size	*200mm*	*450mm*
structur size	*250nm*	*50nm*
killer particles	*> 120nm*	*> 20nm*
life time of a process	*~ 3 years*	

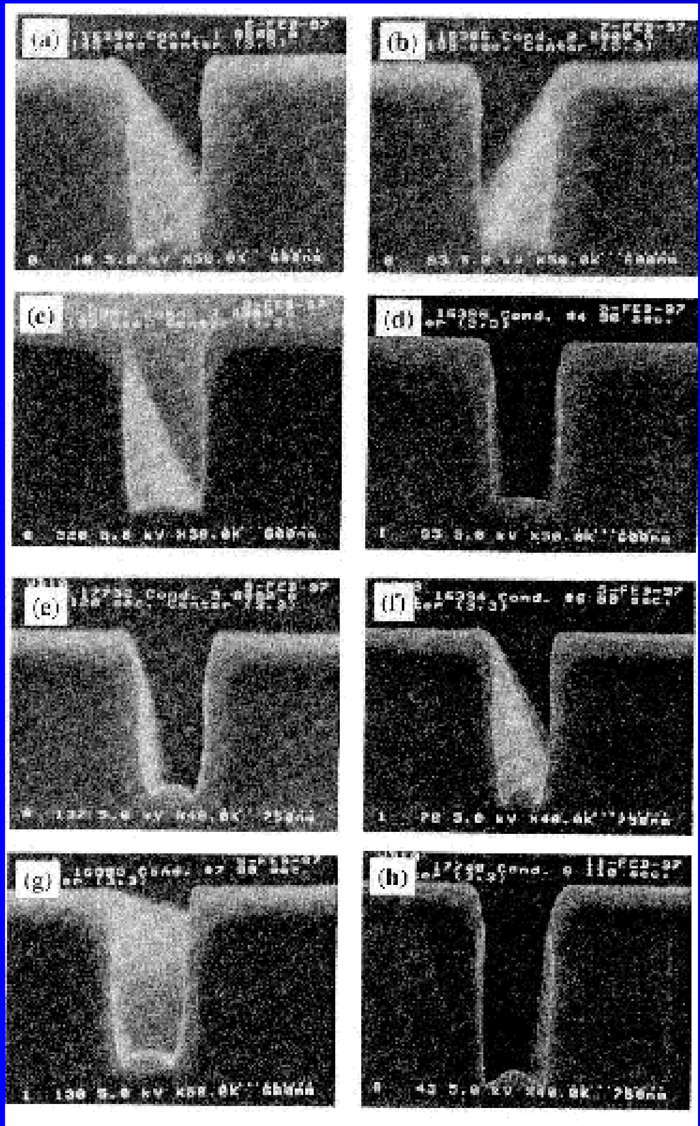


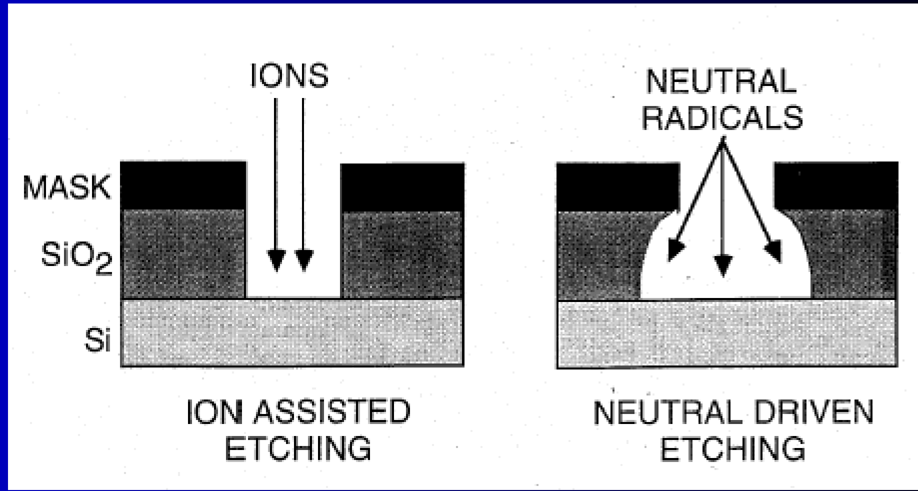
etching,
structurization
of semiconductors





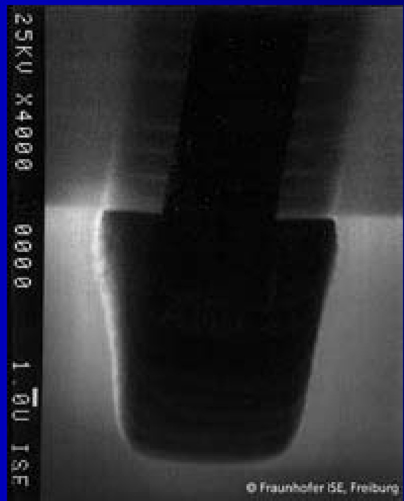
demands for plasma etching



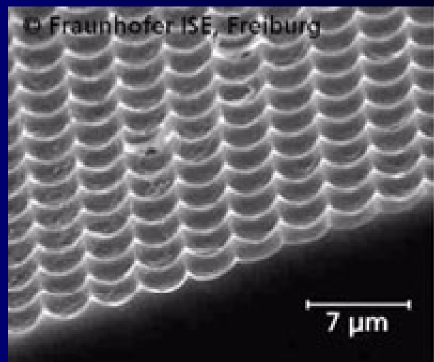


anisotropy

selectivity

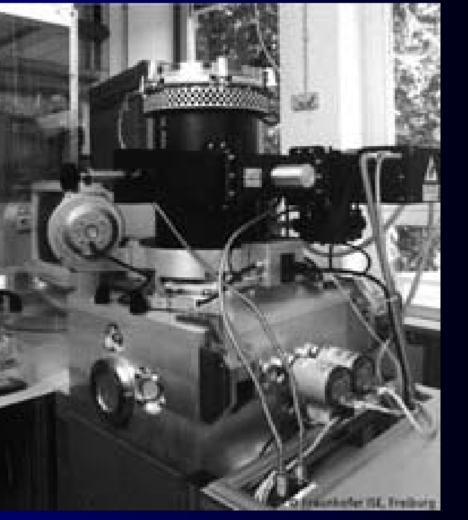


homogeneity

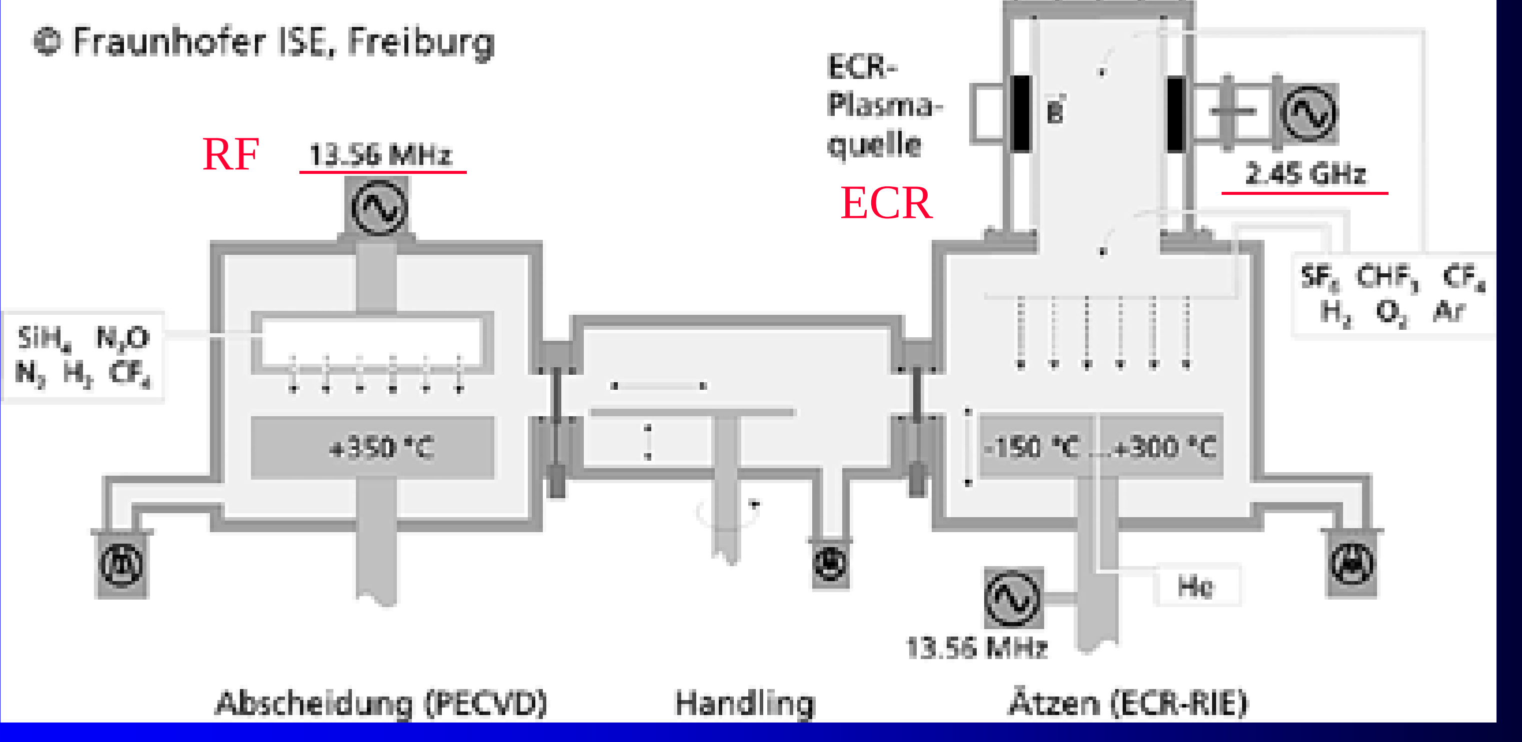


etching and deposition, passivation

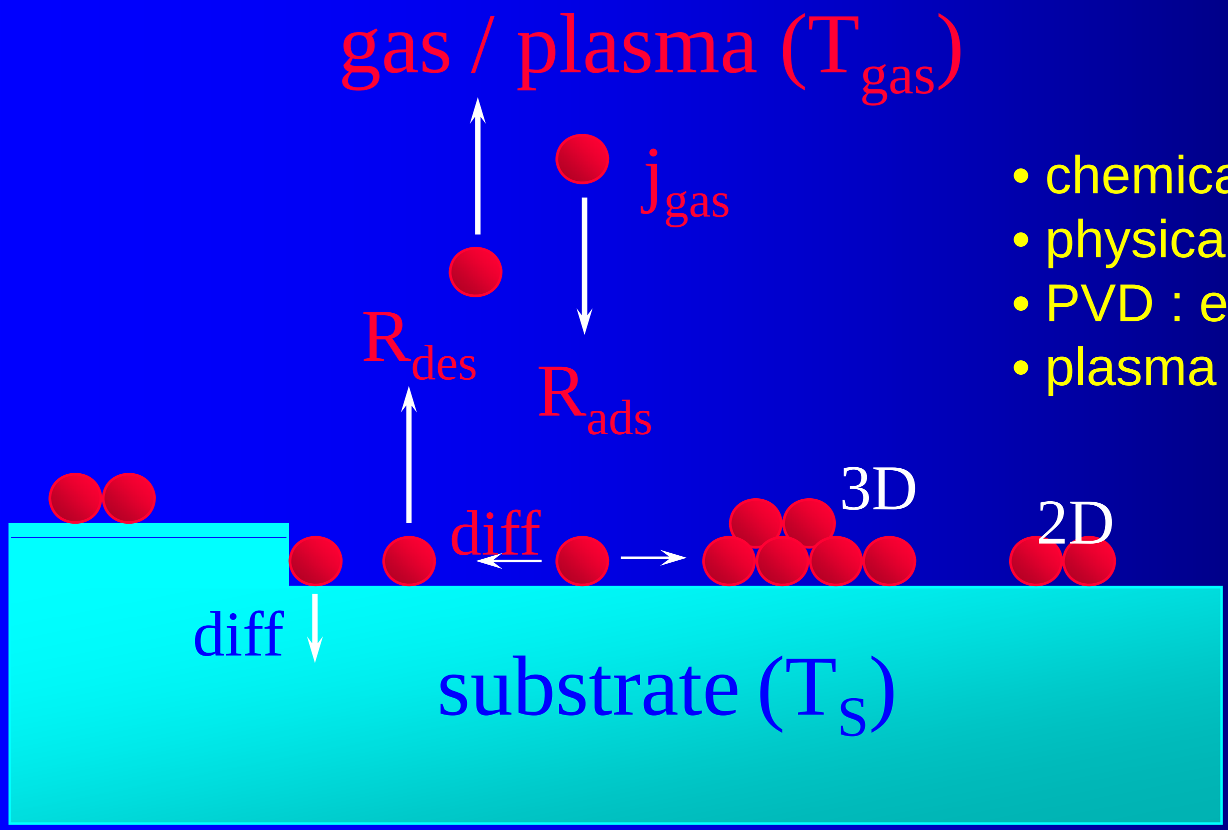
plasma methods



- plasma etching (PE/RNE, RIE,)
- sputtering (SPE, IM)
- beam-supported methods (RIBE, CAIBE)
- plasma ashing, plasma cleaning



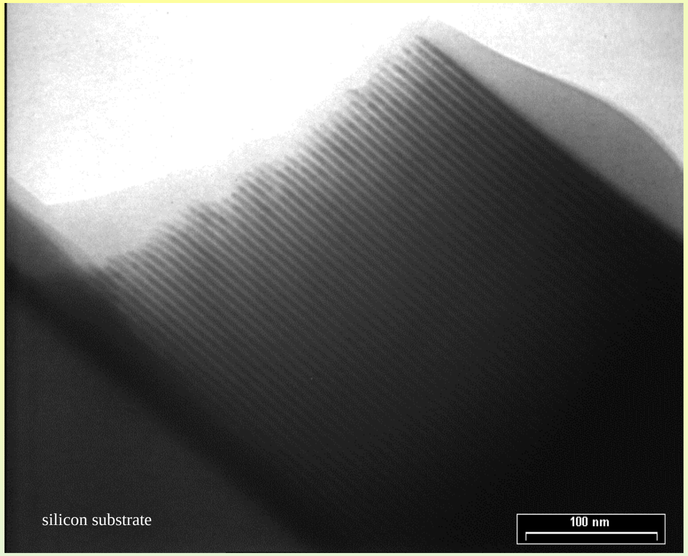
elementary processes at substrate , plasma methods :

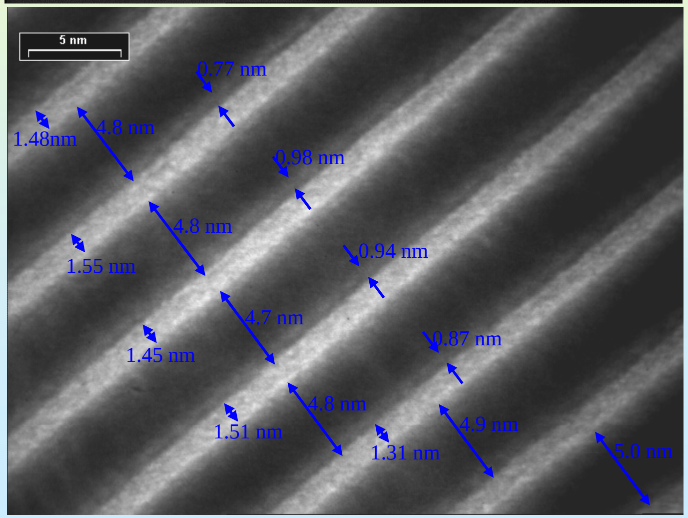


- chemical methods (CVD, MOCVD)
- physical methods : PECVD, *PVD*
- PVD : evaporation, *plasma*, ions
- plasma : PSP, IP/PL, PP, ME

applications

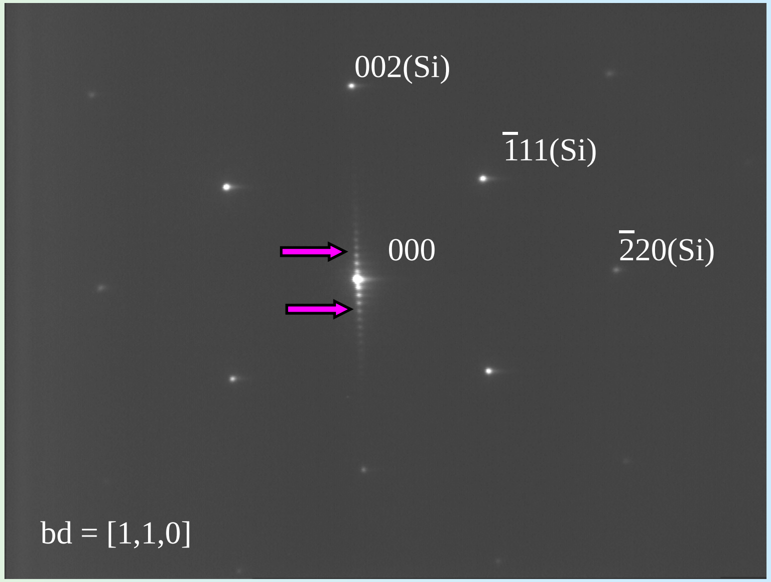
deposition of multilayers for optical components





TEM bright field image of Mo/Si Multilayer

TEM diffraction pattern of Si with Mo/Si Multilayer



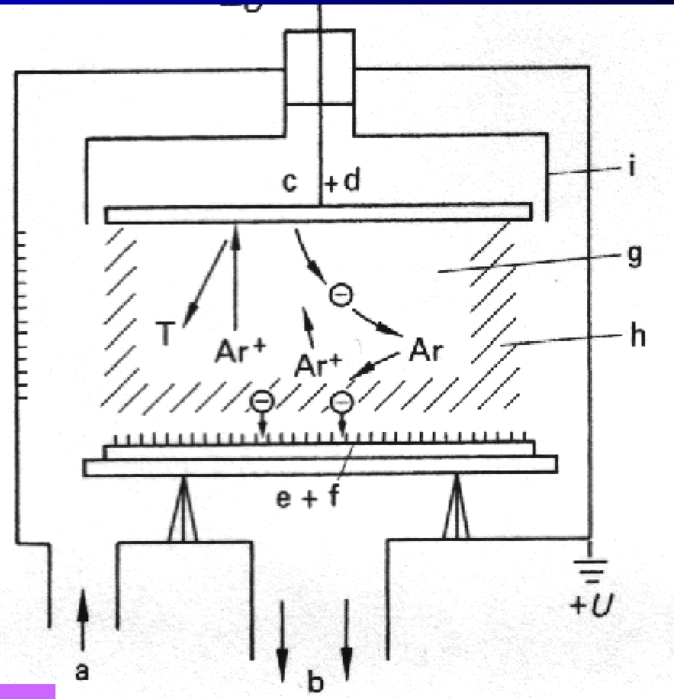
Results

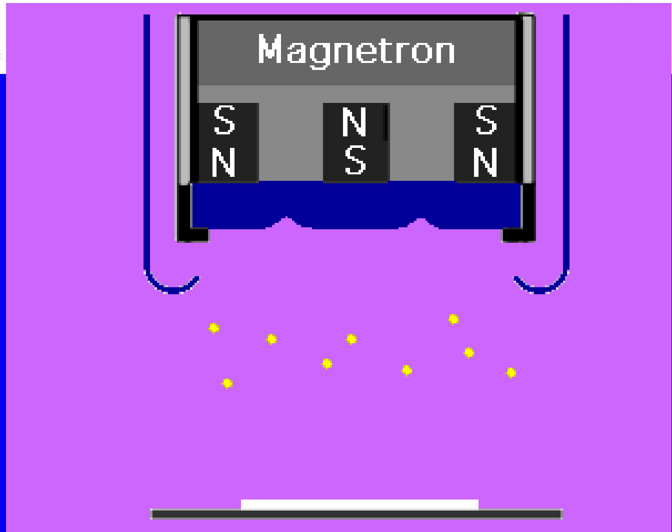
- Deposition of Mo/Si multilayers for 13.4 nm X-ray radiation at **CYBE-RITE** equipment **of *unaxis Deutschland GmbH***
- 50 Periods of 2.7 nm Mo / 4.0 nm Si on 6” Si wafers
- Very **promising reproducibility of film thickness**
- **Stabile superperiodicity of 6.7 nm** seen from TEM photographs and TEM diffraction patterns
- **Film roughness of 0.17 nm**

Sputtering (PSP) for thin film deposition / coating

principle of dc cathode sputtering, diode system

a gas flow
b pump
c cathode
d target
e anode
f deposited layer
g cathode fall
h positive column
I screening, shield





magnetron system (E X B)

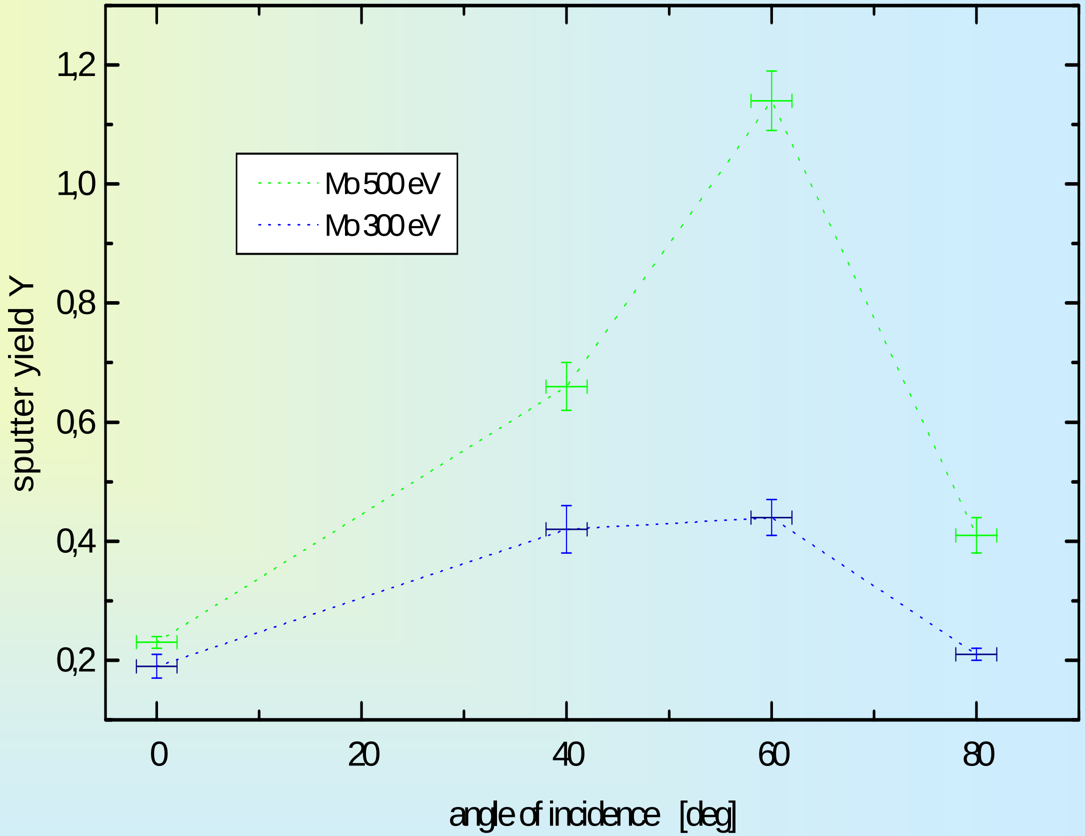
physical sputtering (PSP) :

Collision cascades create:

- Sputtered target material
- Backscattered ions
- Implanted ions
- Damages in the target material

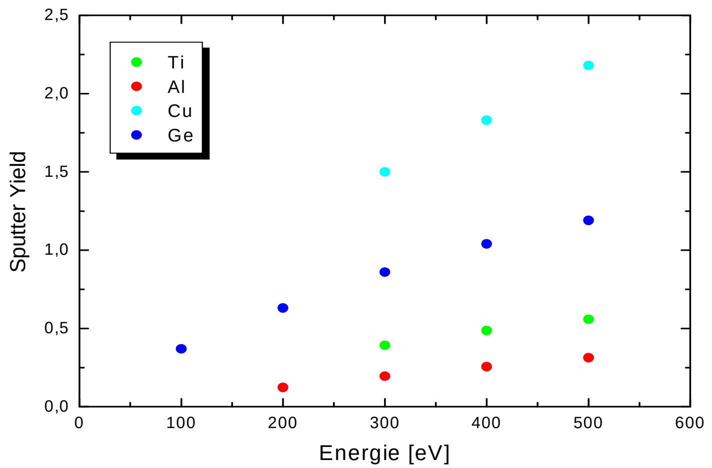
Sputter yield depends on:

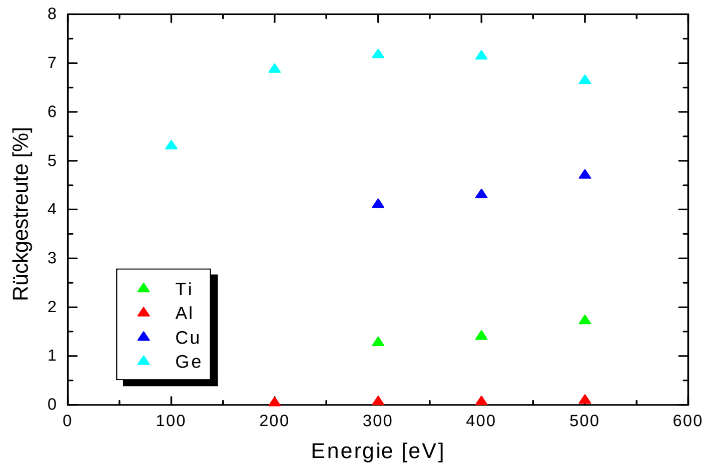
- Surface binding energy of the target
- Reduced mass of ion / target material
- Ion energy
- Angle of incidence of the ion
- Chemical surface conditions

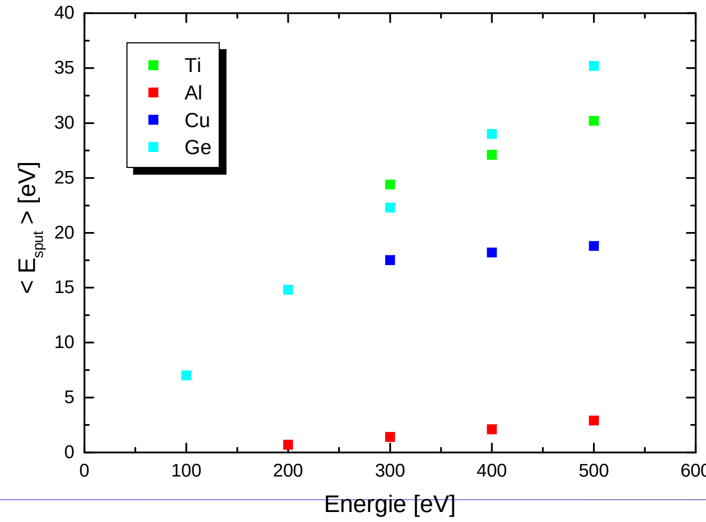


Ion beam sputter yields of Mo with Xe^+ at different angle of incidence

physical sputtering (PSP) :

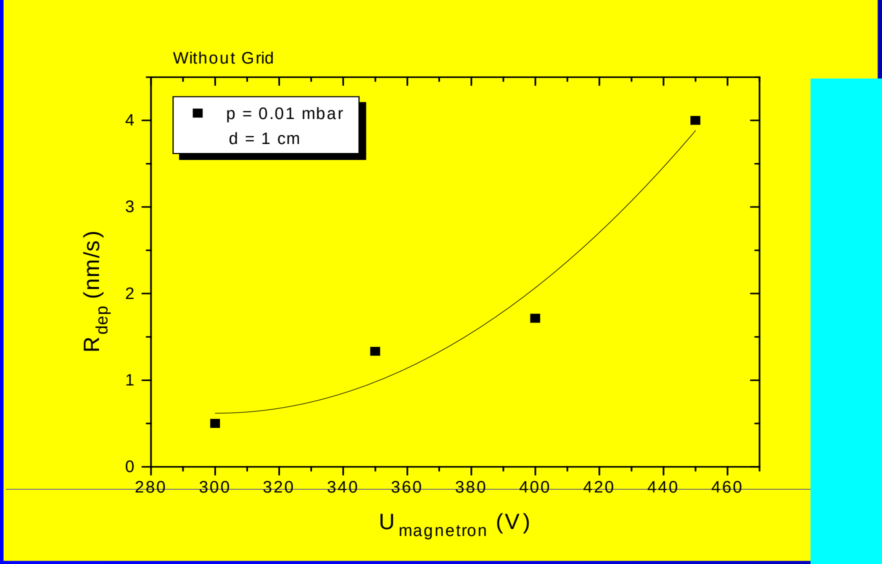




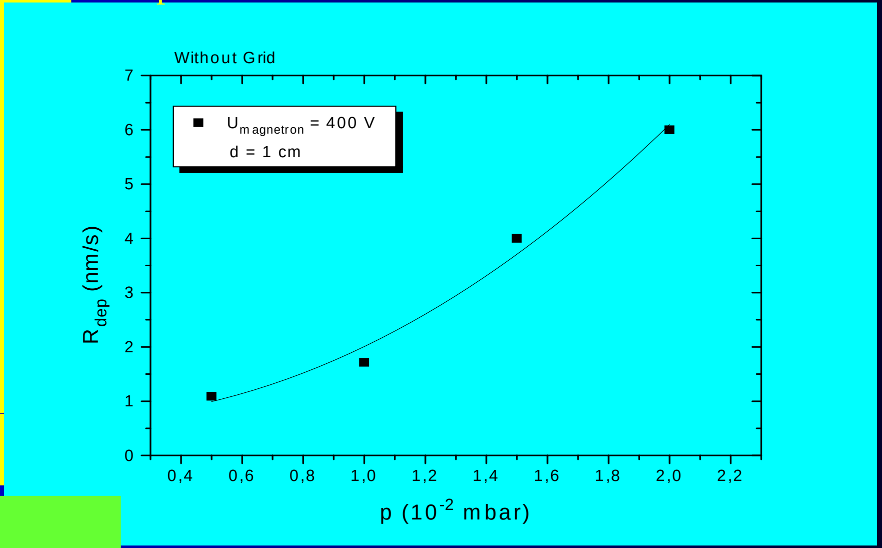


simulation
of sputtering
(TRIM) :
dependence on target material

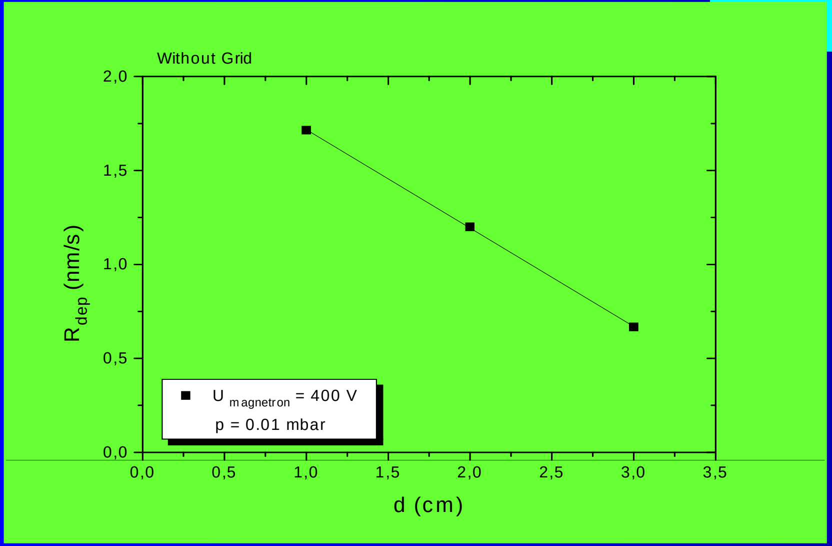
physical sputtering (PSP) :



R_{dep} = f(U) p, d = const.

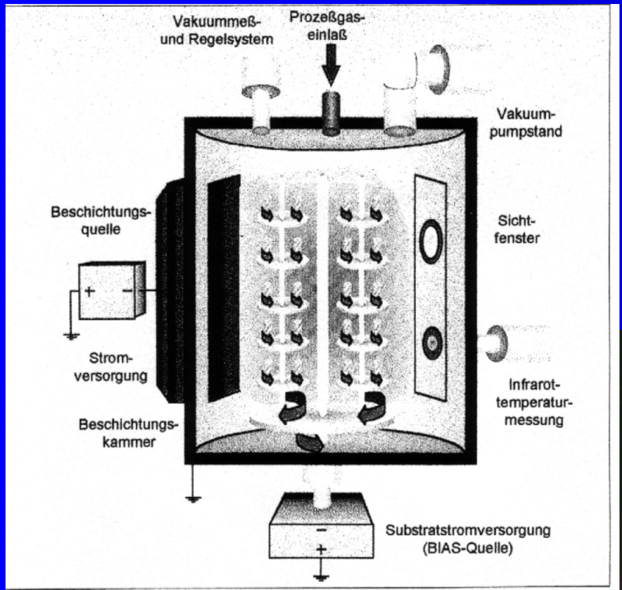


R_{dep} = f(p) U, d = const.



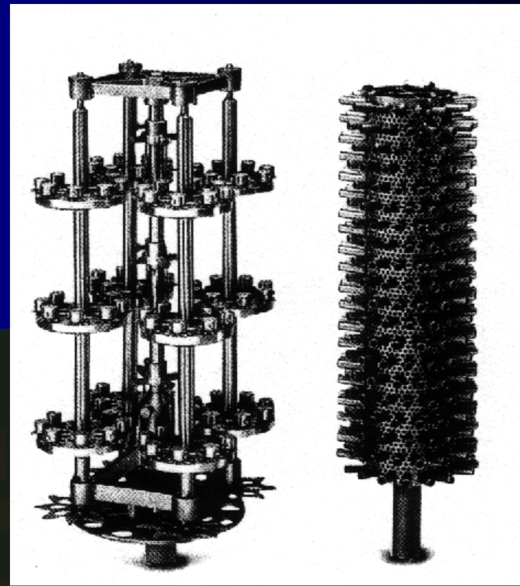
R_{dep} = f(d) p, U= const.

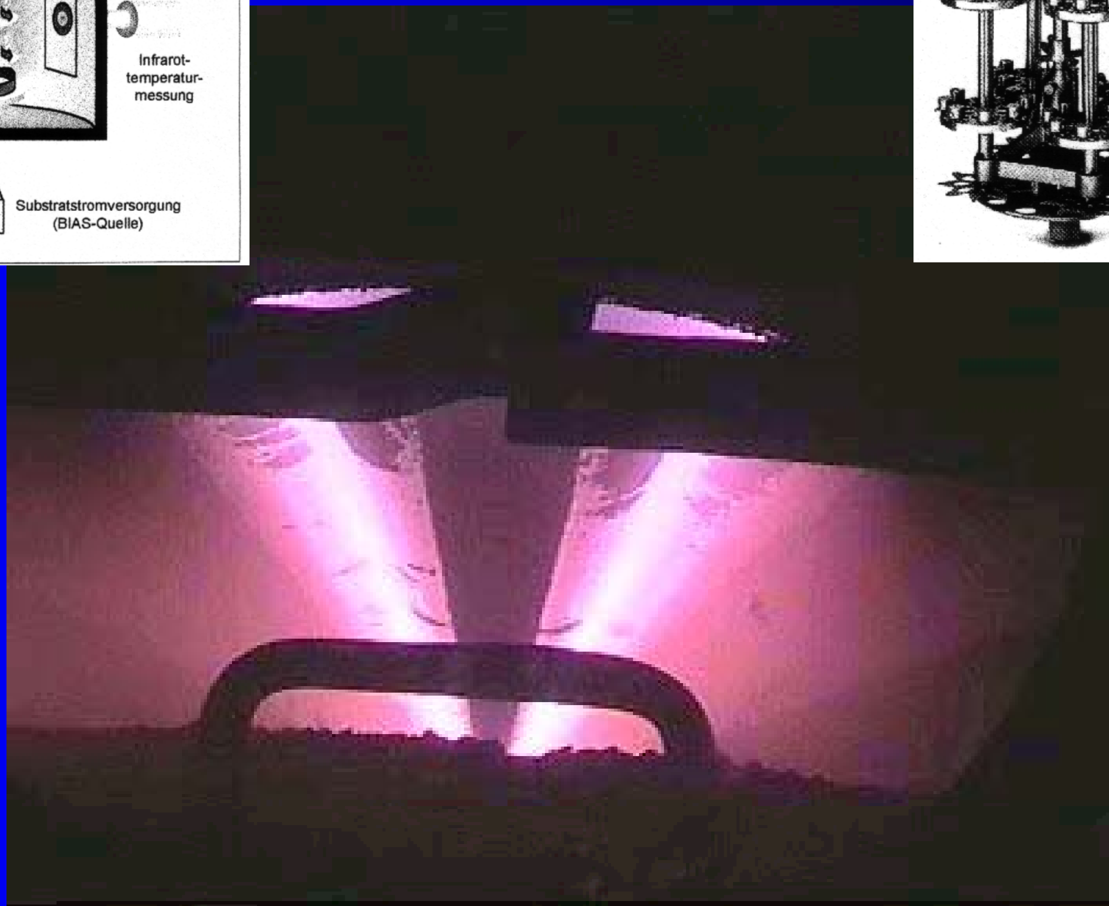
arrangement of substrates



roundabout

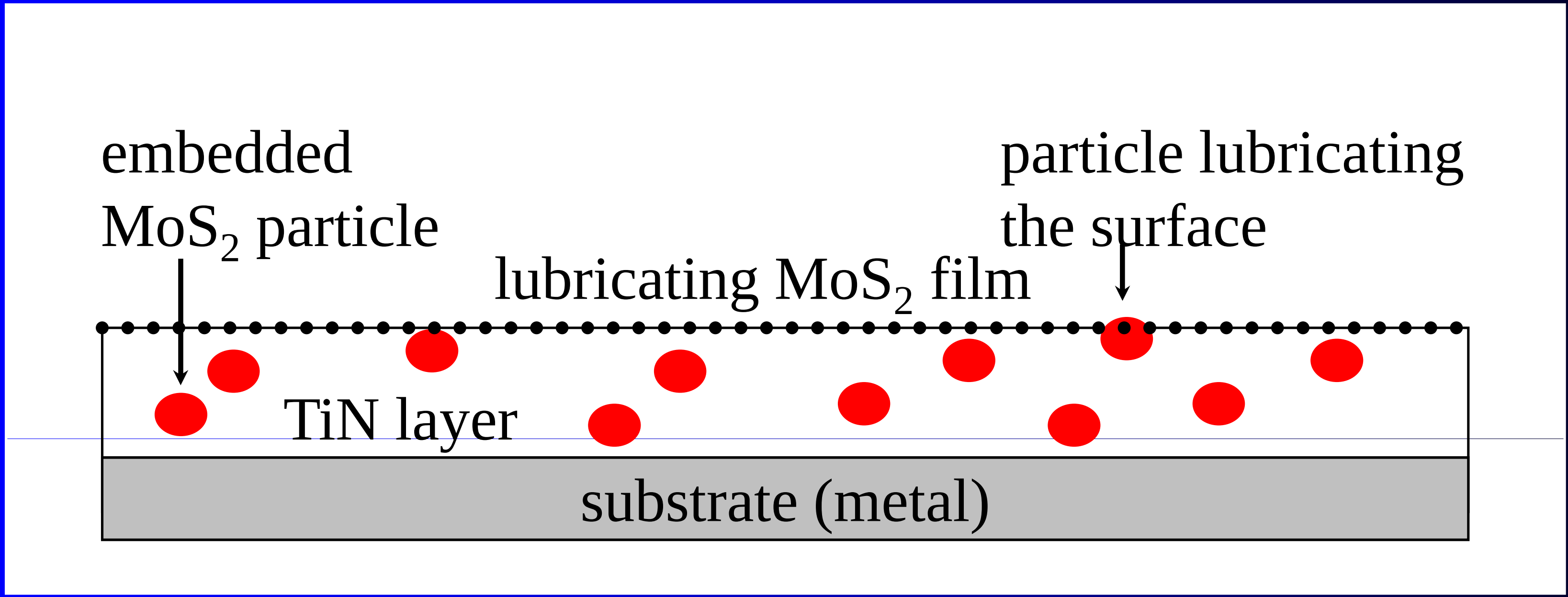
holder





conveyor belt

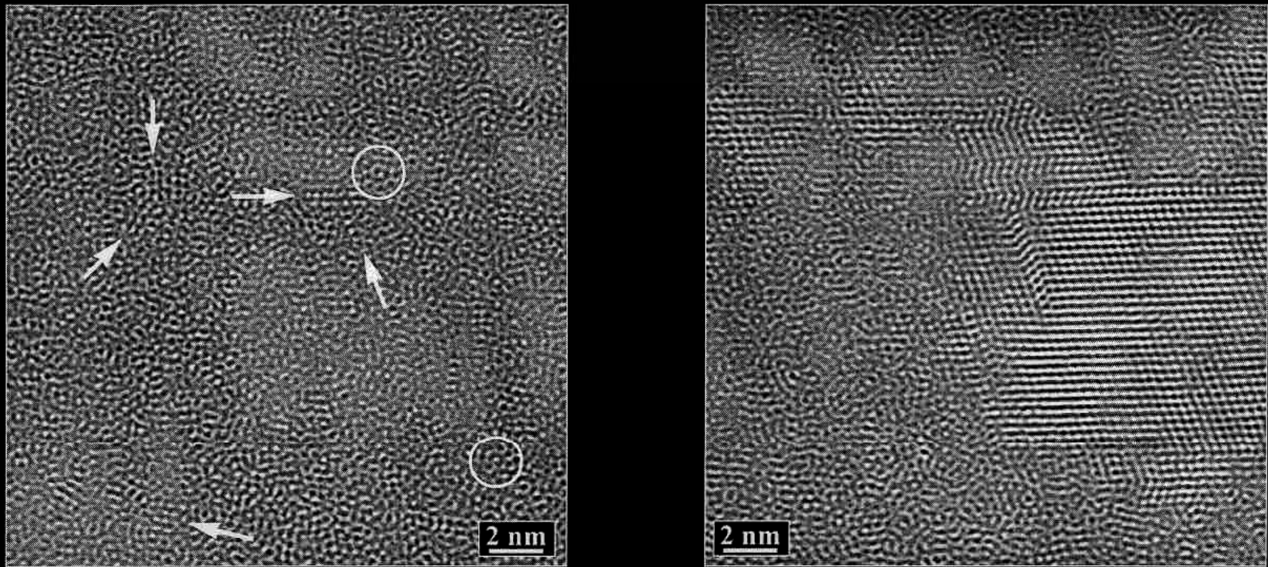
PECVD of self-lubricating coatings



- small grains of lubricant are included in the hard matrix
- when surface is exposed to friction and wear, small amounts of lubricant are released to form a thin protective film over the surface
- such hybrid coatings are both effectively lubricated and environmentally clean
- e.g. MoS_2 particles in TiN layer

E. Stoffels et.al., J.Appl.Phys. 86(1999), 3442.

PECVD of nanocrystallites in amorphous Si for solar cells ...



Characteristics of Si films deposited at 50 °C (2% SiH_4 in H_2)

(left) as prepared: ring-like and fringe-like contrast features

(right) in-situ heating to about 425 °C: beginning of crystallization

P. Roca i Cabarrocas, H. Hofmeister et al.

- incorporation in amorphous Si matrix
- precursors in re-crystallization of the film
- high degree of microstructure
- enhanced annealing stability
- reduced defect density

... polymorphous solar cells

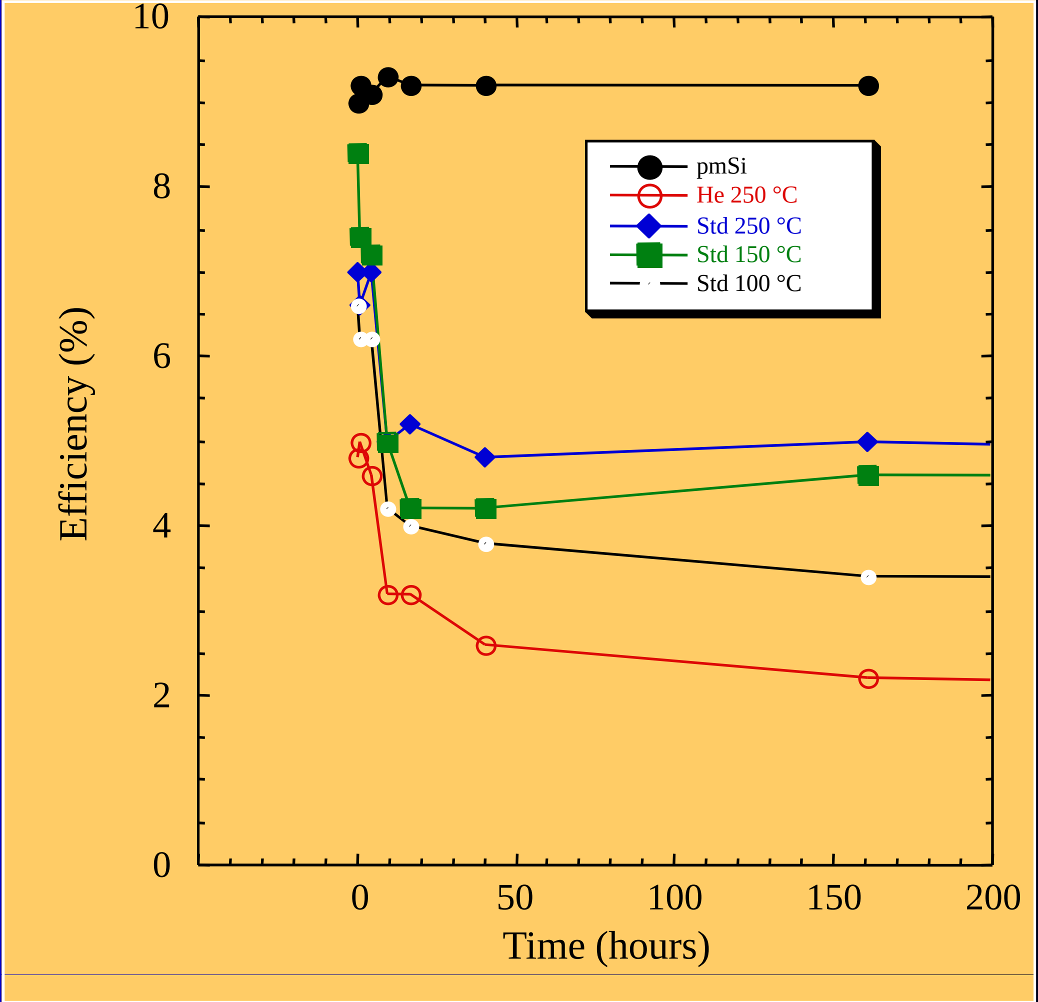
- higher mobility,
  improved transport properties
- higher efficiency
- long term stability

⇓

new solar cell with

better photon yield

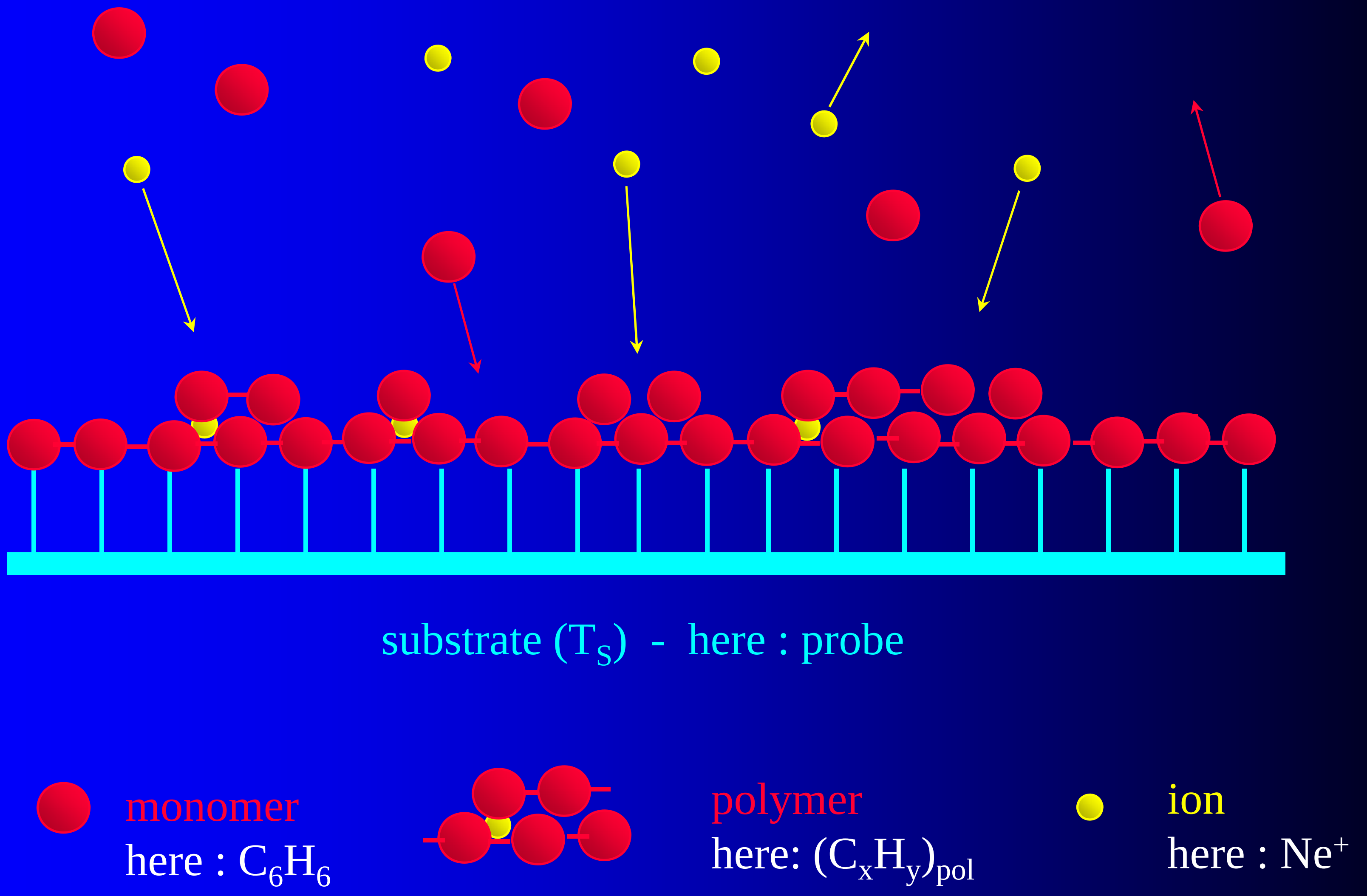
(potential for future)



Roca,Y.Cabarocas et.al.J.Vac.Sci.Technol.A14/2(1996), 655.

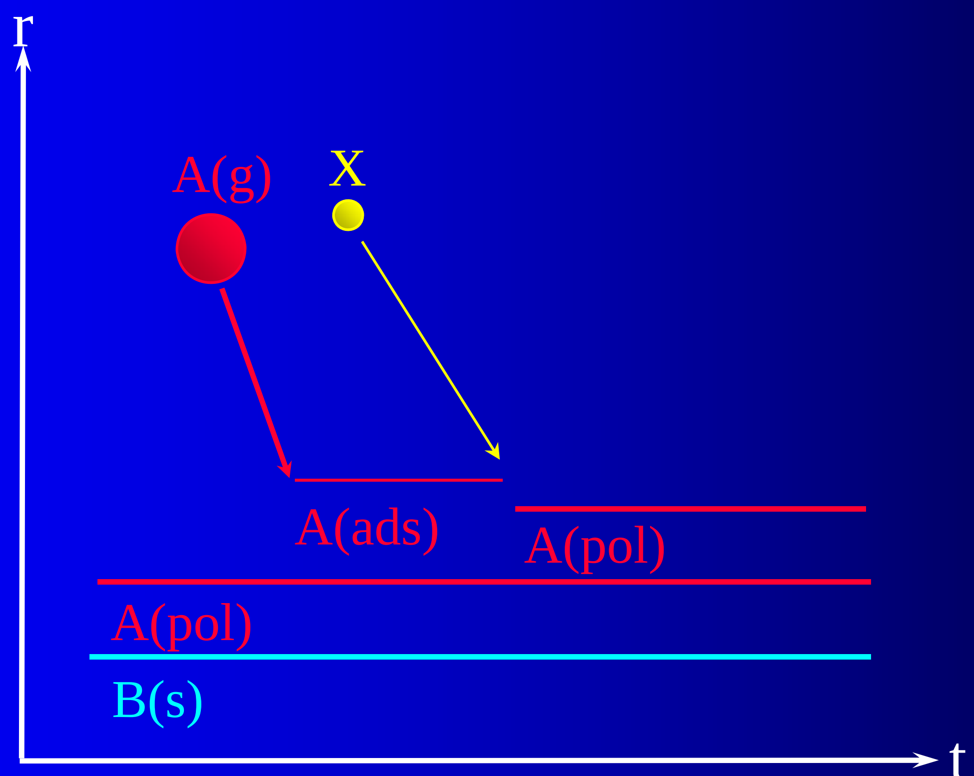
example : plasma polymerization

(cross-linking by ions)



$$A(g) + A(pol) \underset{\tau}{\overset{\gamma}{\rightleftharpoons}} A(ads) + A(pol)$$

$$A(ads) + X \overset{P}{\longrightarrow} A(pol)\ (+\ X)$$



$\gamma = \text{const.}$ $\tau = \tau^0 \exp\{-E_{des}/kT_S\}$ $P = n_0\Theta\sigma\, j_i / e_0$

model :

$$A(g) + A(pol) \underset{\tau_{des,A}}{\overset{\gamma_A}{\rightleftarrows}} A(ads) + A(pol)$$

$$A(ads) + X — P \longrightarrow A(pol)\ (+\ X)$$

$$\frac{d\, n_{ads,A}}{d\, t} = \gamma_A j_A (1-\Theta_A) - n_{ads,A} / \tau_{des,A} - n_{ads,A} \sigma_{pol,A}\, j_X = 0$$

$$\frac{d\, n_{pol,A}}{d\, t} = n_{ads,A} \sigma_{pol,A}\, j_X = n_0 \Theta_A \sigma_{pol,A}\, j_i / e_0 = \mathbf{P} \qquad \mathbf{W_{pol} = \frac{M_{pol}}{L\rho_{pol}} P}$$

$$P = \frac{n_0 \sigma_{pol,A} \gamma_A\, j_A\, j_X}{\gamma_A\, j_A + n_0 (1/\, \tau_{des,A} + \sigma_{pol,A}\, j_X)}$$

low T_S $(\Theta_A \sim 1)$ $\longrightarrow$ $P = n_0 \sigma_{pol,A}\, j_X \sim$ const.

high T_S $(\Theta <<1)$ $\longrightarrow$ $P = \sigma_{pol,A} \gamma_A\, j_A\, j_X\, \tau_{des,A}{}^0 \exp(E_{des,A}/kT_S)$

measurement : $\mathbf{W_{pol} \sim d\, R_{pol} / d\, t \sim f(T_S)}$

experiment :

plasma : I = 30mA, p_{Ne} = 133Pa, p_{C6H6} = 6.7Pa

substrat : heated probe r_p = 13µm, l_p = 8mm

measurement : $\mathbf{W_{pol} \sim d\,R_{pol} / d\,t \sim f(T_S)}$

(resistance of the polymer layer at different temperatures)

measurement by the change of the floating potential :

$$\frac{d}{dt}\left|\frac{\Delta U_{fl}}{U_{fl}}\right| = 1/R_E\,(d\,R_{pol} / dt) \qquad \text{if} \quad R_p < R_{pol} << R_E$$

$$= 1/R_E\,(\rho_{pol} / (2\pi l_p r_p)\,W)$$

$$\text{mit} \quad \rho_{pol} = \rho_{pol}^{0}(1+\alpha\Delta T_S)$$

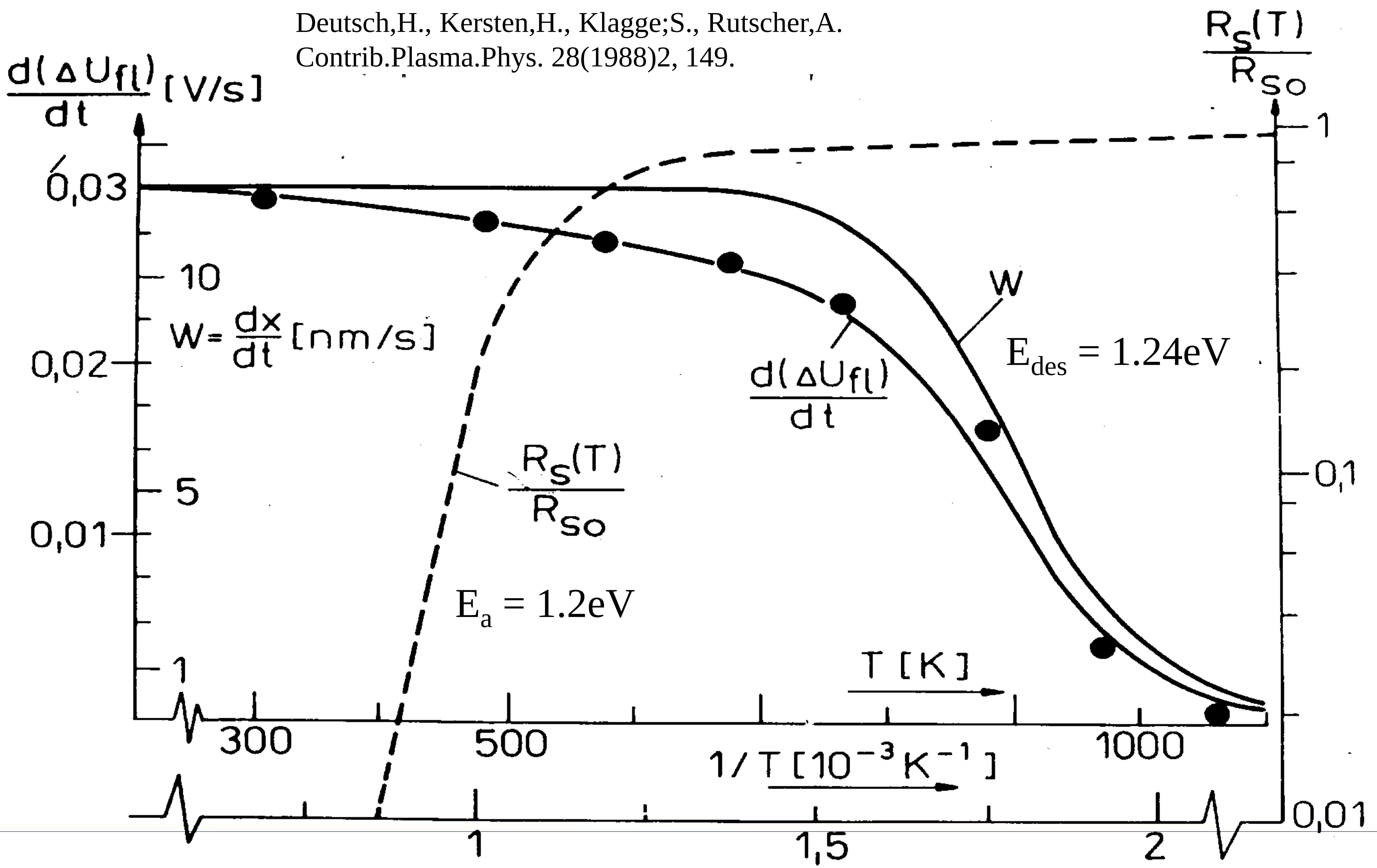
$$(\rho_{pol}^{0} = 2*10^{9}\Omega\text{cm}, \;\; \alpha = -3.5*10^{-4}\text{K}^{-1})$$

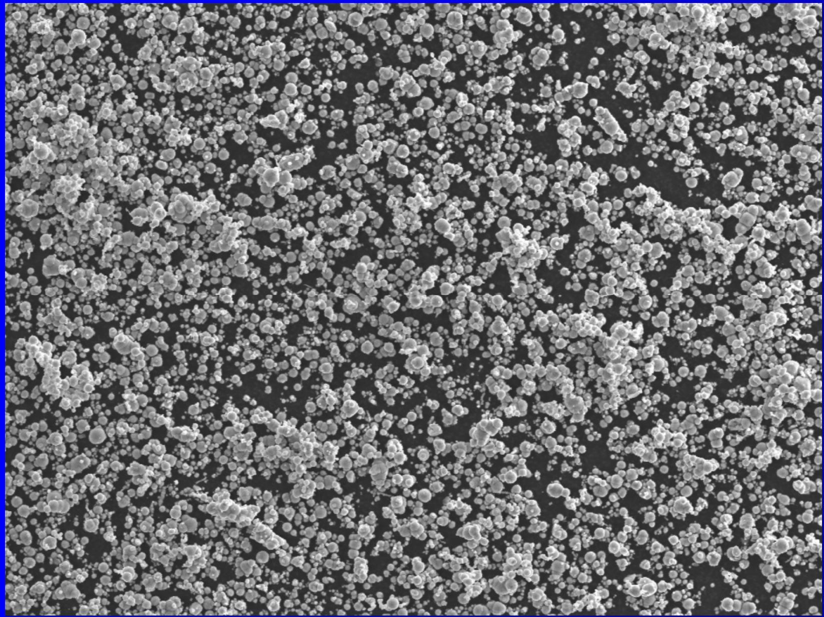
measurement by the film resistance of the probe before and after polymerization :

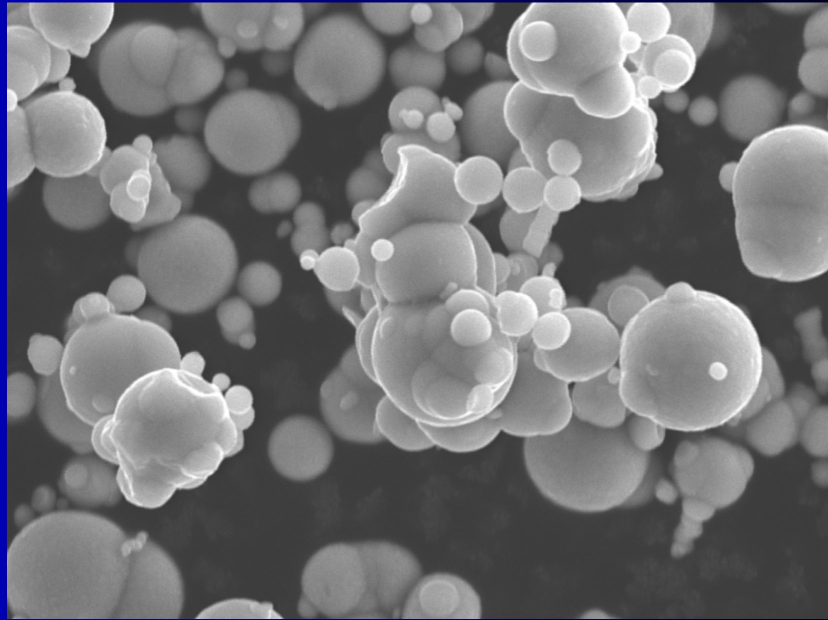
$$d\,R_{pol} / dt = \frac{(d\,I_p / d\,U_p)^{-1}(t) - (d\,I_p / d\,U_p)^{-1}(t=0)}{\Delta\,t}$$

model and experiment : plasma polymerization

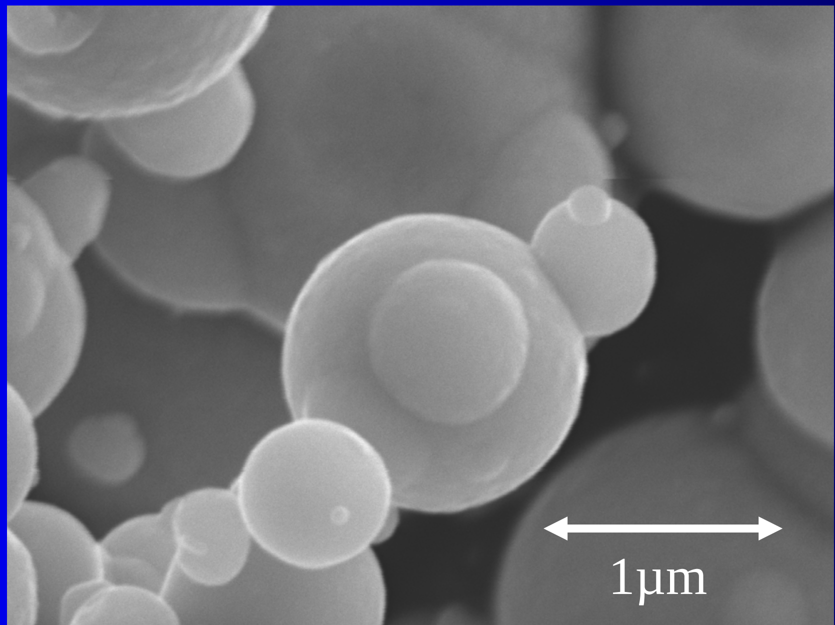
Deutsch,H., Kersten,H., Klagge;S., Rutscher,A.
Contrib.Plasma.Phys. 28(1988)2, 149.





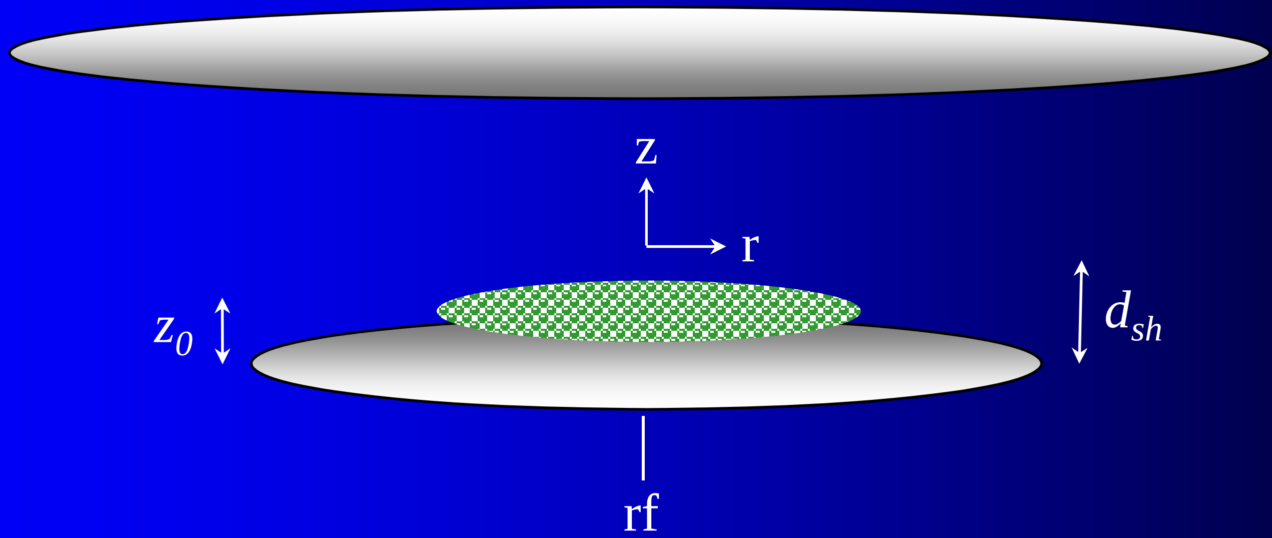


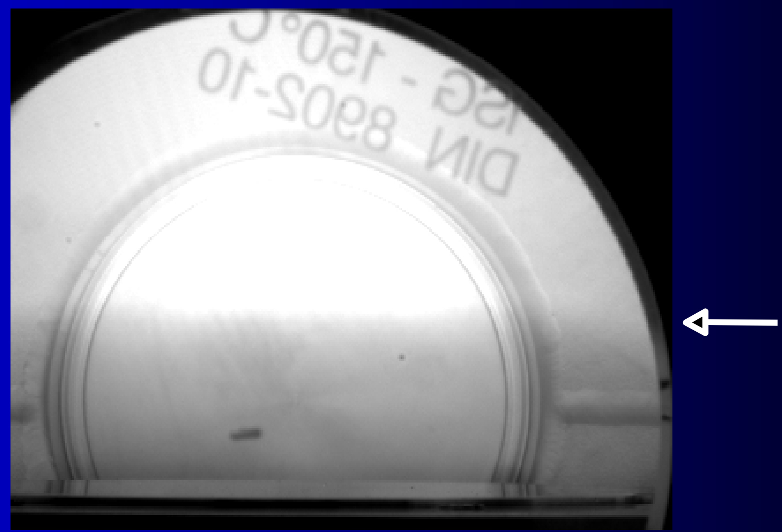
original particles
(e.g. c-Fe)



at positions, where $F_{ges} = \Sigma F_x = 0$, the particles are confined

→ dust particles are confined in plasma





modification of powders in plasma

goal : to tailor particle properties for specific purposes
(size, shape, chemical activity, optical properties, ...)

e.g. for

- chemical catalysis (large specific surfaces)
- improvement of optical properties of powder particles, pigments
- surface treatment in respect to powder sintering

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here : coating of Fe particles (~2µm) with Al (~70nm)
by an rf-discharge (charging and confinement)
and dc-magnetron sputtering

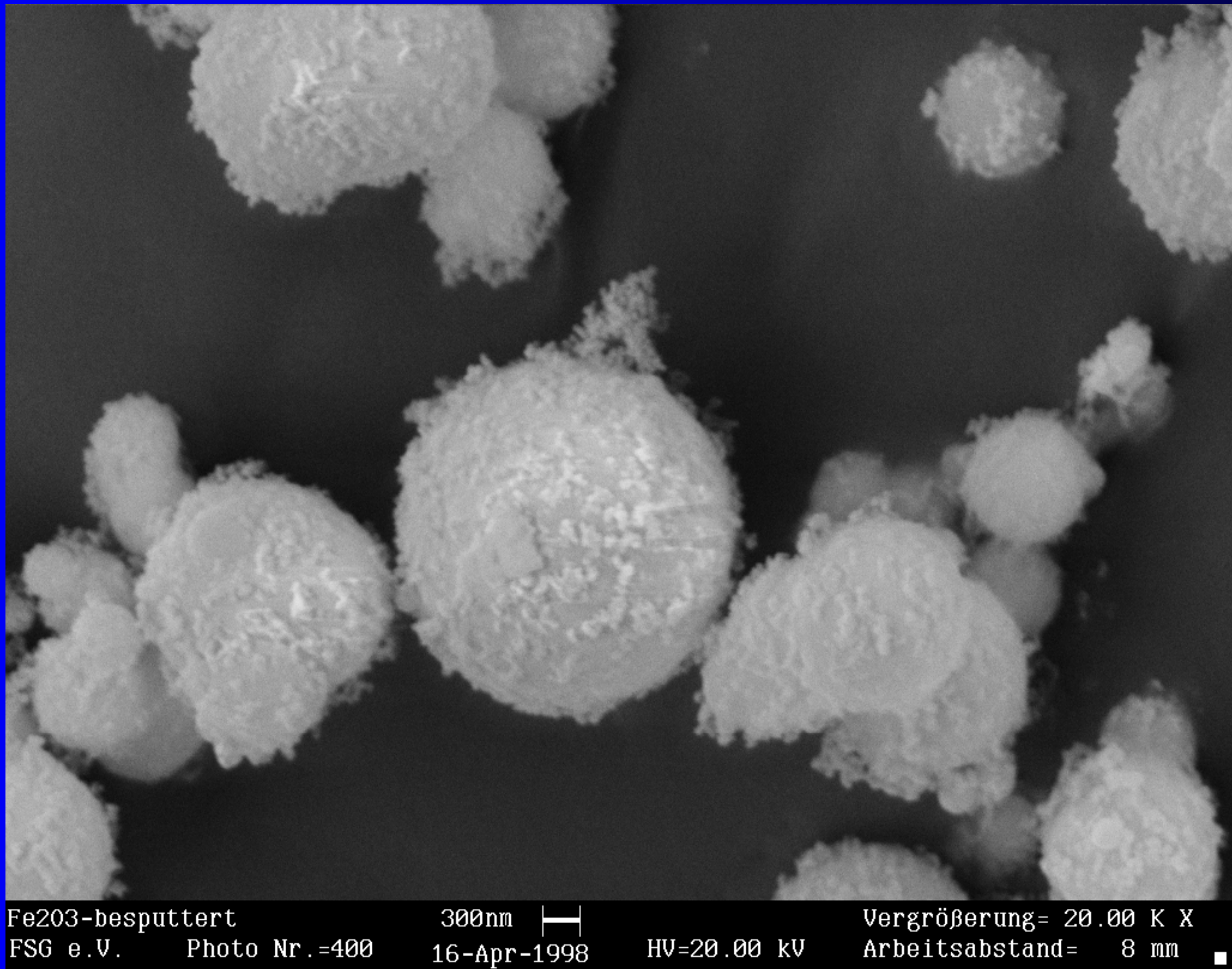
feasibility ?
functionality ?
efficiency ?
etc. ?

treated powder particles

Al onto Fe, 150 … 200nm, compact coating

Kersten,H., Schmetz,P., Kroesen,G.M.W.,
Surface and Coatings Technology 108-109(1998), 507.

c-Fe powder, partly coated by Al



deposition of Al (< 50nm) onto particles

⇨ islands on each particle

⇨ change of chemical properties (catalysis)