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ASTeC

Optimization of non-evaporable getter coating for accelerator beam pipe

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Outlook

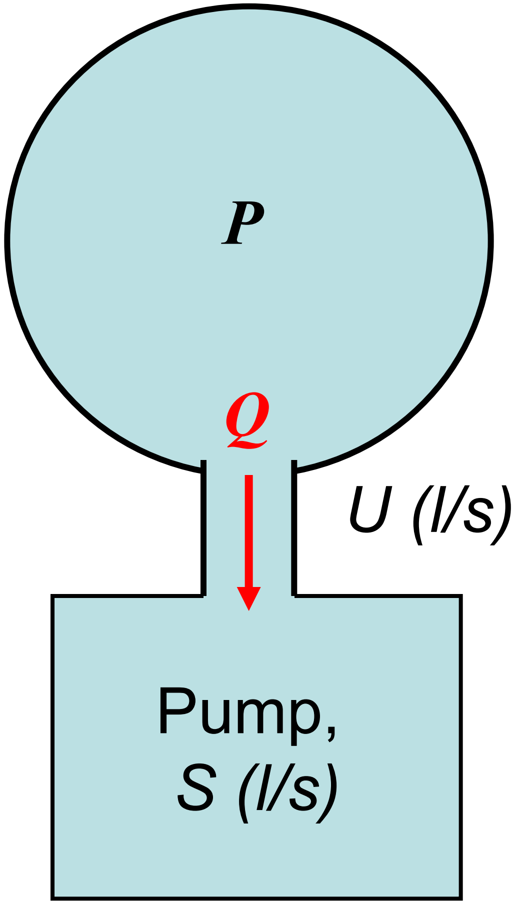
- Introduction
  - What is NEG coatings
- Pumping property
  - Film deposition
  - Surface analysis
  - NEG activation procedure
  - Pumping properties measurements
  - Activation temperature
  - Sticking probability and capacity for different NEG coatings
- Desorption properties
  - How to reduce ESD
  - What film is needed
  - What achieved
- Conclusions

What are usual considerations for vacuum

Required pressure P is defined by gas desorption Q in the vessel and effective pumping speed S_{eff}.

In a simple case it is

$$P = \frac{Q}{S_{eff}} = Q\left(\frac{1}{S} + \frac{1}{U}\right)$$



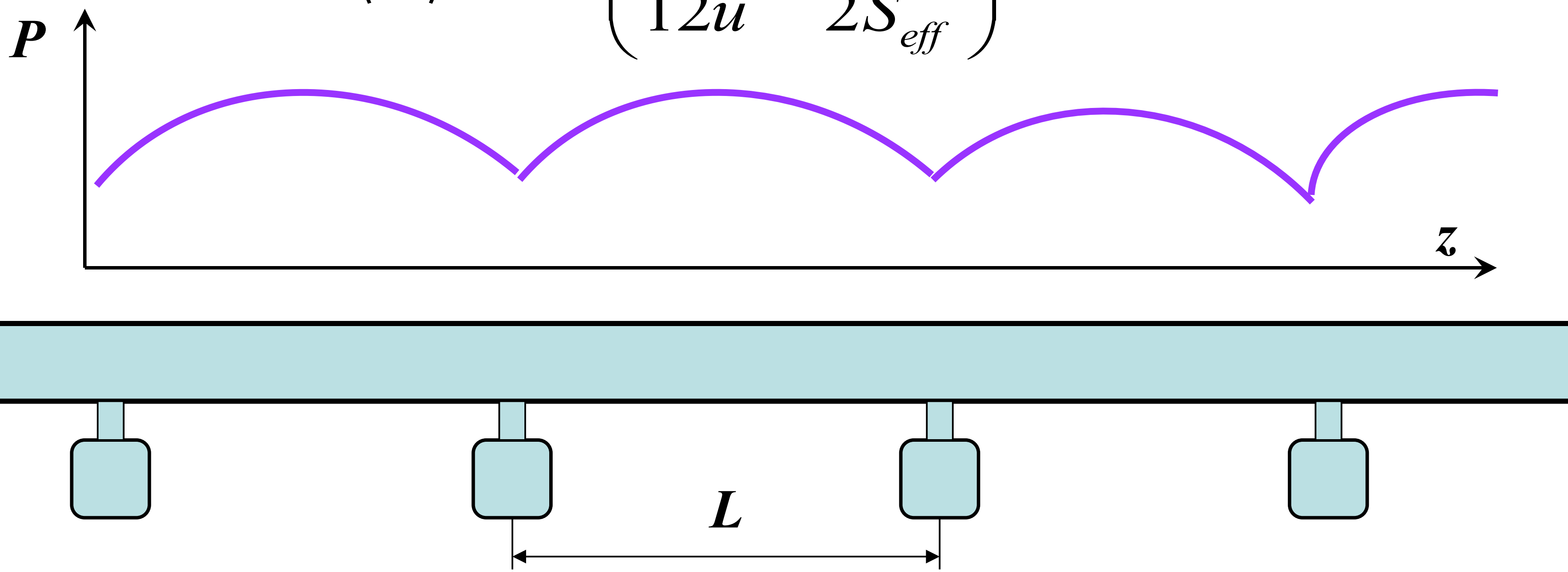
$$Q = qA + \eta_{\gamma}\Gamma + \eta_{e}\mathrm{I}_{e} + \eta_{ion}\mathrm{I}_{ion}$$

Thermal, photon, electron and ion stimulated desorption

Usual accelerator vacuum chamber

- Long tube with length ***L* >> *a*,** where *a* - transversal dimension
- Average pressure depends on vacuum conductance ***u(L,a)*** of the beam vacuum chamber

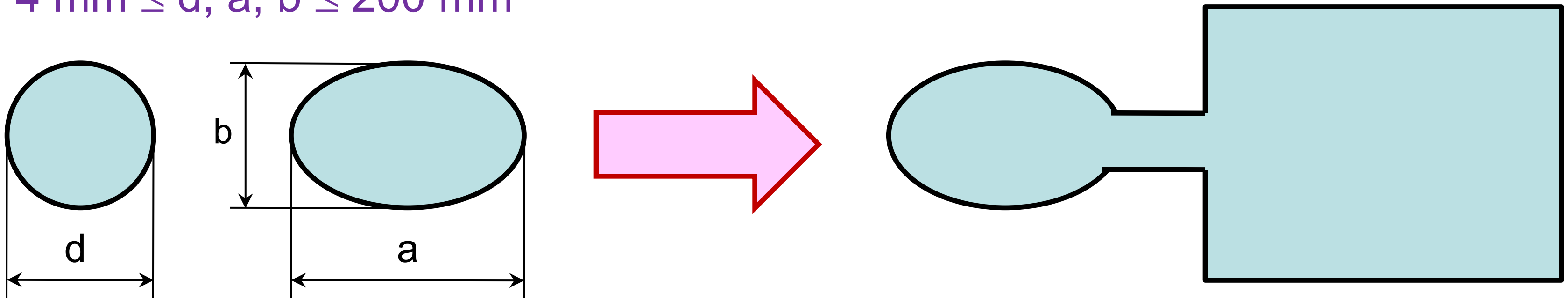
$$\langle P \rangle = qL\left(\frac{L}{12u} + \frac{1}{2S_{eff}}\right)k_B T$$



Vacuum chamber cross sections

Beam pipe
Circular or elliptical
4 mm $\le$ d, a, b $\le$ 200 mm

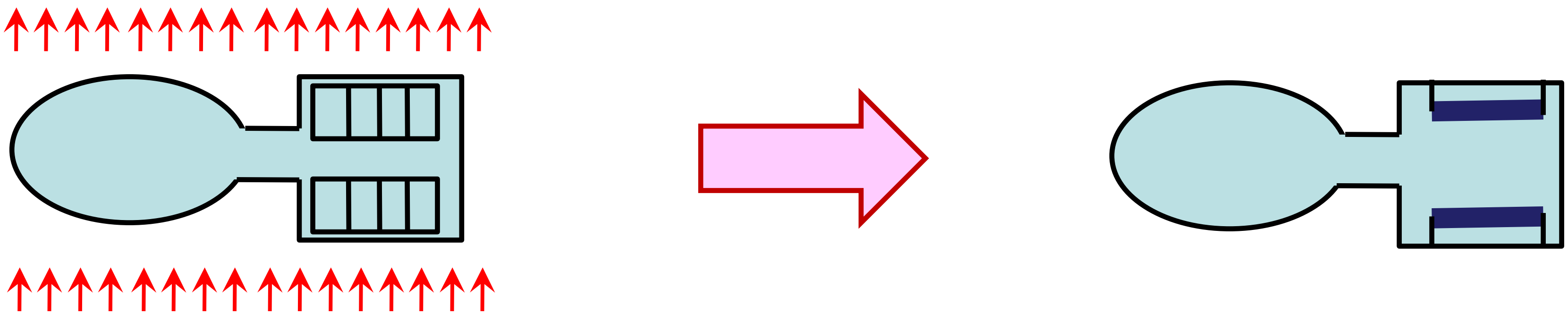
Vacuum chamber with an antechamber for larger vacuum conductance, *U*



Distributed pumping

In dipole magnetic field

With NEG strips
(LEP in CERN)



Two concepts of the ideal vacuum chamber

Traditional:

- surface which outgasses as little as possible ('nil' ideally)
- surface which ***does not pump*** otherwise that surface is contaminated over time

Results in

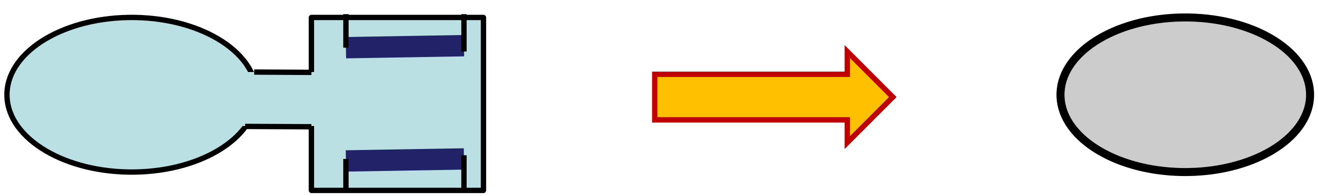
- Surface cleaning, conditioning, coatings
- Vacuum firing, *ex-situ* baling
- Baking *in-situ* to up to **300°C**
- Separate pumps

'New' (C. Benvenuti, CERN, ~1998):

- surface which outgasses as little as possible ('nil' ideally)
- a surface which ***does pump***, however, will not be contaminated due to a very low outgassing rate

Results in

- NEG coated surface
- There should be no un-coated parts
- Activating (baking) *in-situ* at **150-180°C**
- Small pumps for C_xH_y and noble gases



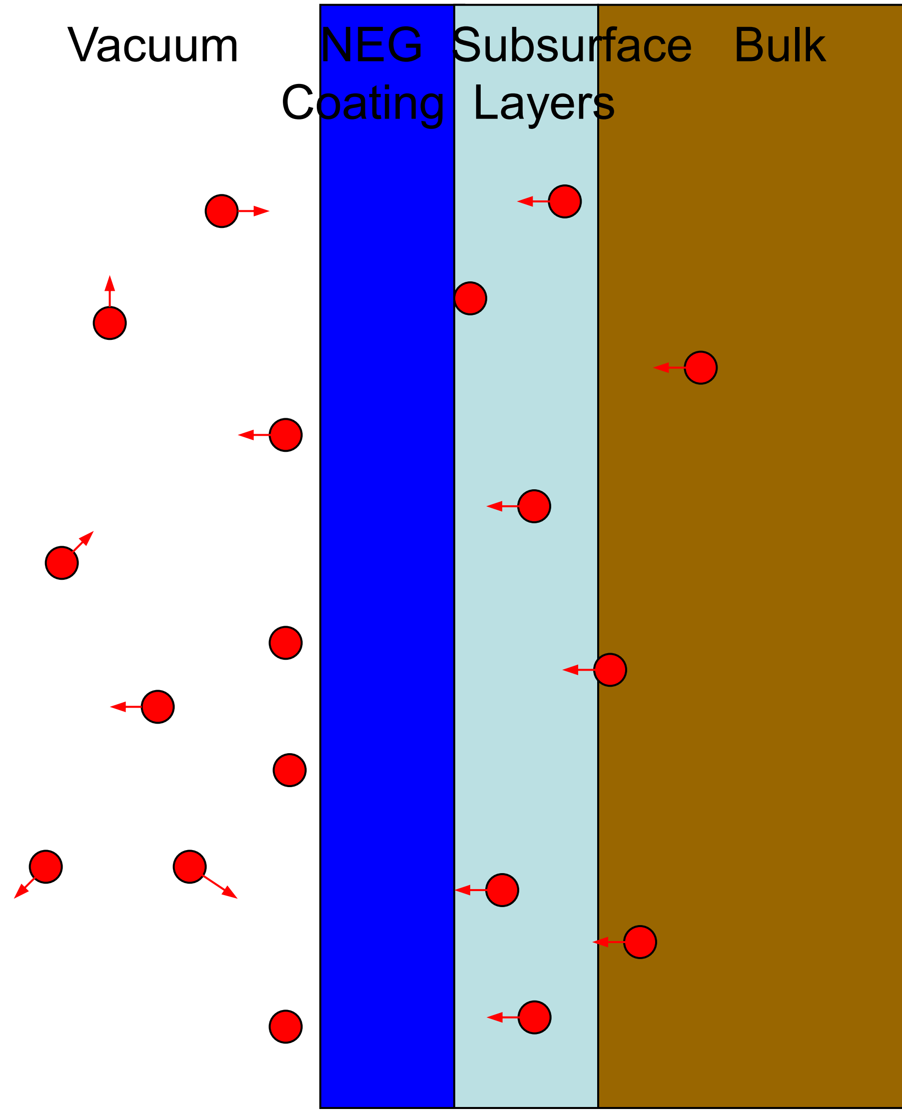
What the NEG coating does

- **Reduces gas desorption:**
  - **A pure metal film ~1-μm thick without contaminants.**
  - **A barrier for molecules from the bulk of vacuum chamber.**

- **Increases distributed pumping speed, *S*:**
  - **A sorbing surface on whole vacuum chamber surface**

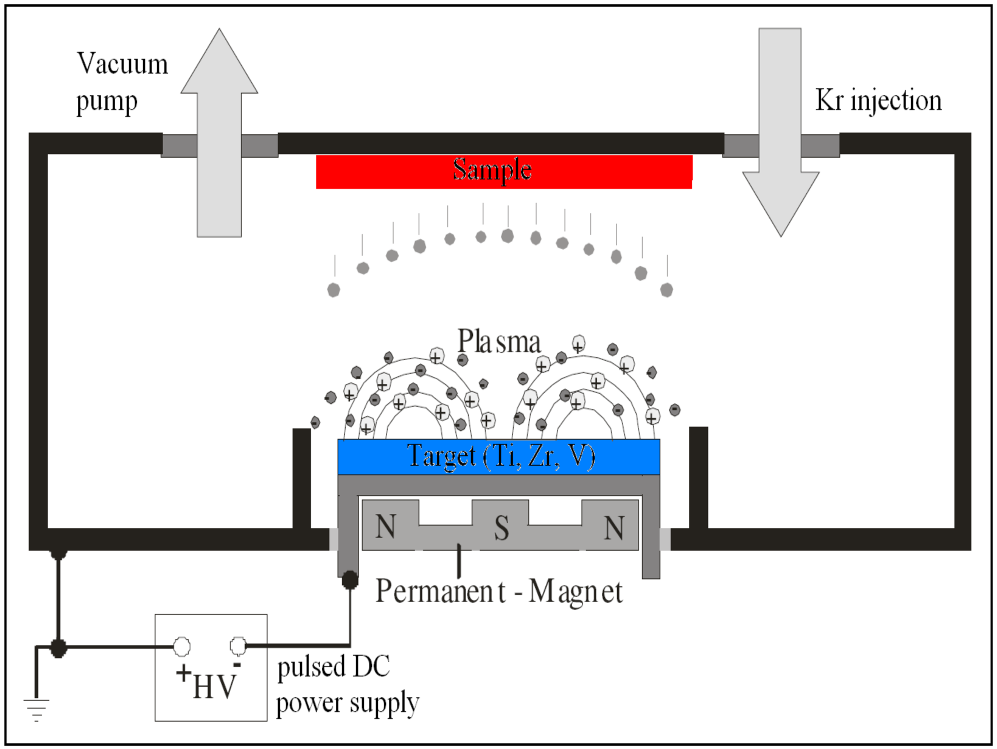
$$S = \alpha \cdot A \cdot v/4;$$

where **α – sticking probability,**
A – surface area,
v – mean molecular velocity

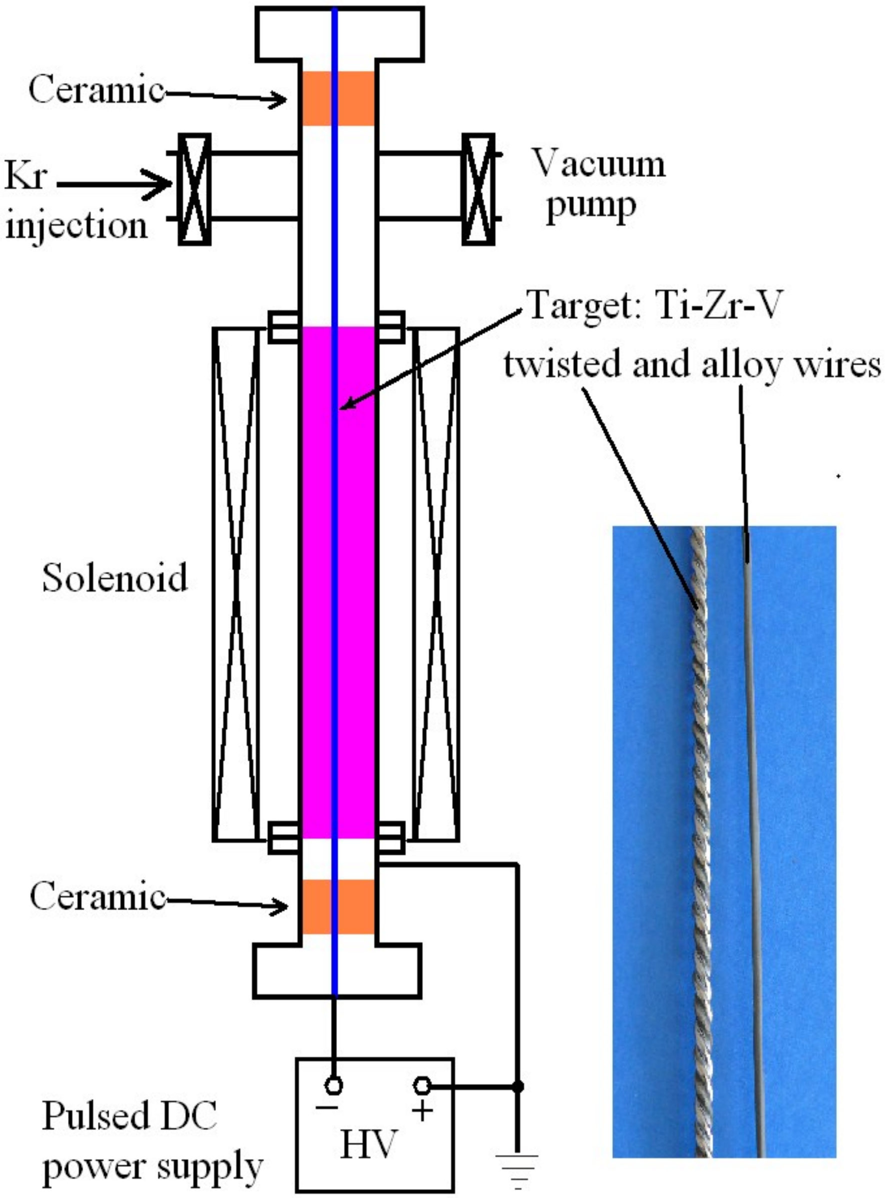


Deposition method

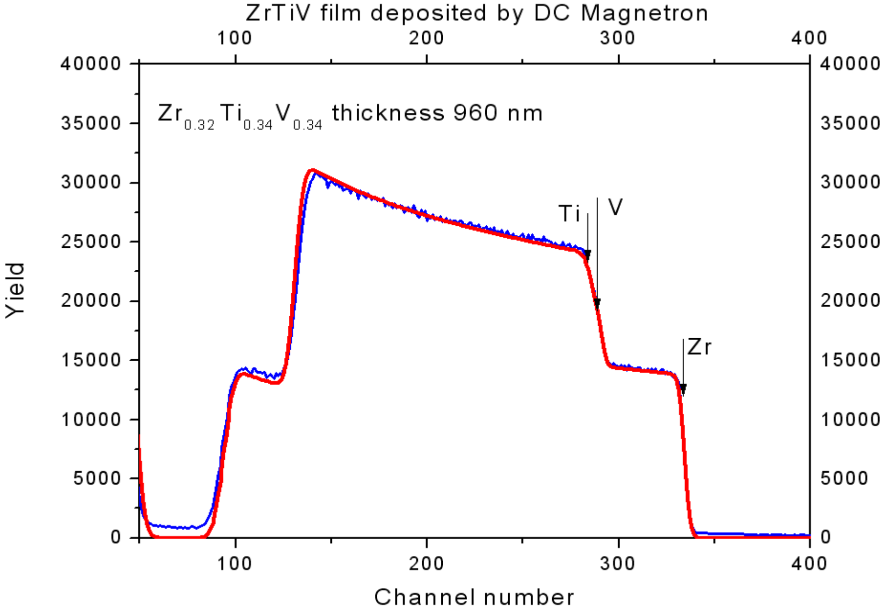
Planar magnetron deposition

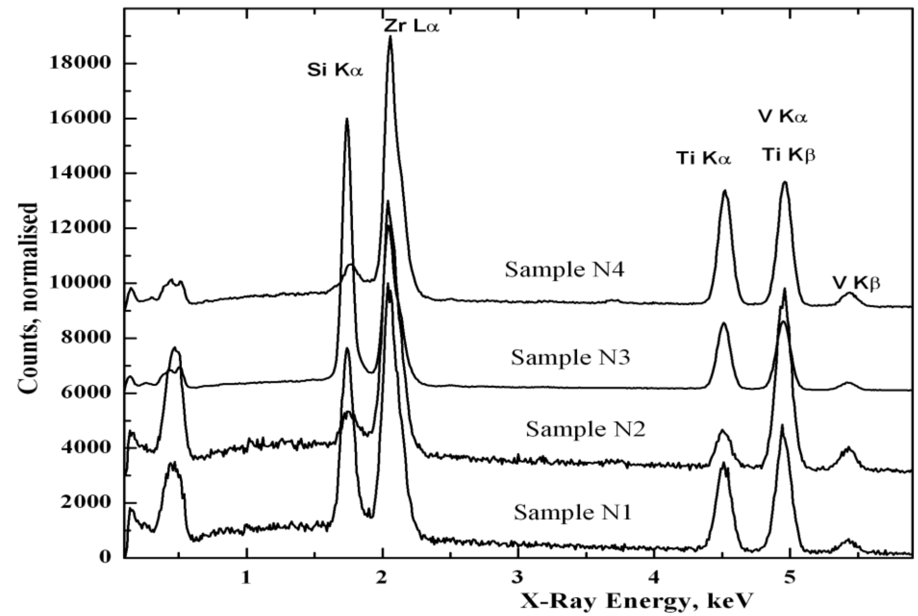


Cylindrical magnetron deposition



Bulk and Surface Composition

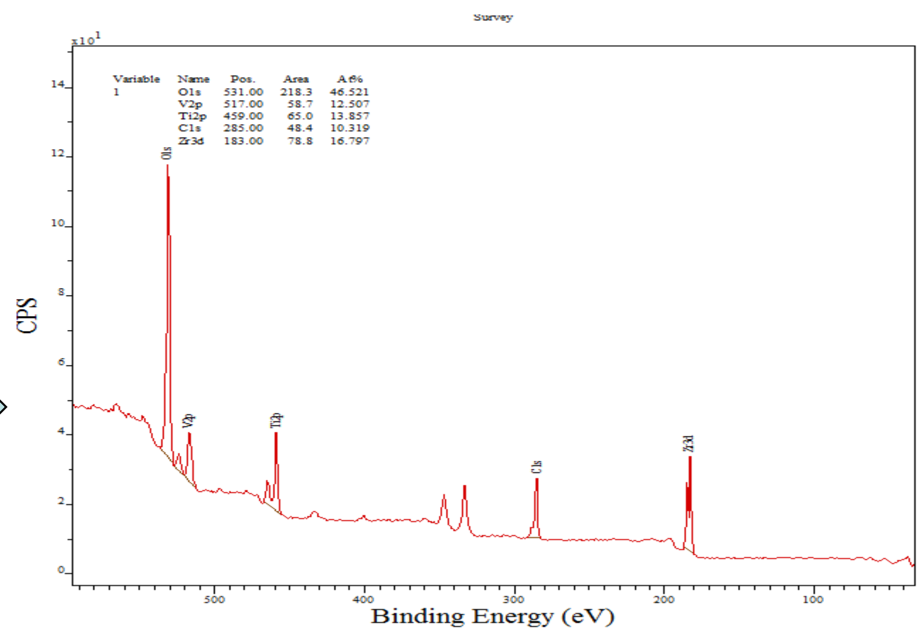




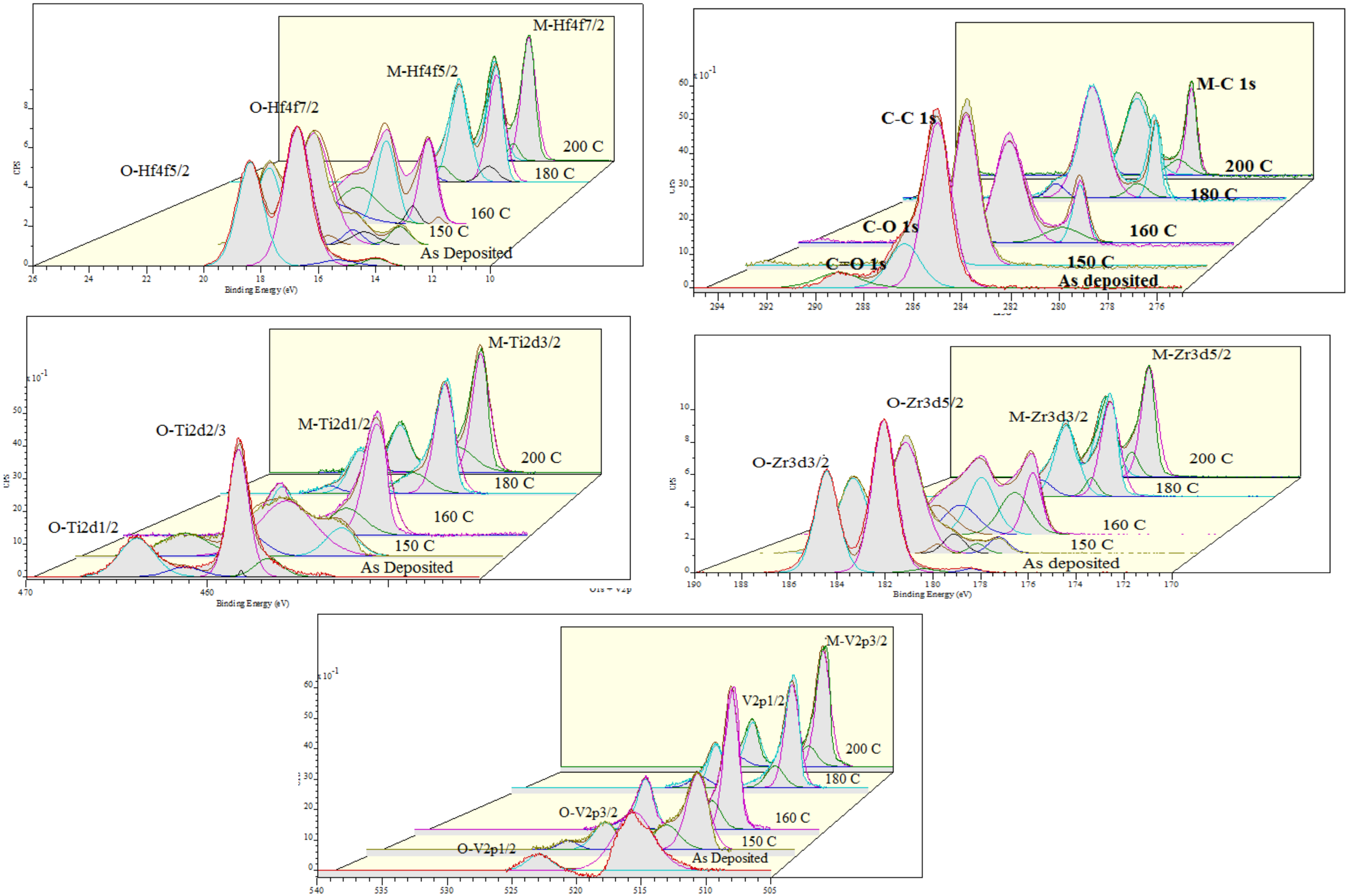
RBS (film composition in bulk)

EDX (determination of film composition)

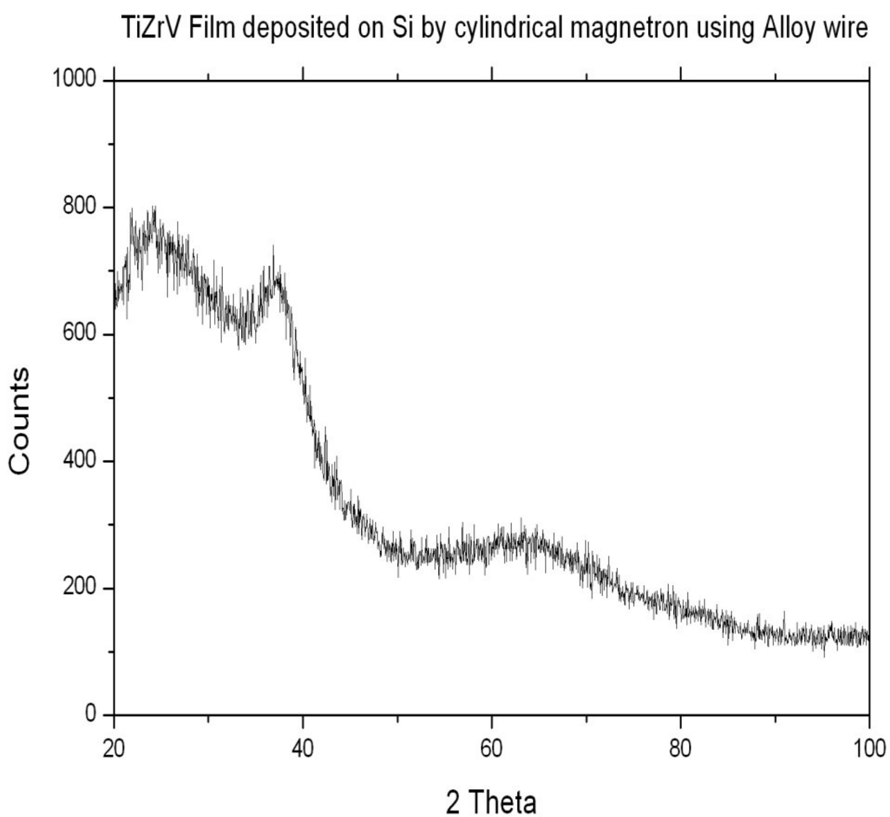
XPS (surface composition and chemical bounding)

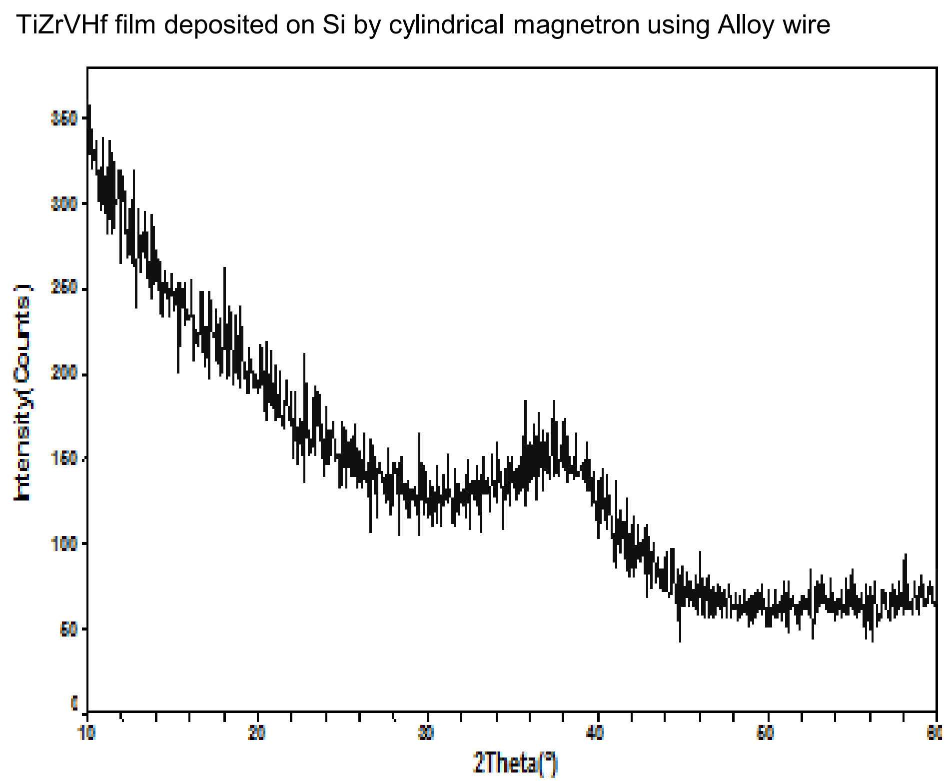


Region scan of XPS core levels of Ti, Zr, C,Hf and V of a Ti-Zr-V-Hf film (surface composition and chemical bounding)



XRD of Film deposited from Ternary and Quaternary alloy wire as target.

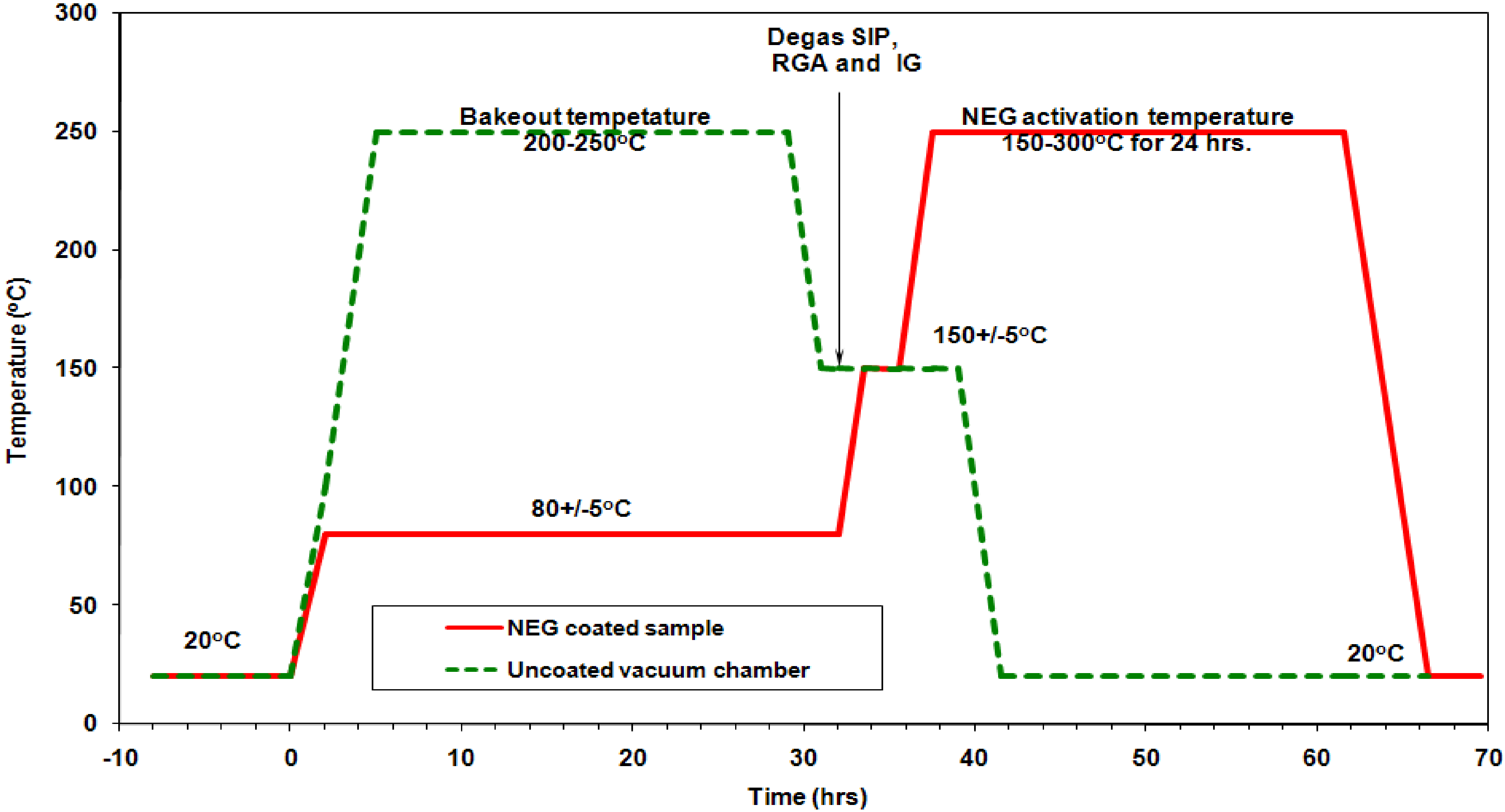




In Both cases there is only one broad peak near $2\theta = 36.8°$

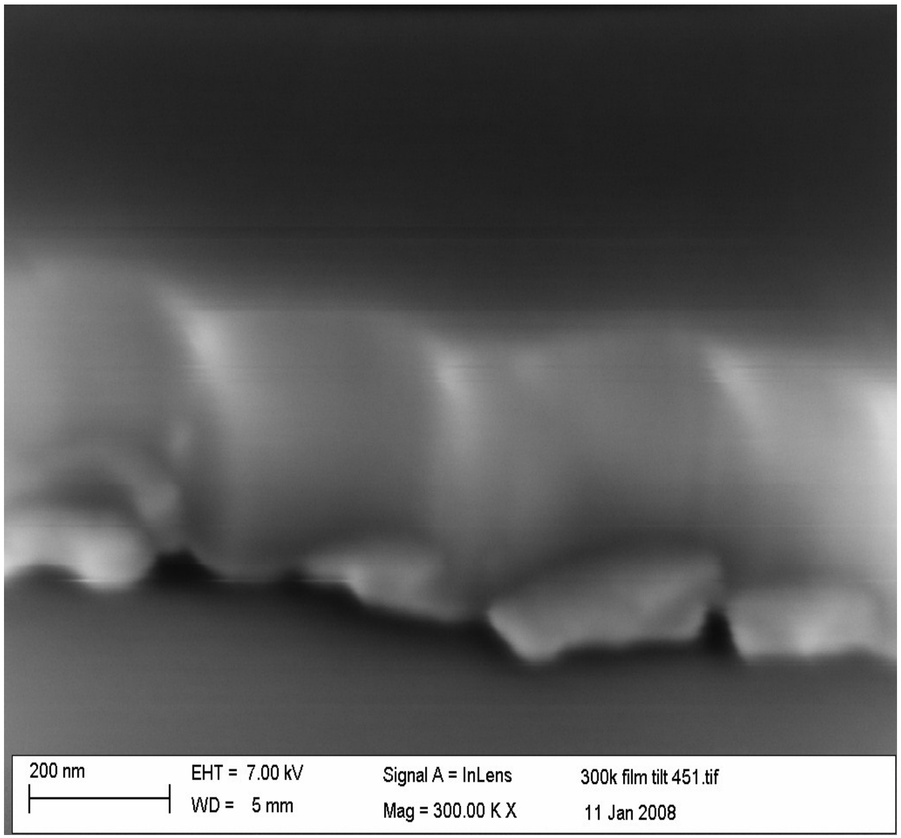
The film is nearly amorphous.

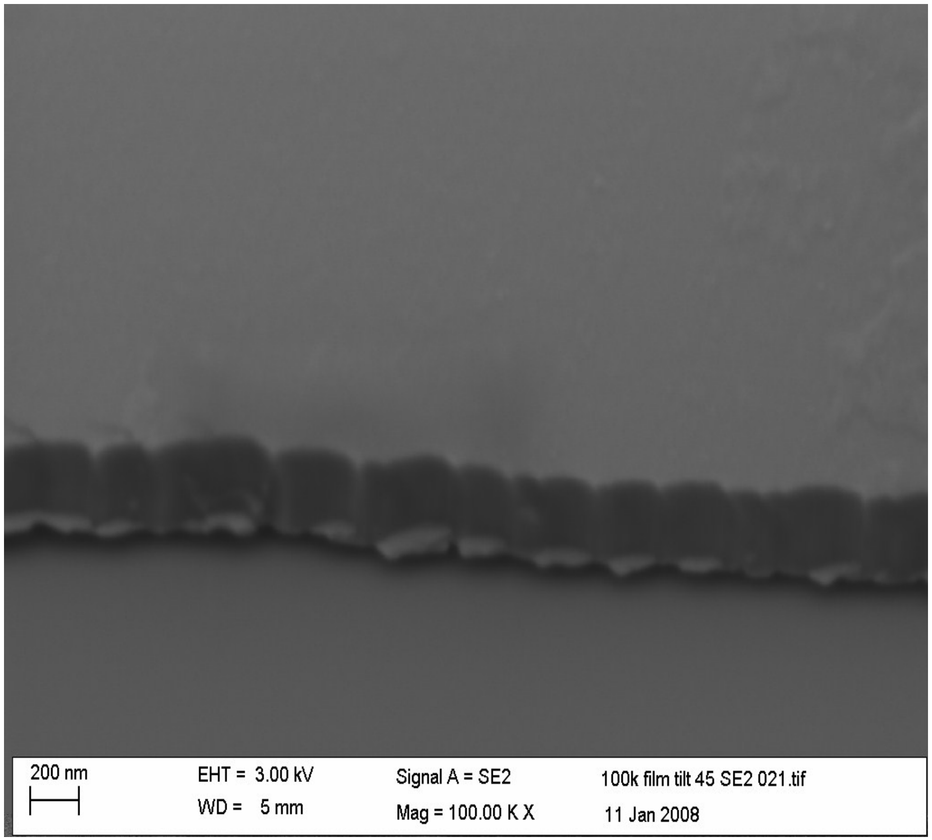
ASTeC activation procedure



O.B. Malyshev, K.J. Middleman, J.S. Colligon and R. Valizadeh. J. Vac. Sci. Technol. A 27 (2009), p. 321.

Quaternary NEG alloy film deposited on Si test sample from twisted Ti, V, Zr, and Hf wires.





Cylindrical Magnetron: Power = 60 W, $P_{Kr} = 10^{-2}$ mbar, deposition rate = 0.12 nm/s, T = 120°C.
Very glassy structure.

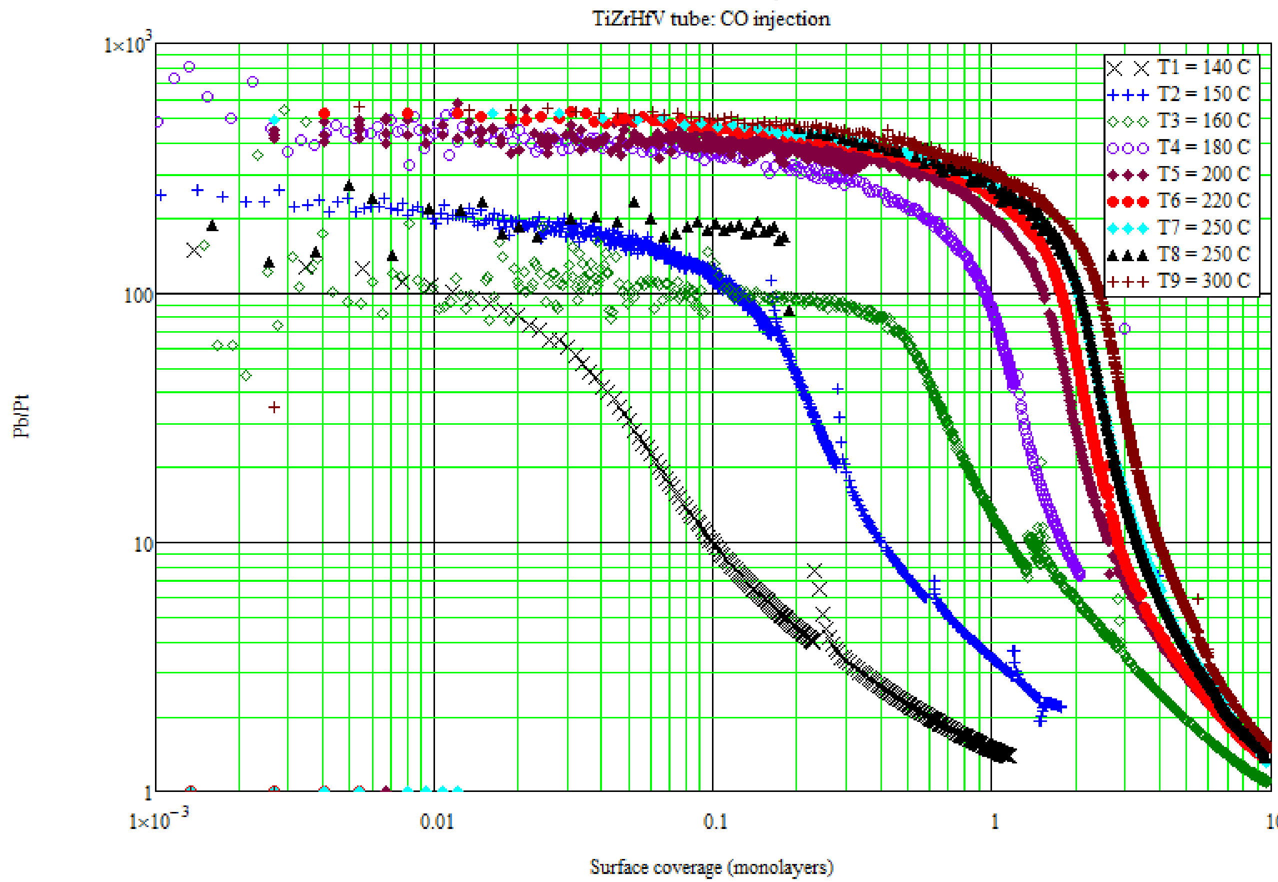
Pumping properties measurements

H_2, CO and CO_2 injection

pumping capacity taken at $P_{bottom} / P_{top} = 10$

Initial sticking probability can be obtained from pressure ratio

P_{bottom} / P_{top}



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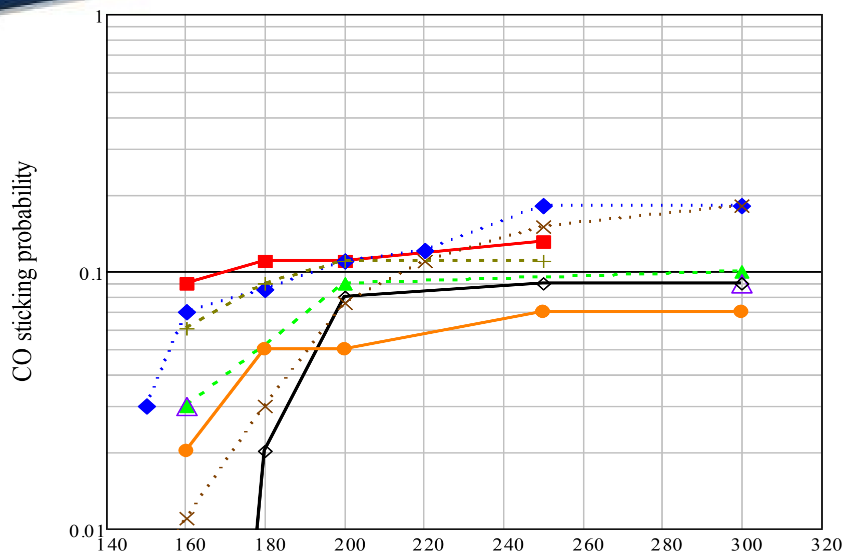
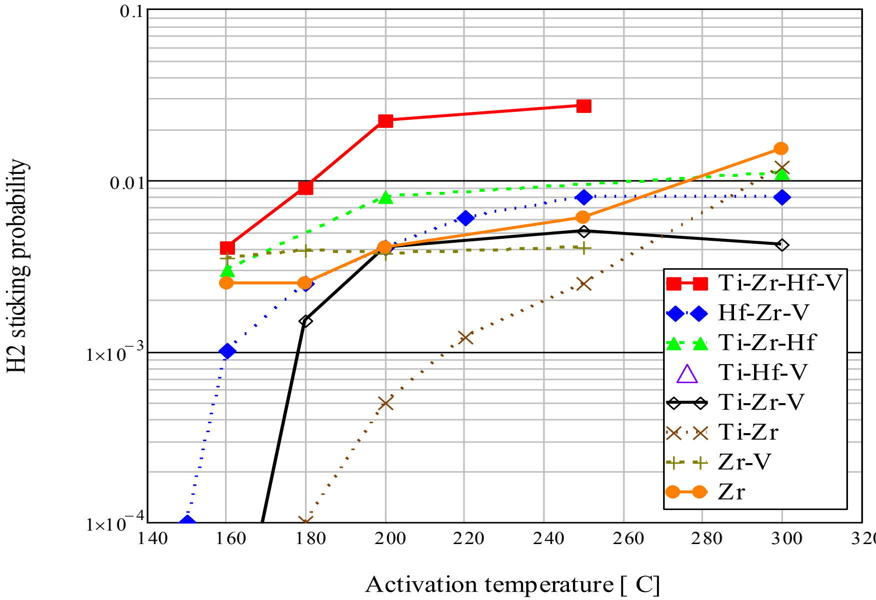
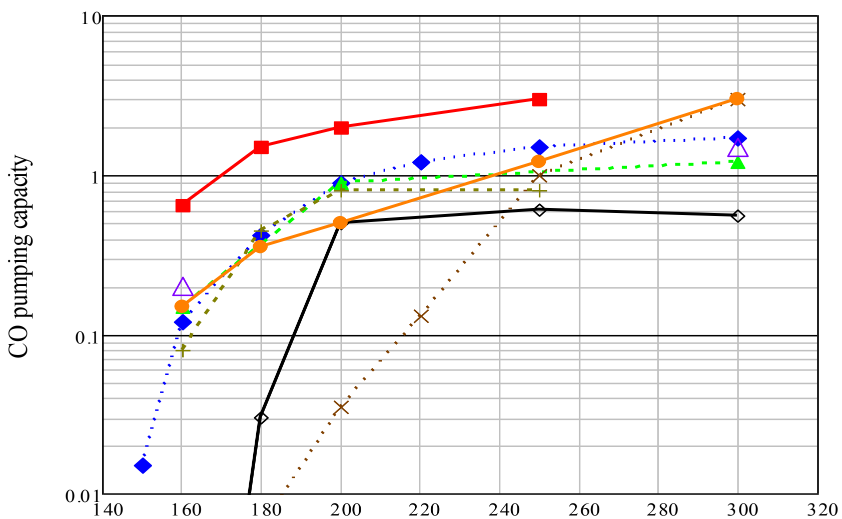
Pumping properties of some films







- **Ti-Zr-Hf-V** is the best
- **Hf-Zr-V**, **Ti-Zr-Hf**, **Ti-Hf-V** and **Zr** are comparable
- **Ti-Zr-V** is lower
- **Zr-V** (best binary alloy) has the lowest activation temperature

Pressure in the accelerator vacuum chamber

$$P \propto \frac{\eta}{\alpha}$$

where

- η - desorption yield
- α - sticking probability

- Improving the pumping properties is limited:

$$\alpha \leq 1.$$

$$0.005 < \alpha_{H2} < 0.01$$
$$0.1 < \alpha_{CO} < 0.5$$
$$0.4 < \alpha_{CO2} < 0.6$$

- Reducing the desorption yields η <u>in orders of magnitude</u> is a realistic task

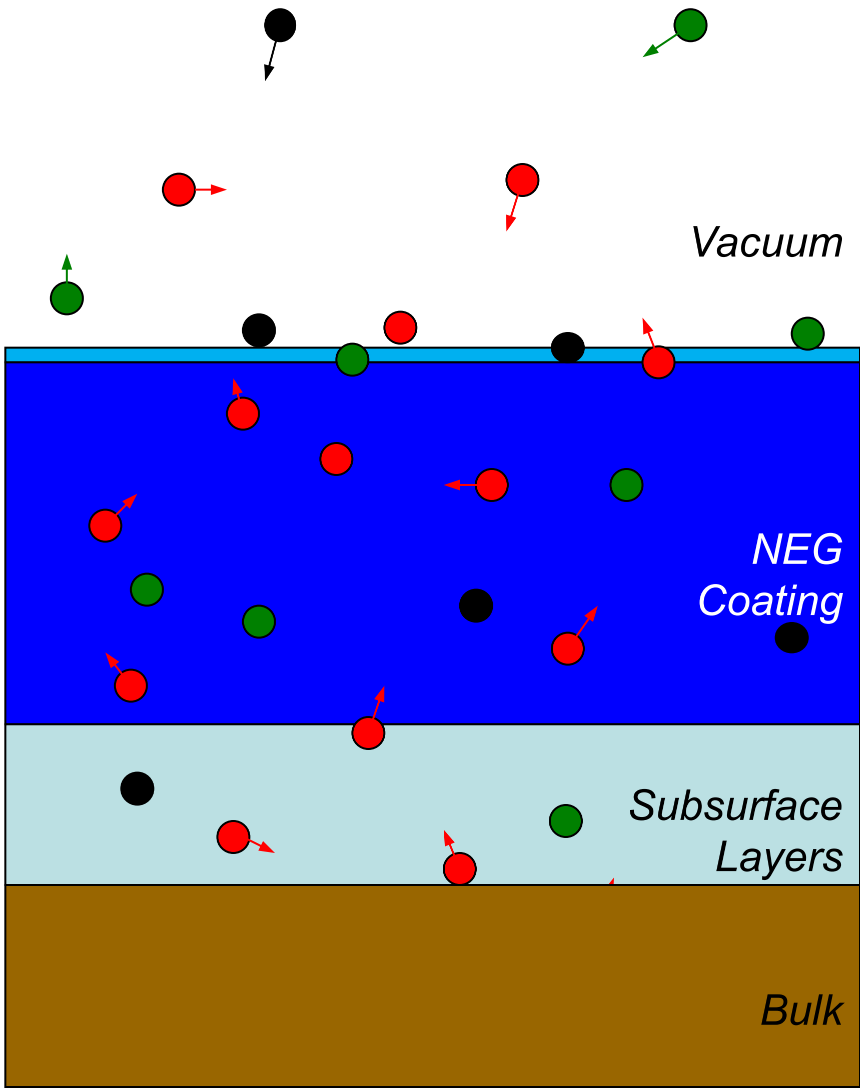
Reducing the gas desorption from the NEG coatings

- Main gases in the NEG coated vacuum chamber are H_2 and CH_4
  - Only H_2 can diffuse through the NEG film under bombardment or heat
  - CH_4 is most likely created on the NEG surface from diffused H_2 and C (originally from sorbed CO and CO_2)
  - Therefore the H_2 diffusion must be suppressed
    - **Where H_2 come from?**

Reducing the gas desorption from the NEG coatings

Gas molecules are contained

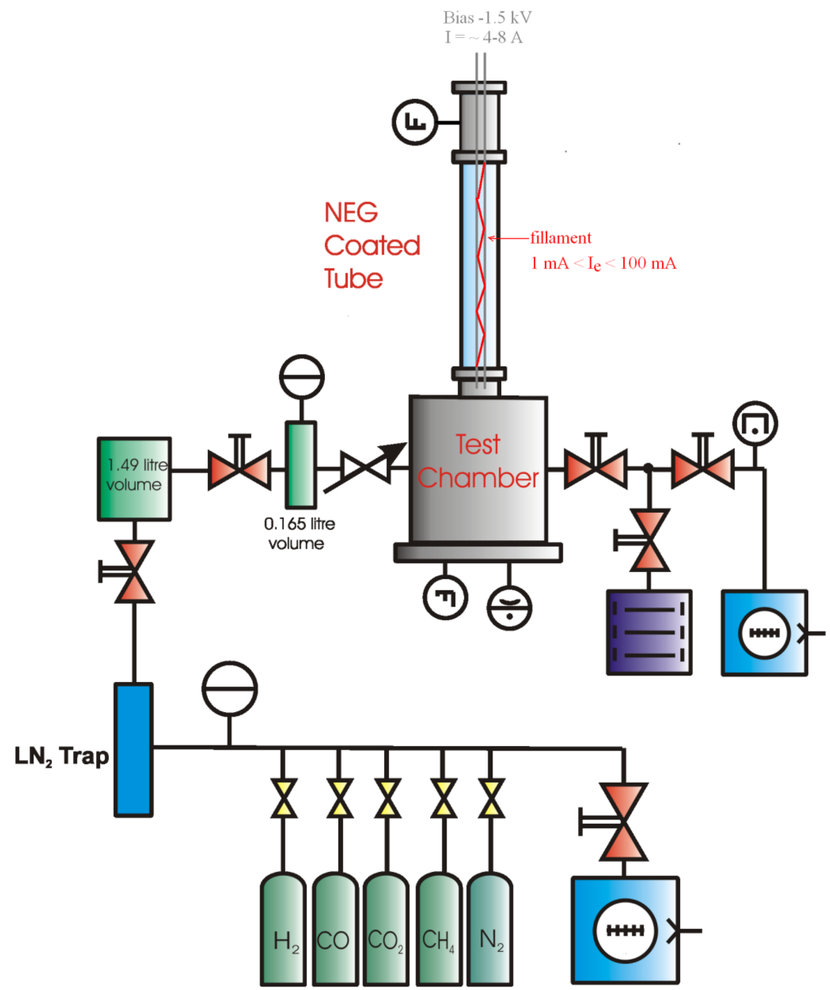
- on the NEG coating surface
  - after exposure to air
    - minimise exposure to air
- inside the NEG coating
  - trapped during deposition
    - purity of discharge gas
    - background pressure
- in subsurface substrate layer
  - substrate bakeout before NEG deposition
- in the substrate bulk
  - vacuum firing



Electron stimulated desorption rig

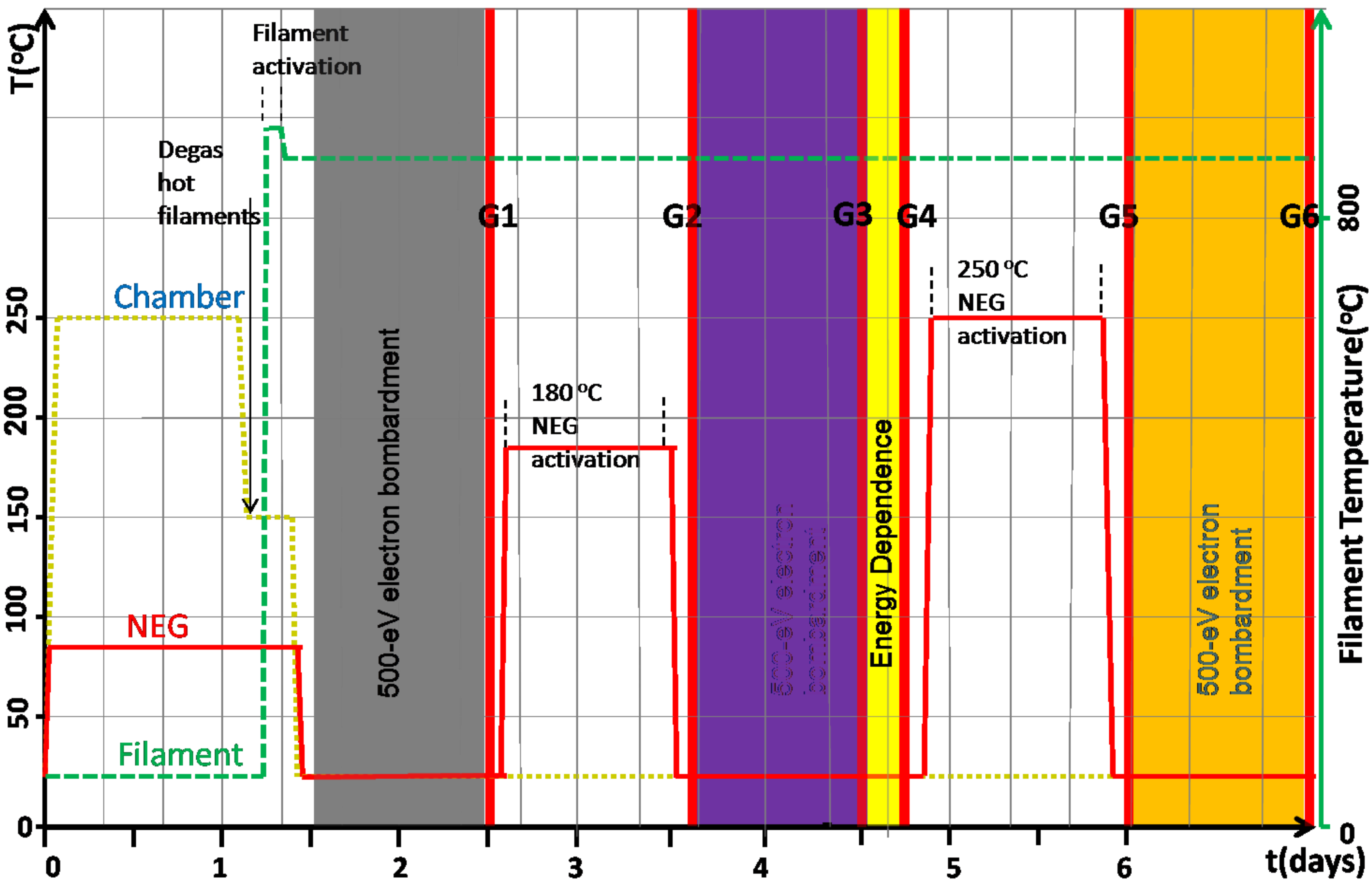
ESD is studied as a function of
- Electron energy
- Dose
- Wall temperature (-5 to +70°C)
- Activation/bakeout temperature

Can be used for samples with:
- Specially treated samples
  - Vacuum fired, polished, etc.
- Low desorption coating
- No coatings
- NEG coating
  - ESD measurements
  - Sticking probability measurements



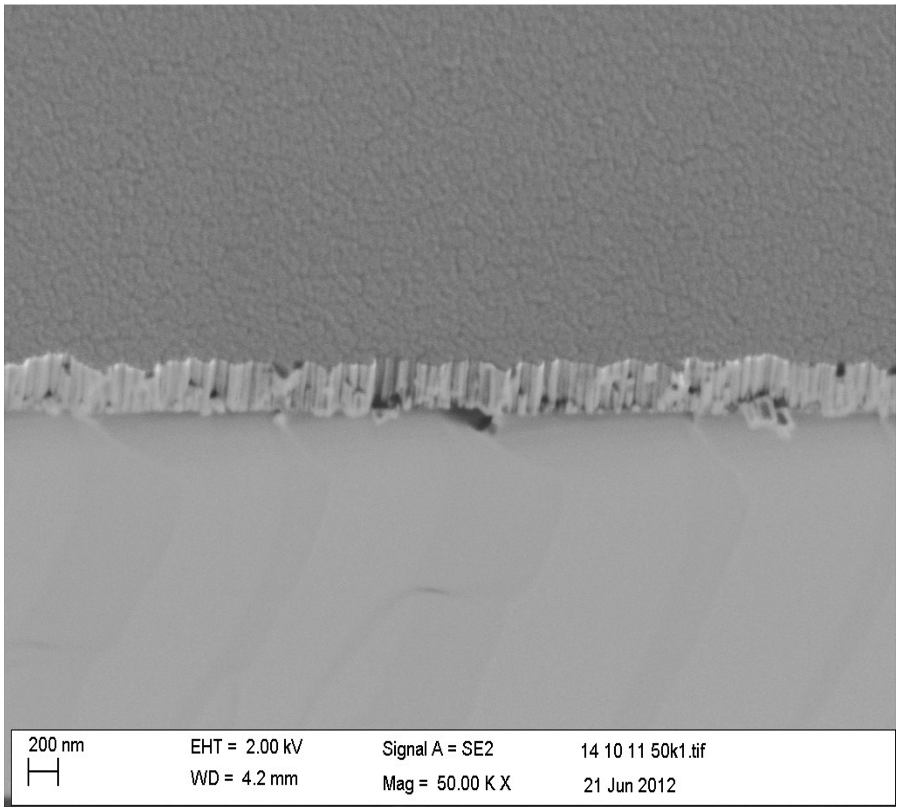
O.B. Malyshev, A.P. Smith et al. J. Vac. Sci. Technol. A 28 (2010), p. 1215.

Experimental procedure for NEG coated samples

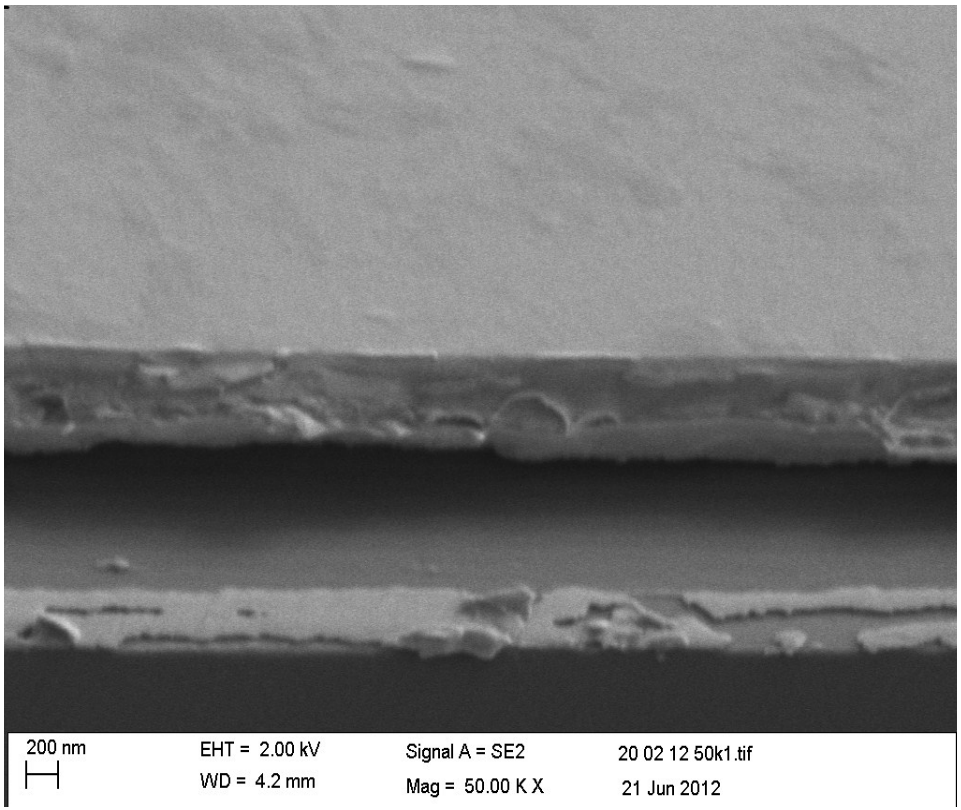


SEM images of films (film morphology)

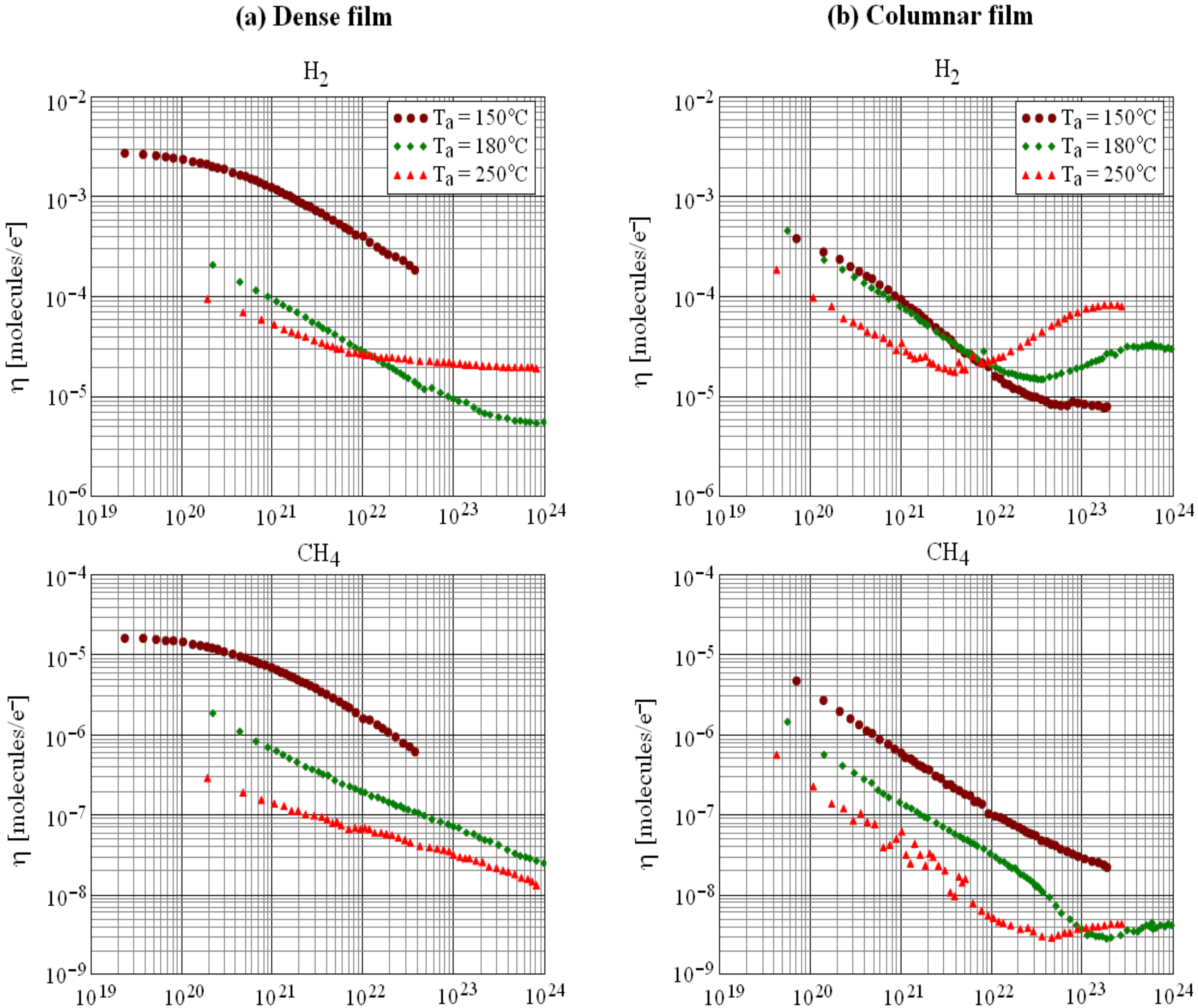
columnar (TiZrVHf)
Best for pumping



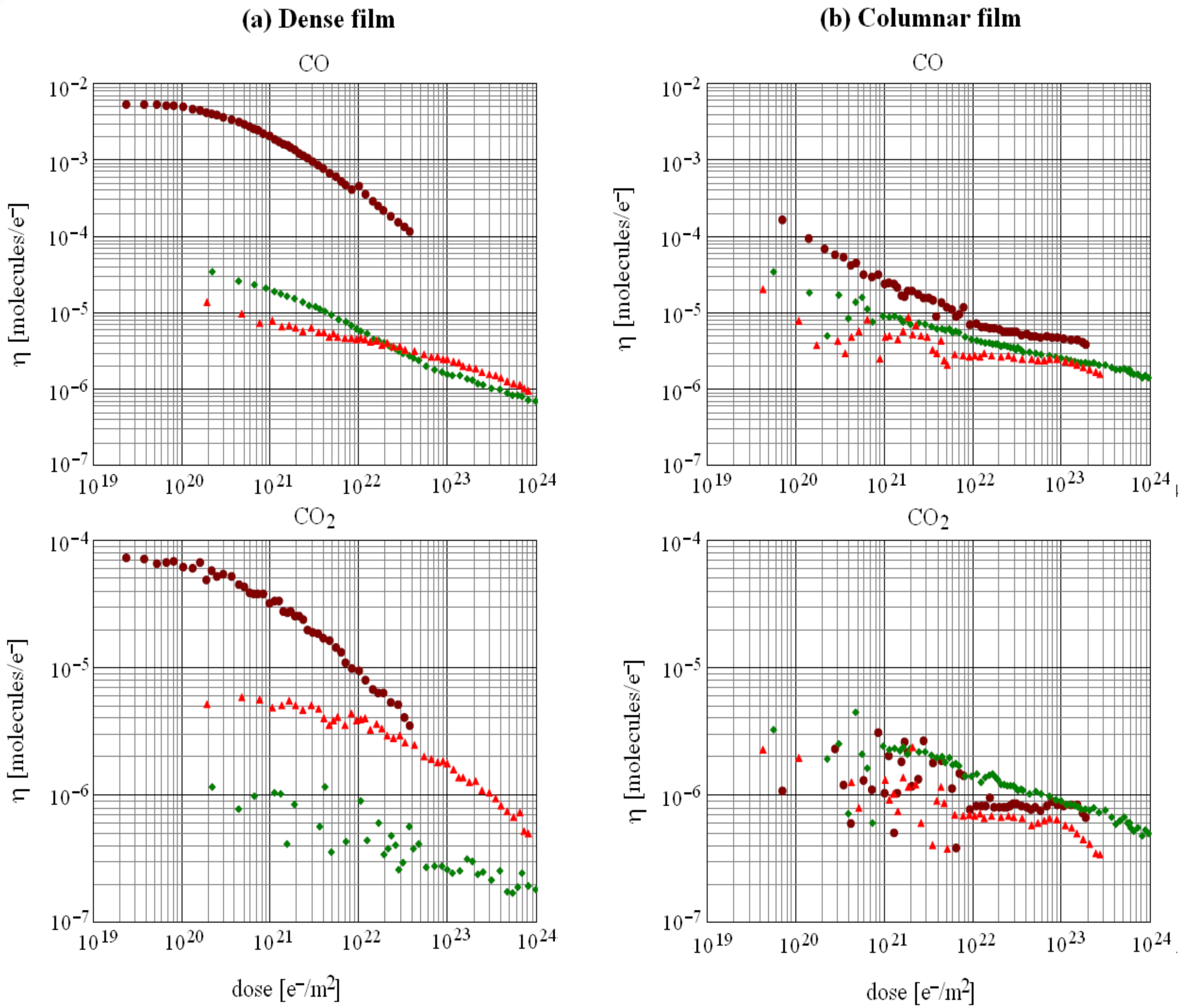
dense (TiZrVHf)
A first candidate for a barrier



ESD yield from NEG coated samples

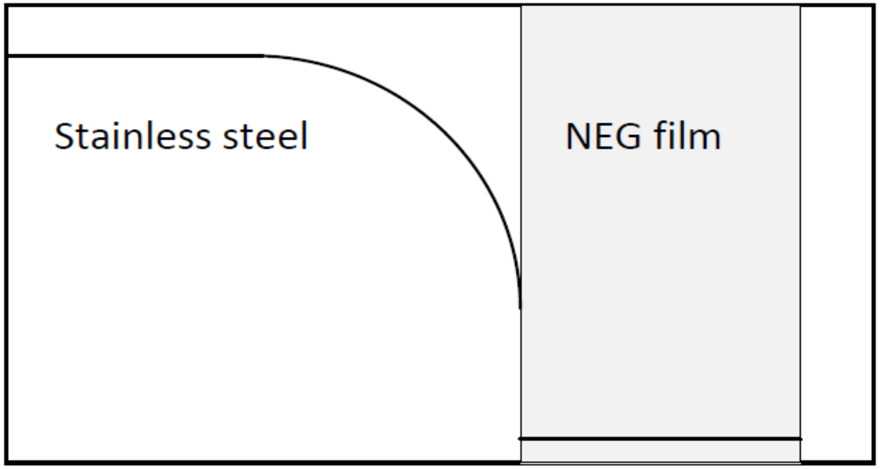


ESD yield from NEG coated samples

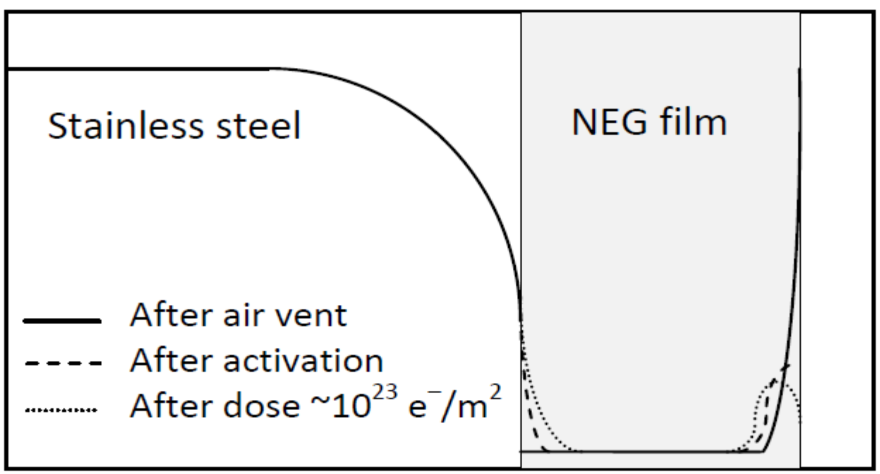


ESD yield from NEG coated samples

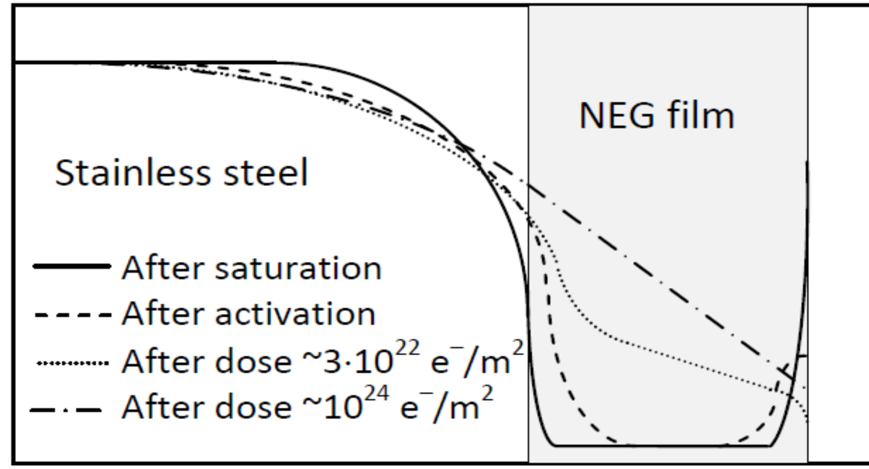
(a) after deposition before vent to air



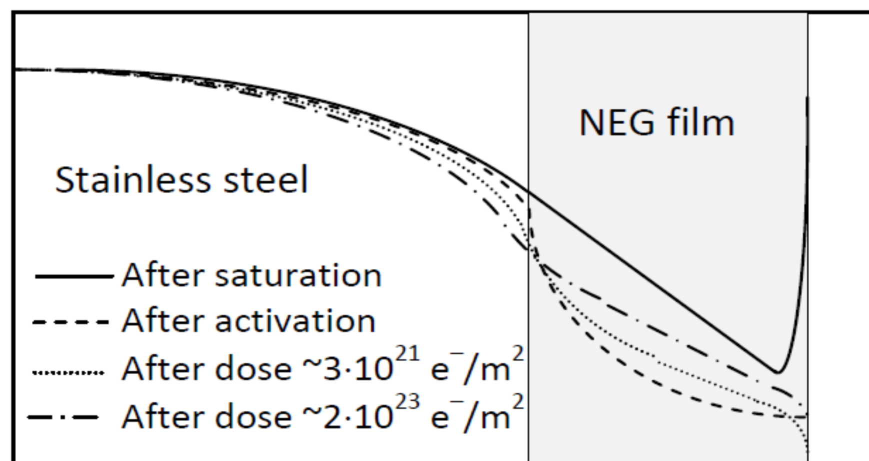
(b) activation at 150 °C



(c) activation at 180 °C



(d) activation at 250°C



Conclusions

- ASTeC activation procedure minimises NEG poisoning from non-coated vacuum chamber components
- Role of element:
  - Zr-based – highest sticking probability and capacity, lowers activation temp.
  - Ti-based – lowest sticking probability and capacity, highest activation temp
- Role of grain size
  - Activation temperature reduces with a grain size due to increase the grain boundary density
- Quaternary alloy demonstrated the lowest activation temperature and best pumping properties;
  - Pure Zr film is good as well
- Alloy target is better than twisted wires
- The improvement and further development of NEG coatings requires
  - Intensive use surface analysis techniques
  - Evaluation under photon, electron and ion bombardment.