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Progress in NEG Coatings for Particle Accelerators

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Outlook

- Introduction
- Desorption properties
- Surface resistance
- Summary

What NEG coating does

1) Reduces gas desorption:

- **A pure metal (Ti, Zr, V, Hf, etc.) film ~1-μm thick without contaminants.**
- **A barrier for molecules from the bulk of vacuum chamber.**

2) Increases distributed pumping speed, *S*:

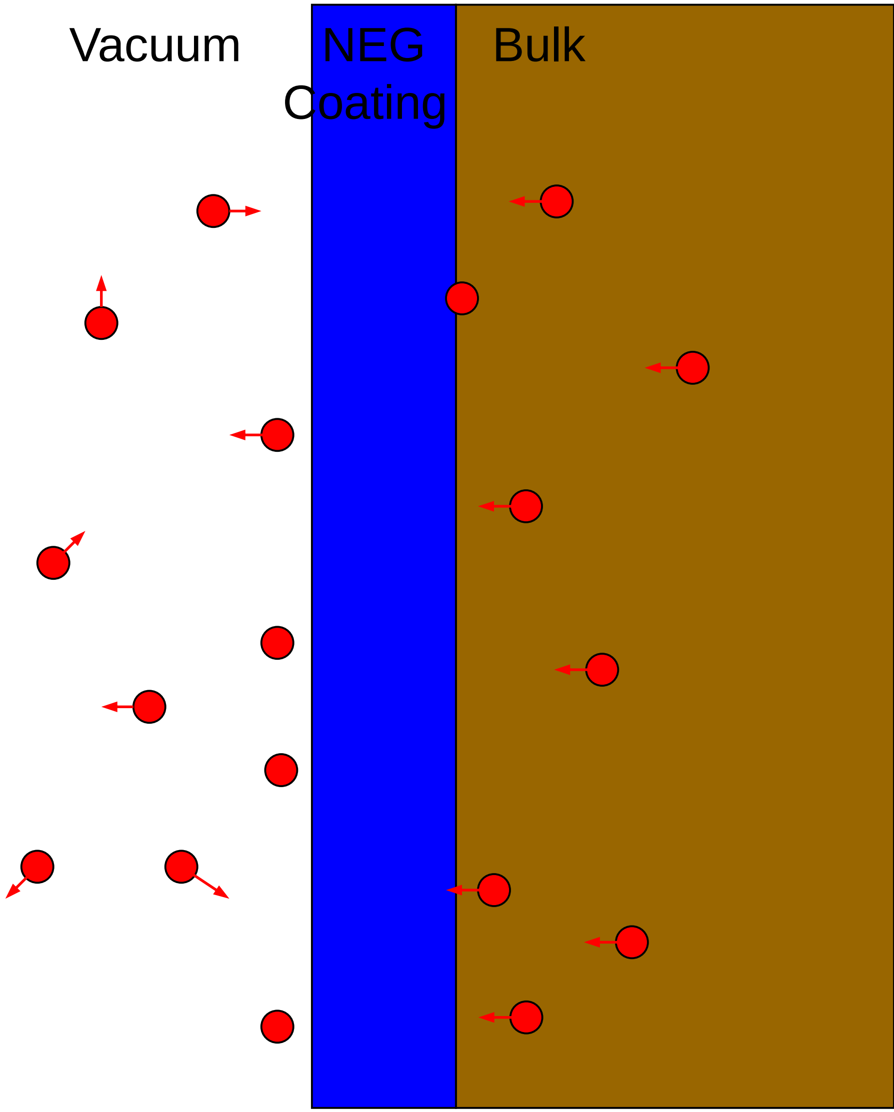
- **A sorbing surface on whole vacuum chamber surface**

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

where α **– sticking probability,**

A – surface area,

v – mean molecular velocity



Earlier experiments with NEG coating

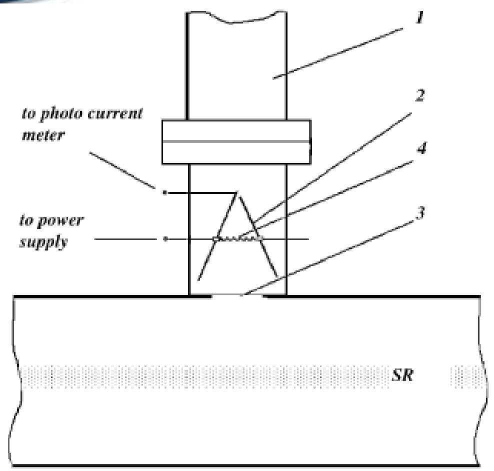
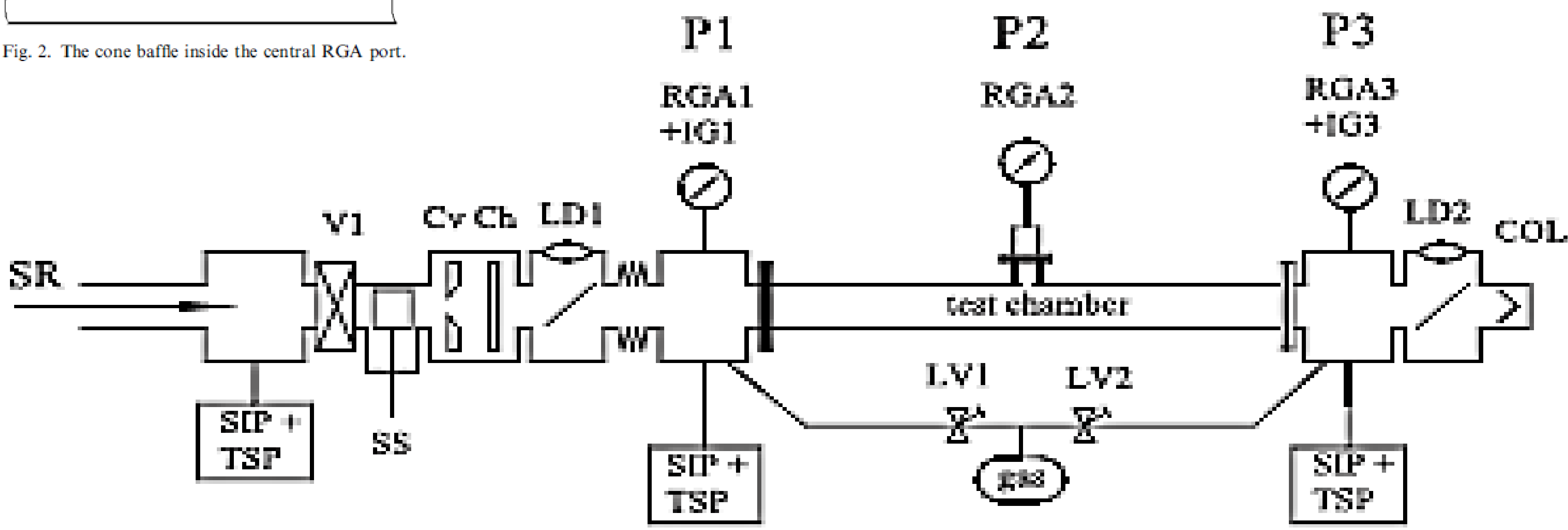


Fig. 2. The cone baffle inside the central RGA port.

- Samples coated with Ti-Zr-V at CERN (Switzerland)
- Experiments SR beam line at BINP (Russia)



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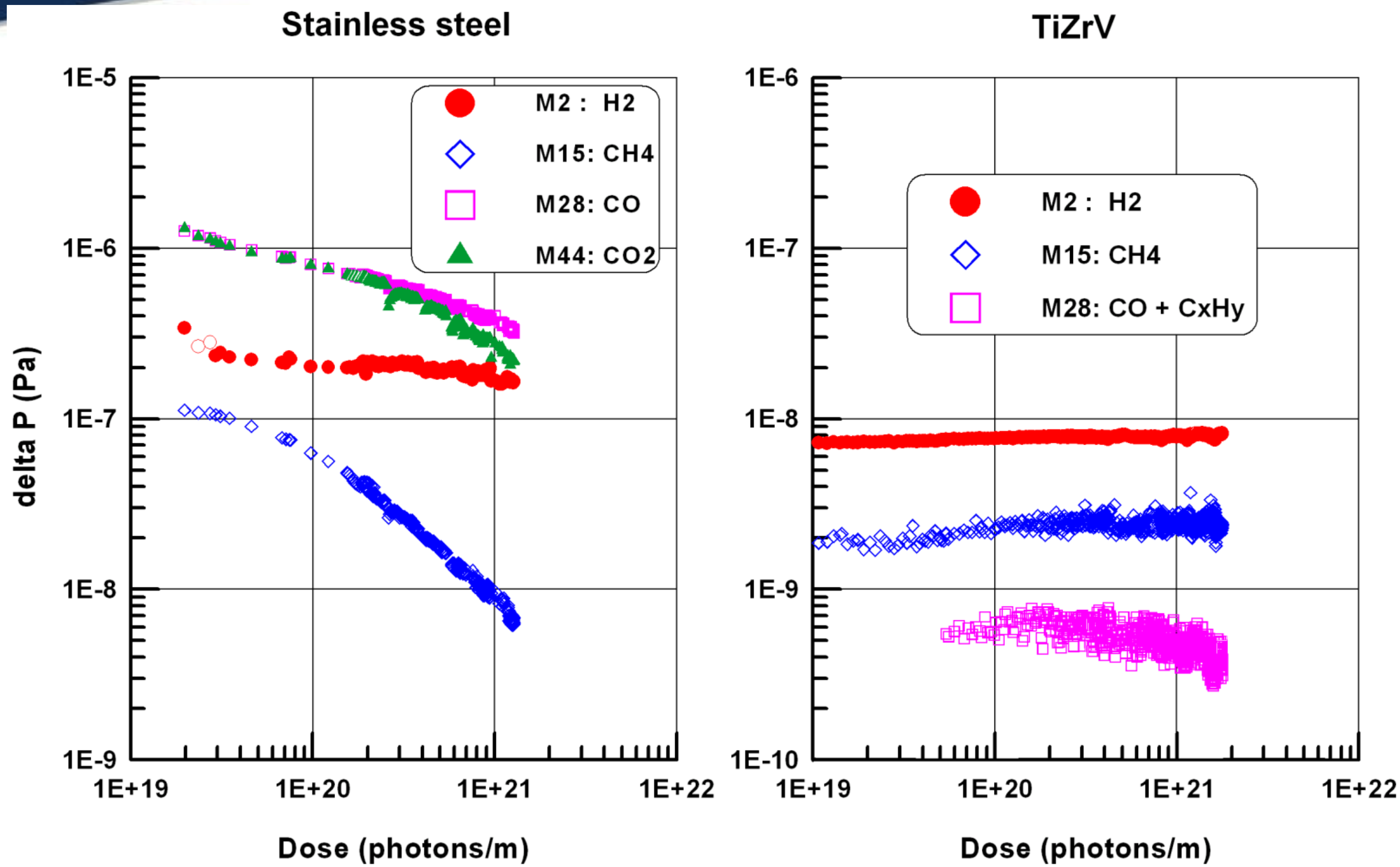
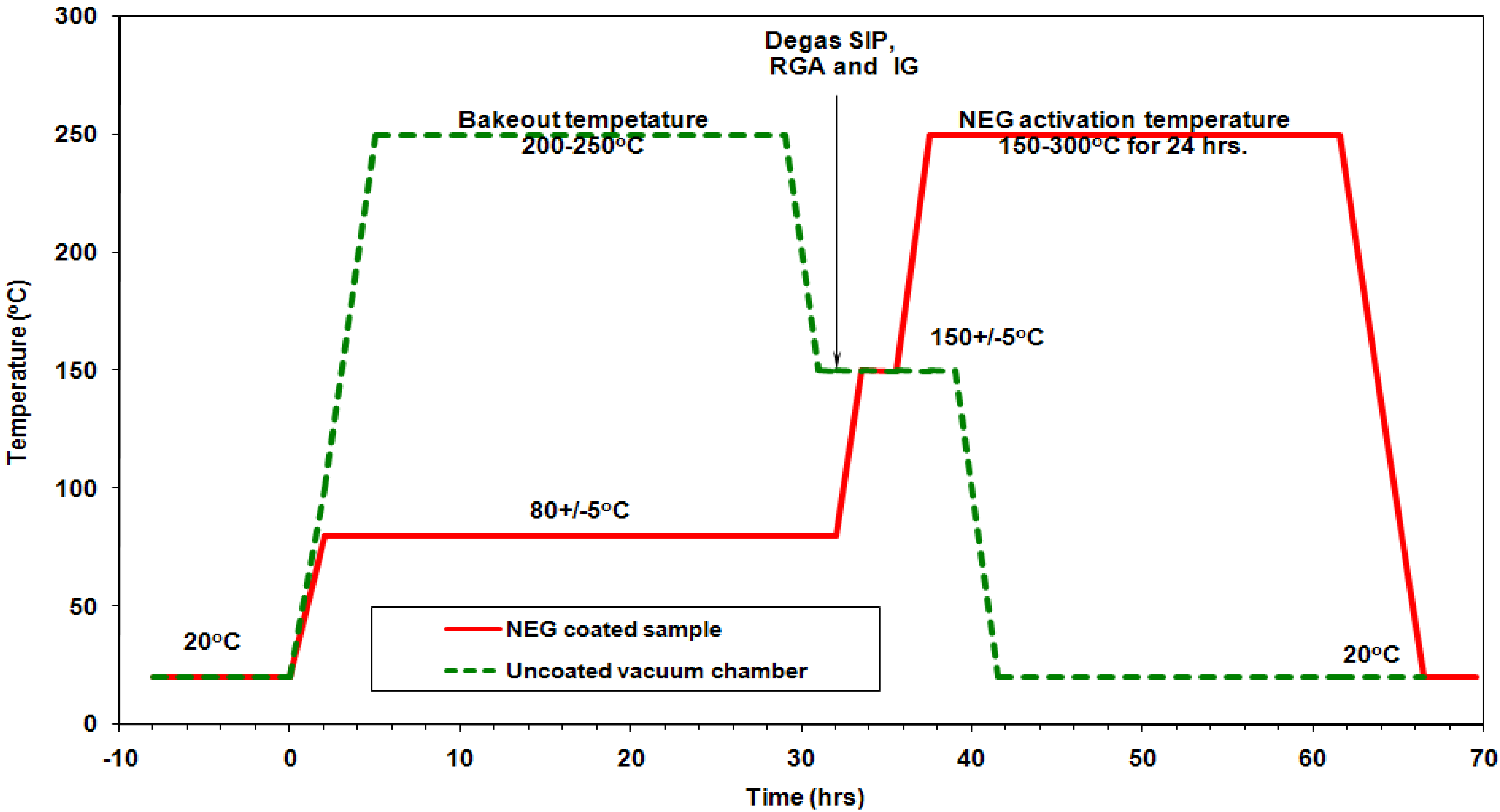
Comparison of PSD from 316LN and NEG



Dynamic pressure rise for the Stainless Steel (baked at 300°C for 24 hrs) and TiZrV coated vacuum chambers (activated at 190°C for 24 hrs)

V.V. Anashin *et al*, Vacuum 75 (2004) p. 155.

ASTeC activation procedure



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

Pressure in the accelerator vacuum chamber

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

where

η - desorption yield (photon, electron or ion stimulated desorption)

α - sticking probability

- Improving pumping properties is limited:

  $\alpha \leq 1$
  - $0.005 < \alpha_{H2} < 0.02$
  - $0.1 < \alpha_{CO} < 0.5$
  - $0.4 < \alpha_{CO2} < 0.6$

- Reducing the desorption yields η in orders of magnitude was our aim

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?**

Electron stimulated desorption facility

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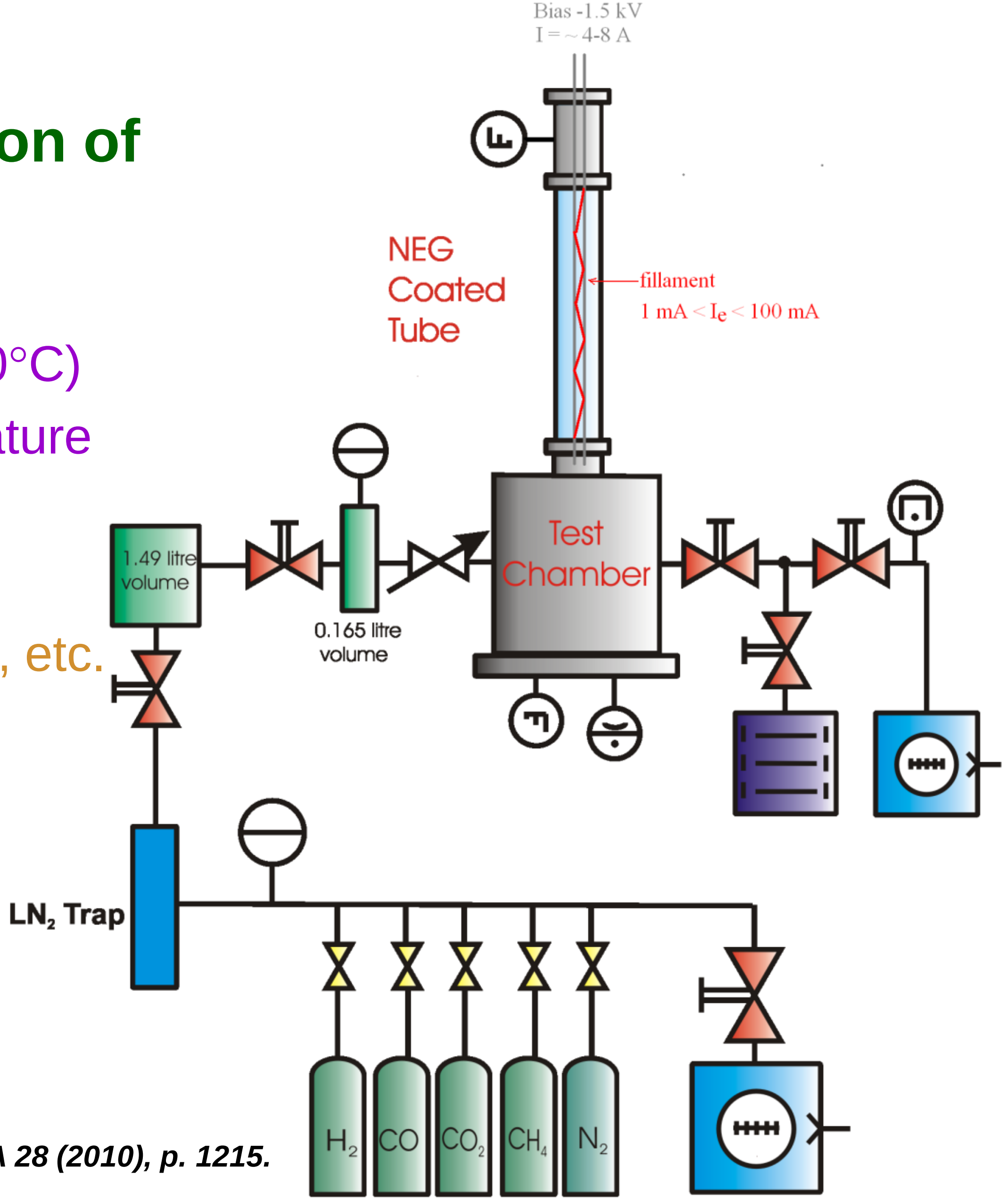
ESD is studied as a function of

- 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

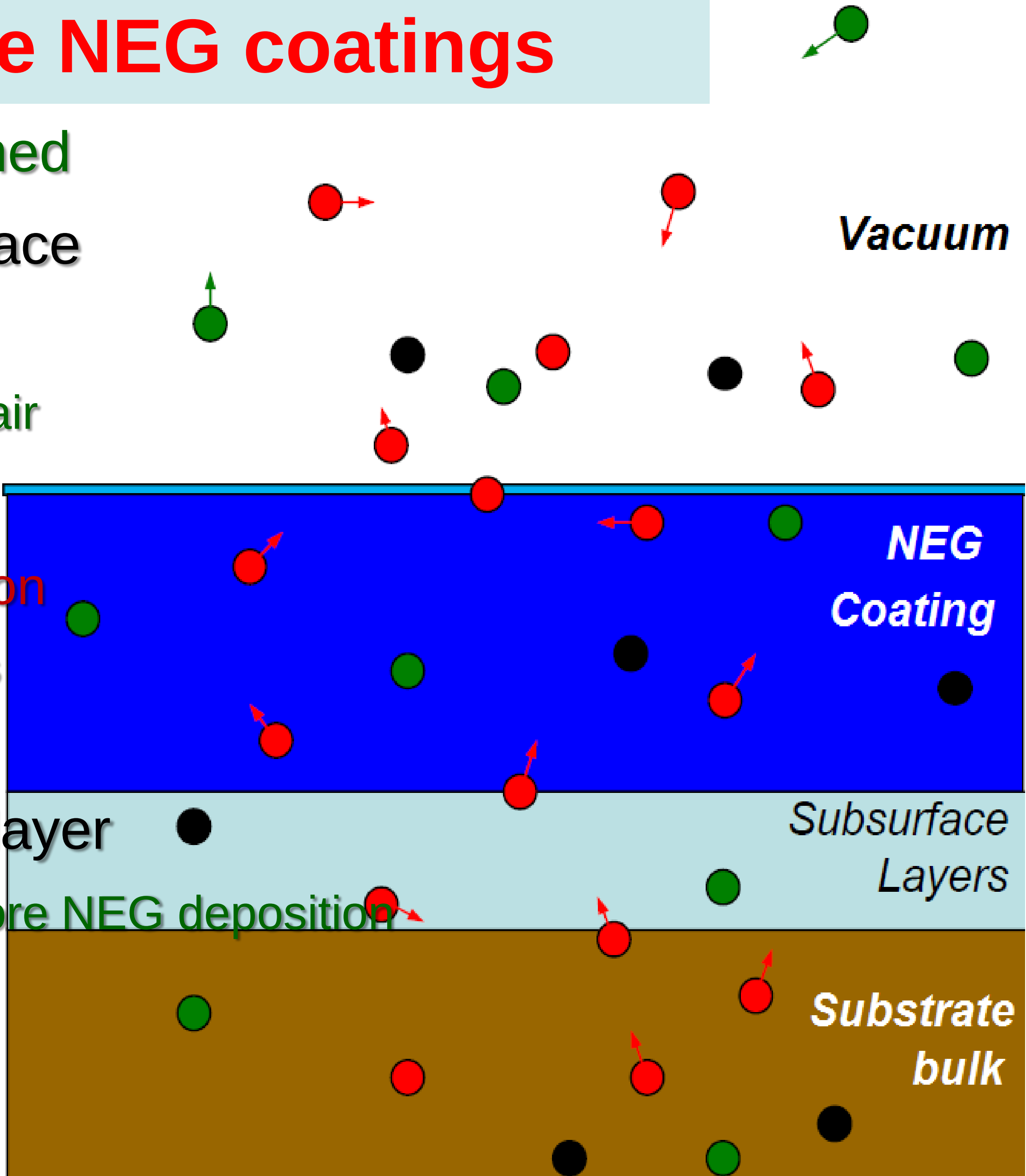


O.B. Malyshev, A.P. Smith et al. J. Vac. Sci. Technol. A 28 (2010), p. 1215.

Reducing the gas desorption from the NEG coatings

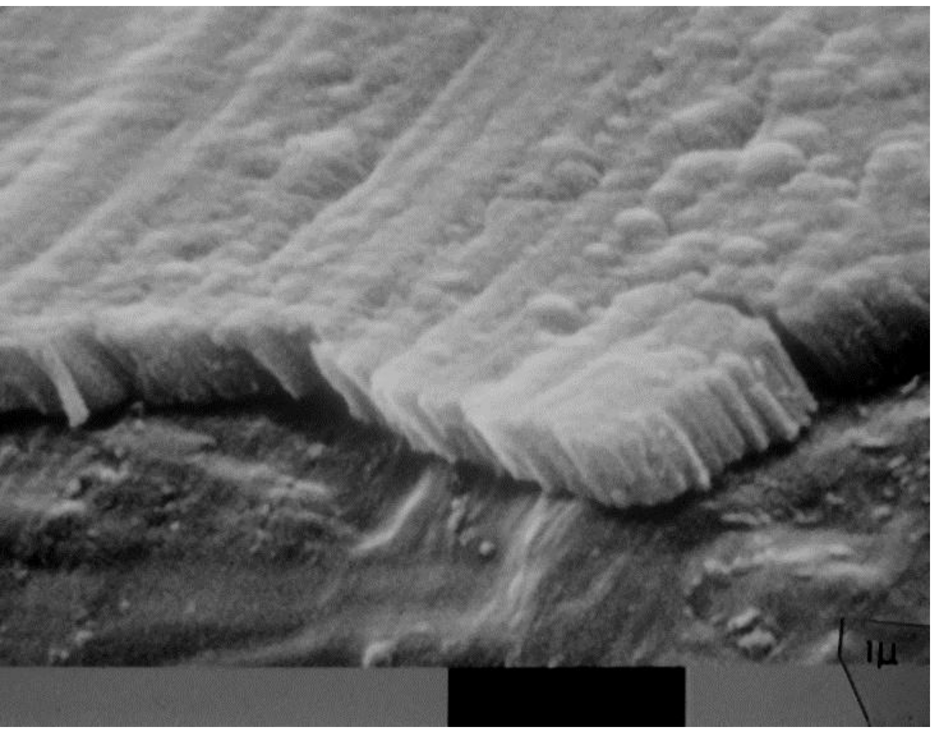
Gas molecules are contained

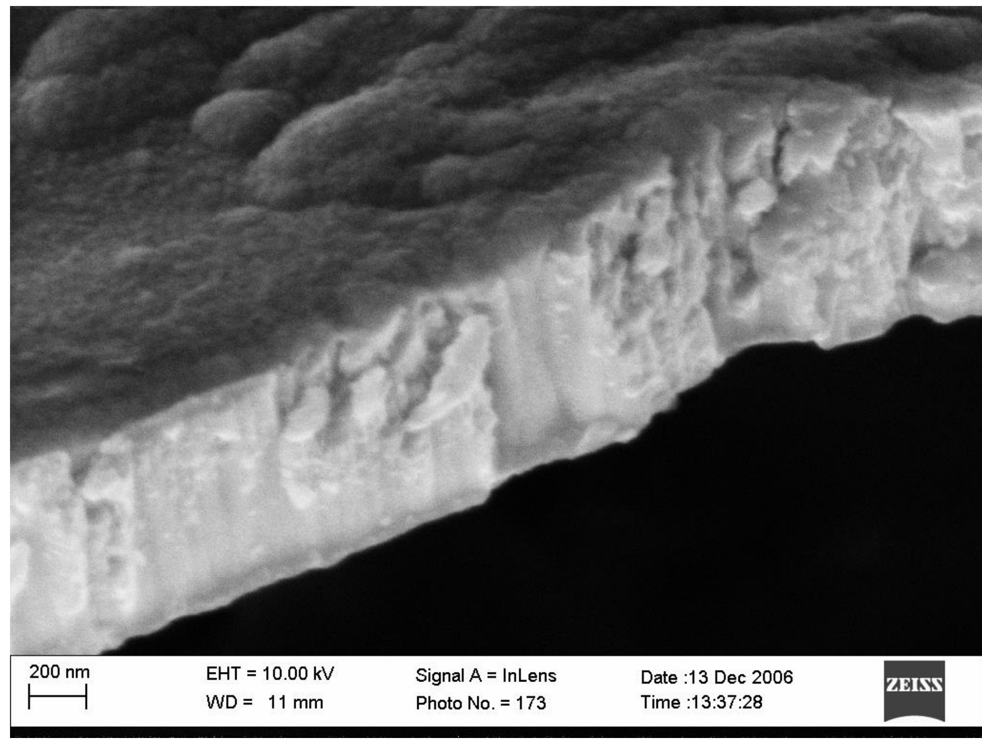
- on the NEG coating surface
  - after exposure to air
    - minimise exposure to air
- inside the NEG coating
  - trapped during deposition
    - purity of discharge gas
    - background pressure
- in subsurface substrate layer
    - substrate bakeout before NEG deposition
- in the substrate bulk
 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



SEM images of films (film morphology)

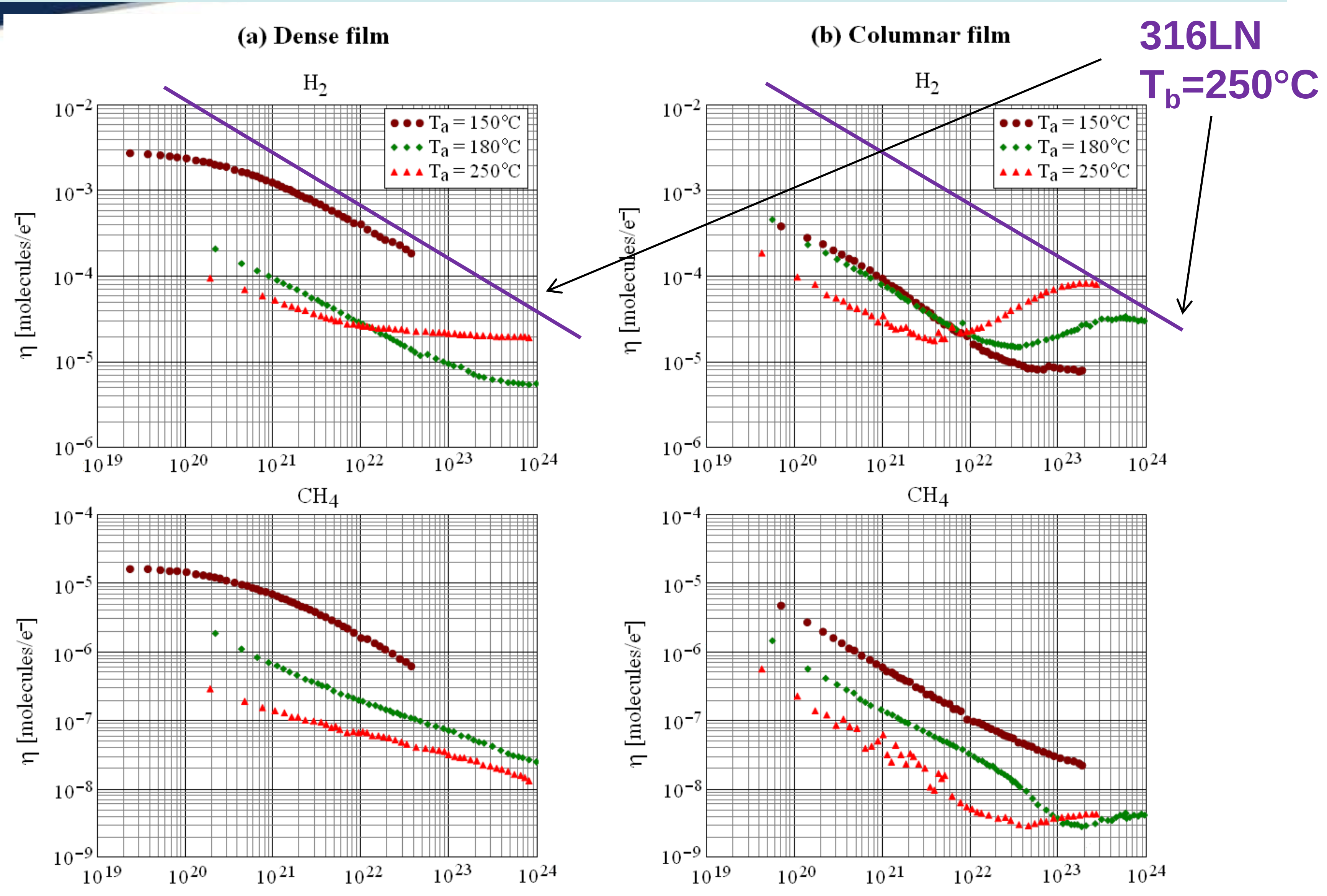
columnar	dense
Best for pumping	A first candidate for a barrier



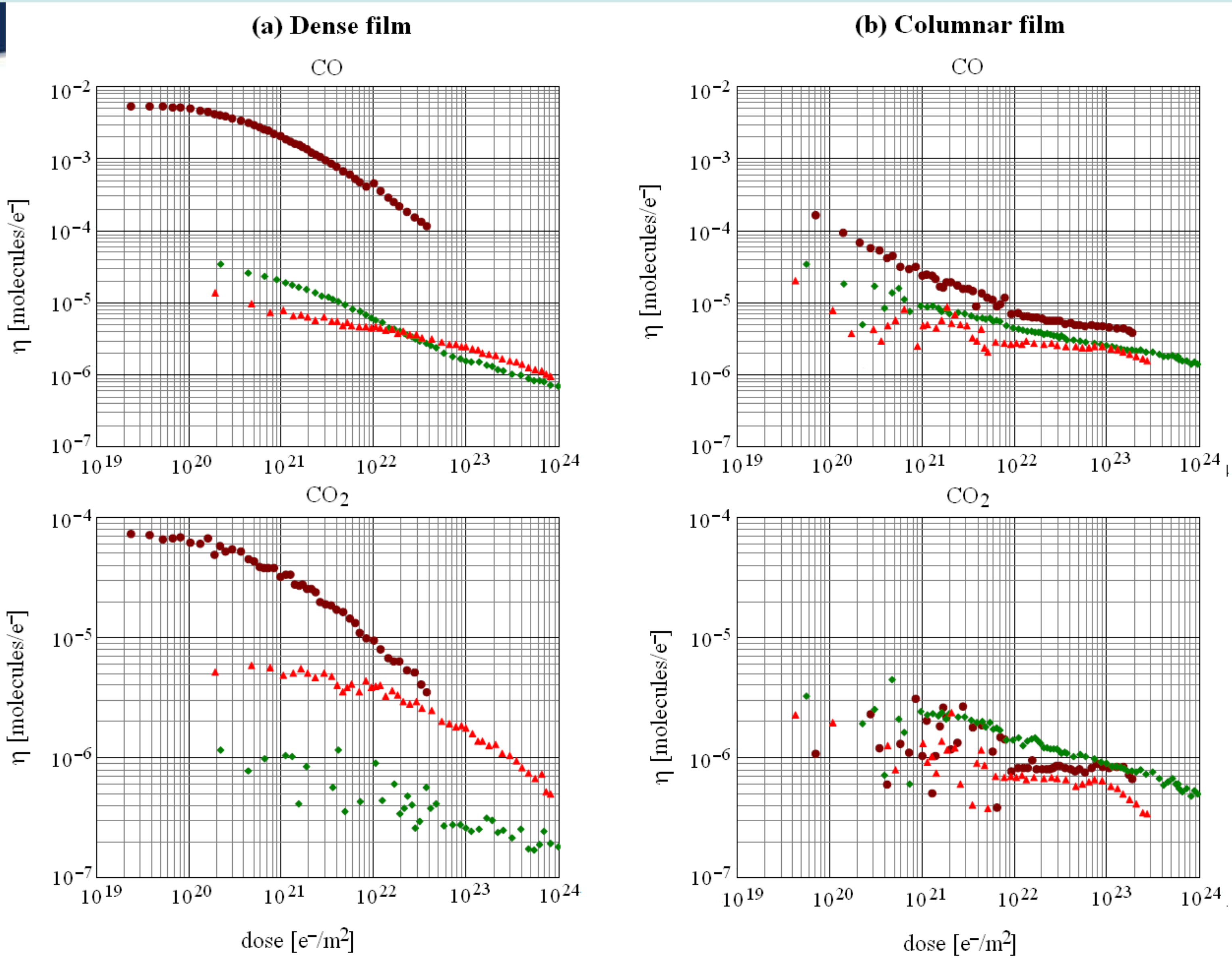


O.B. Malyshev, R. Valizadeh, J.S. Colligon *et al*. J. Vac. Sci. Technol. A 27 (2009), p. 521.

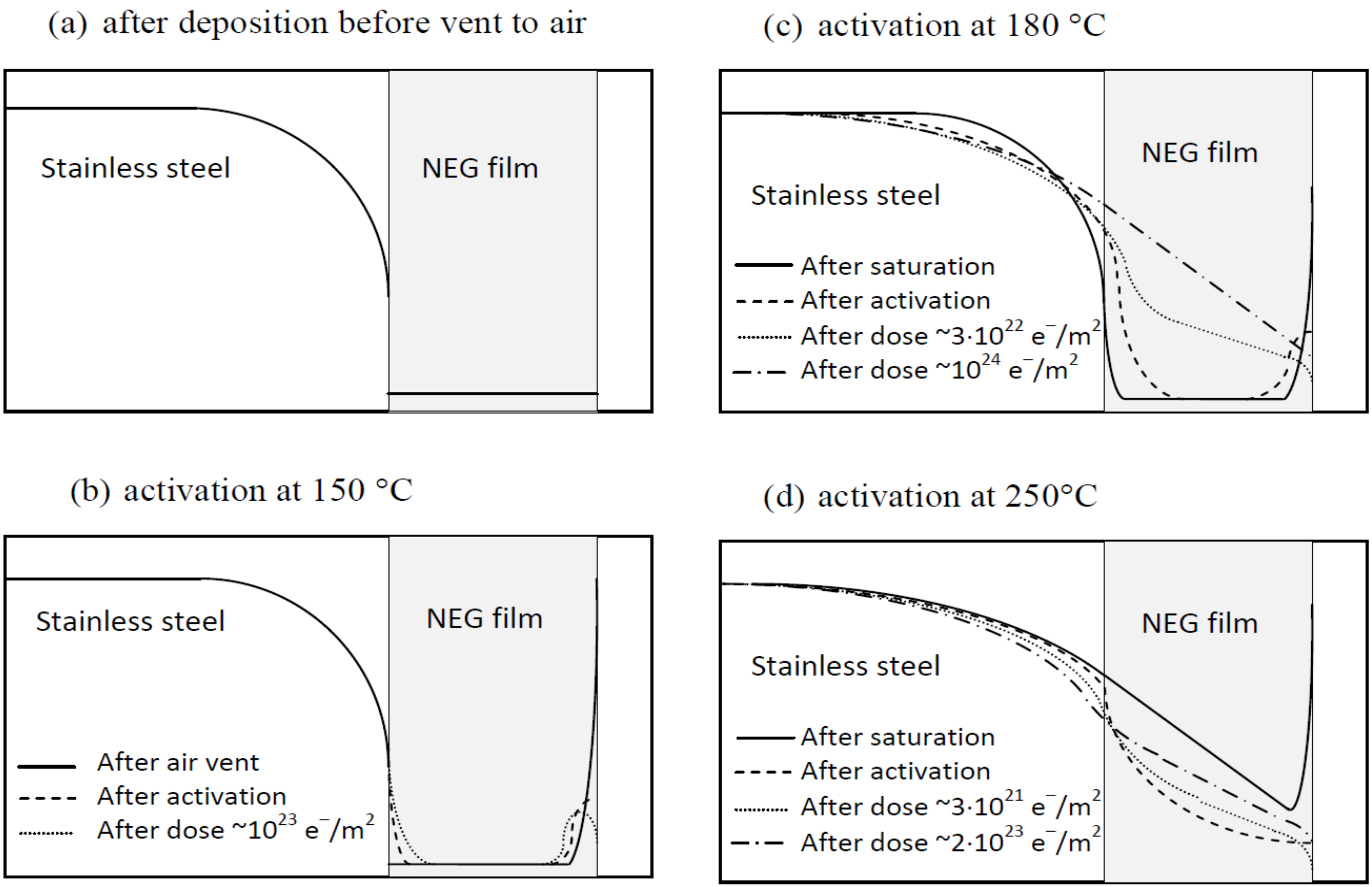
ESD yield from NEG coated samples



ESD yield from NEG coated samples

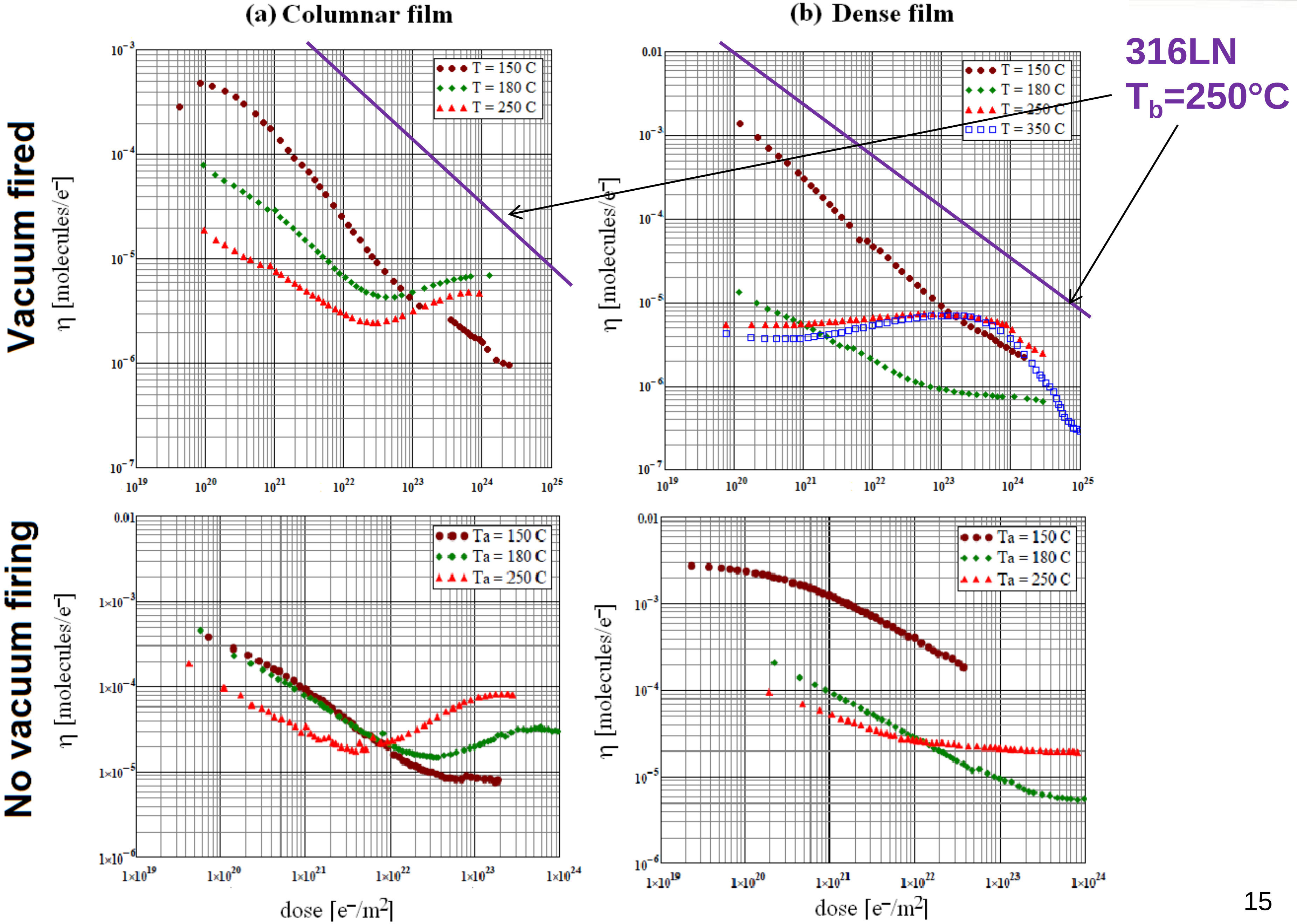


ESD yield from NEG coated samples



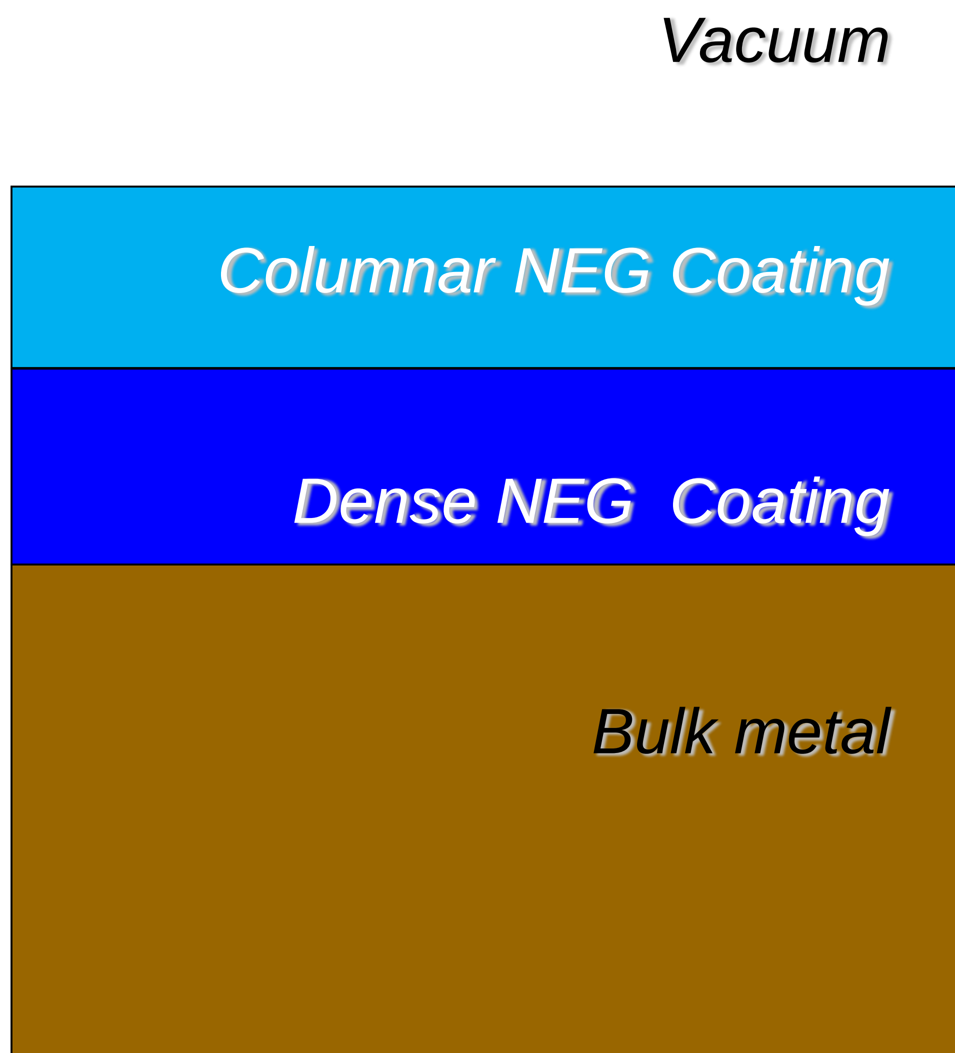
O.B. Malyshev et al. Vacuum (2012) doi.: 10.1016/j.vacuum.2012.04.033

H_2 ESD from NEG coated vacuum fired 316LN

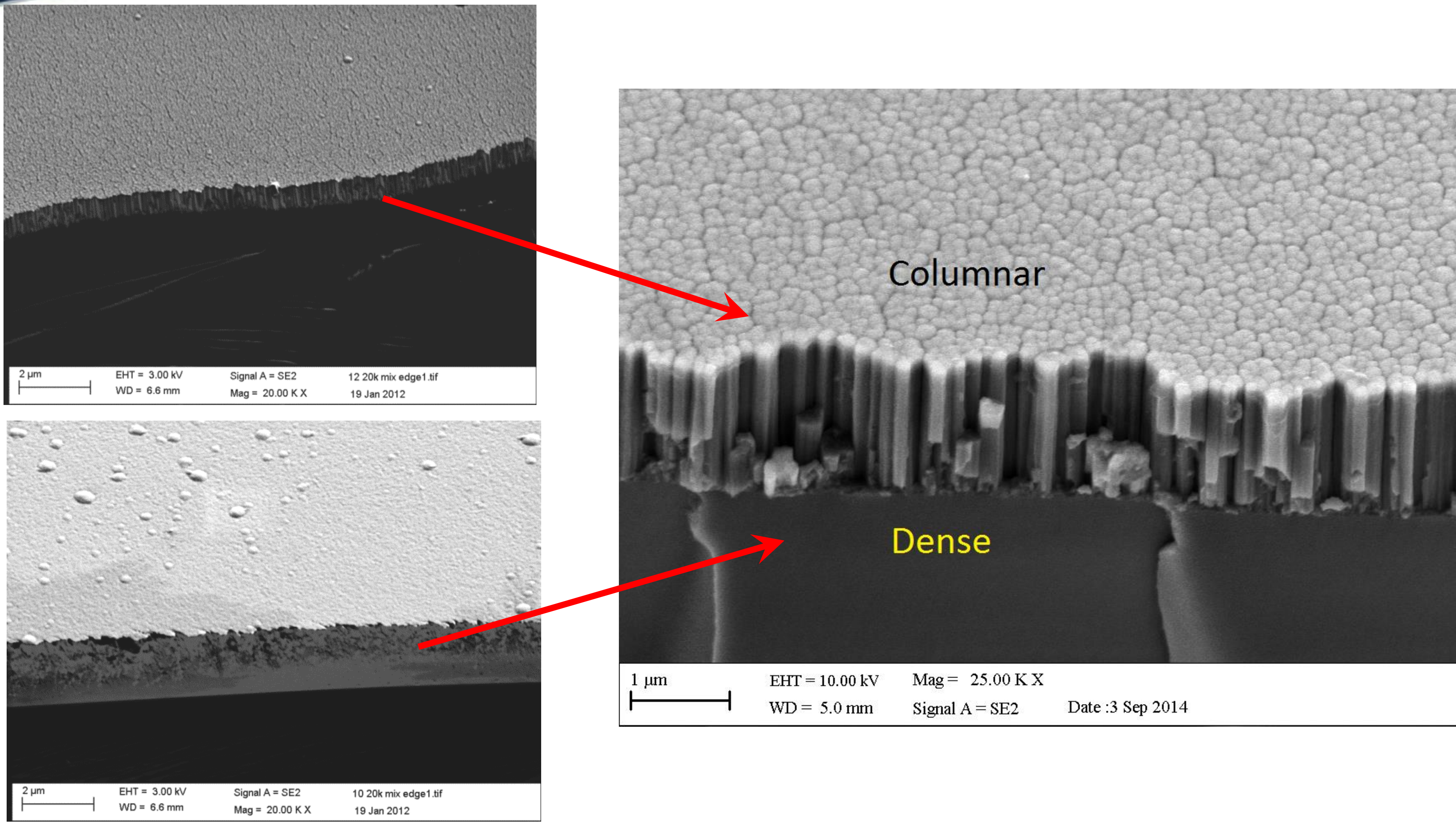


Dual layer

- Columnar layer:
  - Activated at lower temperature
  - Provides higher sticking probability and pumping capacity
- Dense layer:
  - Provides lower ESD
- Dual Layer:
  - Combines benefit of both
  - For more details: see A. Hannah's poster EM286 on Thursday

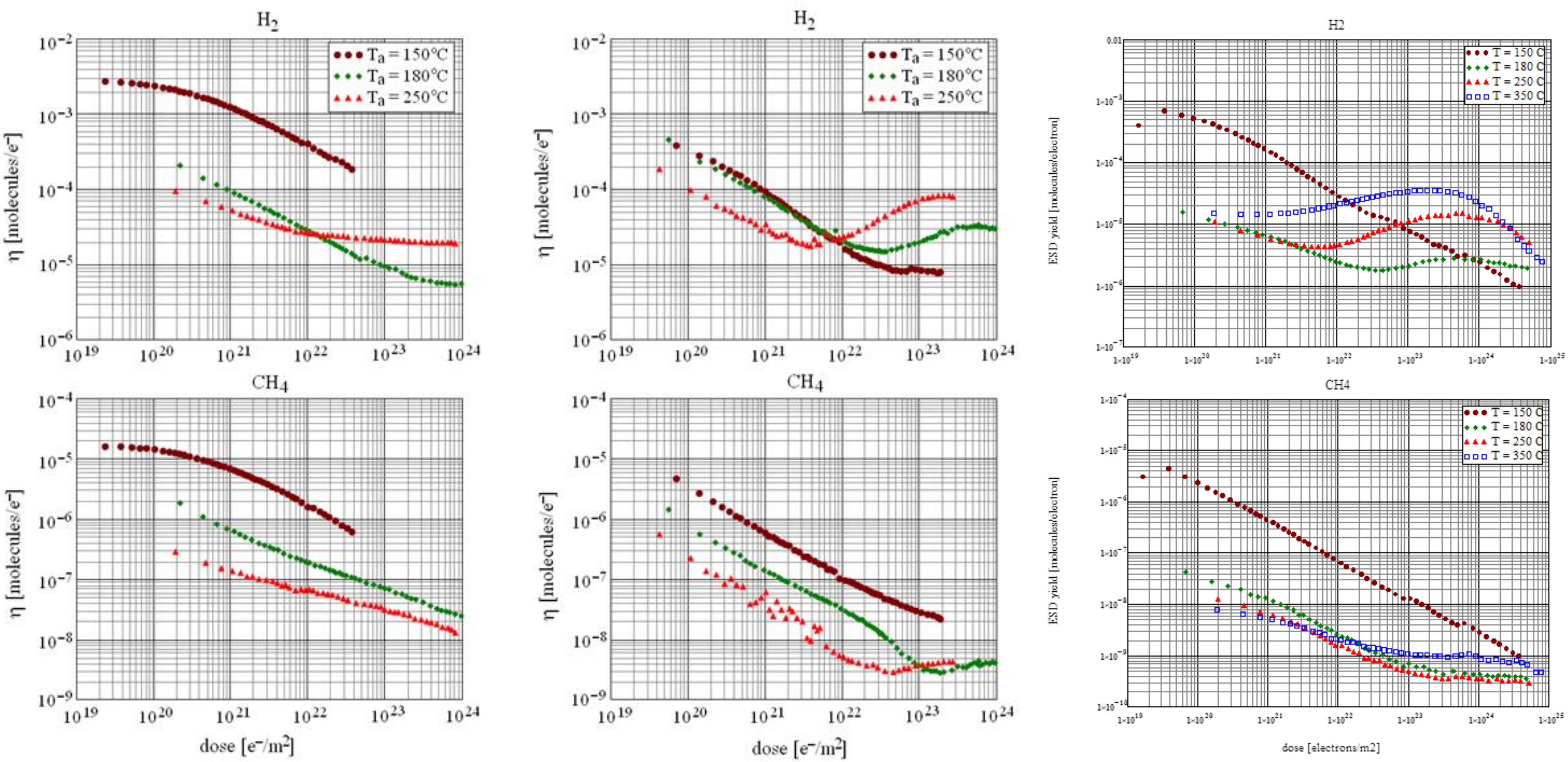


Dual layer


2 µm
EHT = 3.00 kV
WD = 6.6 mm
Signal A = SE2
Mag = 20.00 K X
12 20k mix edge1.tif
19 Jan 2012
2 µm
EHT = 3.00 kV
WD = 6.6 mm
Signal A = SE2
Mag = 20.00 K X
10 20k mix edge1.tif
19 Jan 2012
Columnar
Dense
1 µm
EHT = 10.00 kV
WD = 5.0 mm
Mag = 25.00 K X
Signal A = SE2
Date :3 Sep 2014

ESD for dense, columnar and dual layer NEG

(a) Dense film (b) Columnar film **(c) Dual layer**

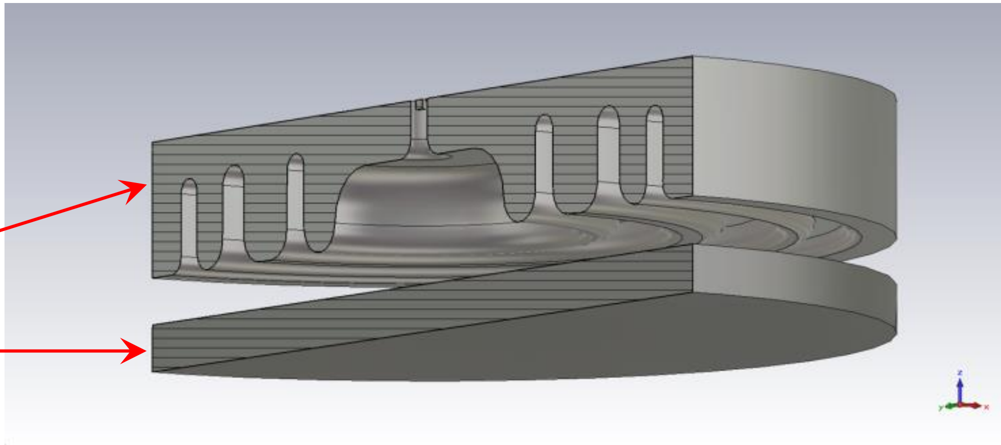


Dual layer combines both benefit:

- ESD yields are like for dense film with
- pumping properties of columnar film

Surface impedance: method

- The cavity geometry consists of two parts:
  - a body of the cavity
  - a planar sample,
  - separated by an air gap.
- Contactless
- RF chokes in order to keep the RF power within the cavity



$$R_S^{sam} = \frac{G\,Q_0^{-1} - R_S^{cav}\,p_c}{p_s}$$

- Modelled with CST Microwave Studio.
- G = 235 Ω.
- The field ratios p_c = 0.625 and p_s = 0.375 for perfect electric conductor boundary conditions.

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Analytical model

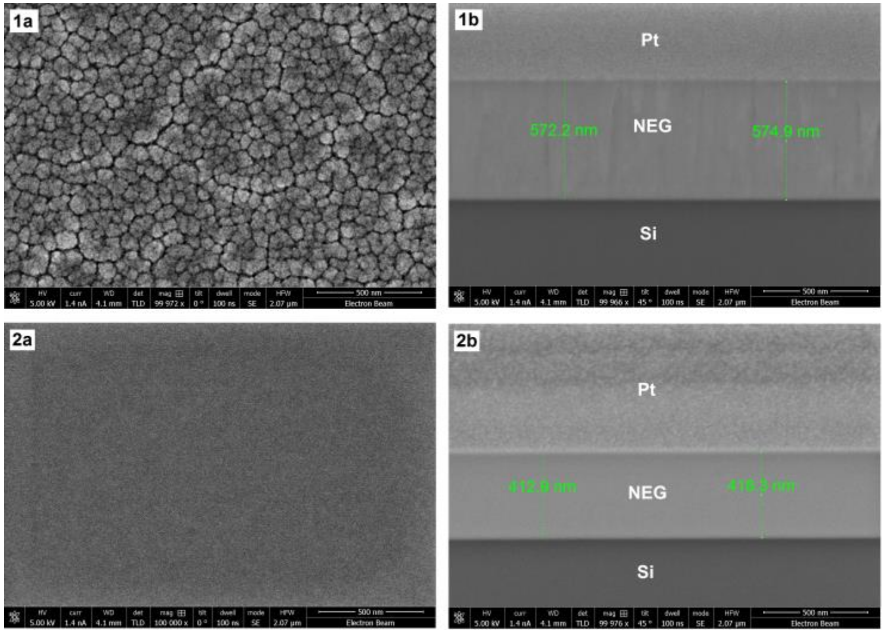
- The expressions for the surface impedance of a planar metallic film deposited on a substrate (dielectric or metallic) are derived by following the standard approach employed in calculating the transmission and reflection coefficients in layered media

$$R_S = R_1 \frac{1-\delta^2 \exp(-4\kappa_1 d_1) - 2\delta \sin(2\kappa_1 d_1)\exp(-2\kappa_1 d_1)}{1+\delta^2 \exp(-4\kappa_1 d_1) + 2\delta \cos(2\kappa_1 d_1)\exp(-2\kappa_1 d_1)} \quad \text{for NEG on metal substrate;}$$

$$R_S = R_1 \frac{1-\exp(-4\kappa_1 d_1) + 2\sin(2\kappa_1 d_1)\exp(-2\kappa_1 d_1)}{1+\exp(-4\kappa_1 d_1) - 2\cos(2\kappa_1 d_1)\exp(-2\kappa_1 d_1)} \quad \text{for NEG on Si substrate.}$$

NEG coatings

- NEG films
  - columnar
  - dense
- Deposited on:
  - polycrystalline copper
  - silicon Si(100) substrates.
- The substrate size was 100 mm × 100 mm × 2 mm
- Sample thickness:
  - from 0.7 to 18 μm



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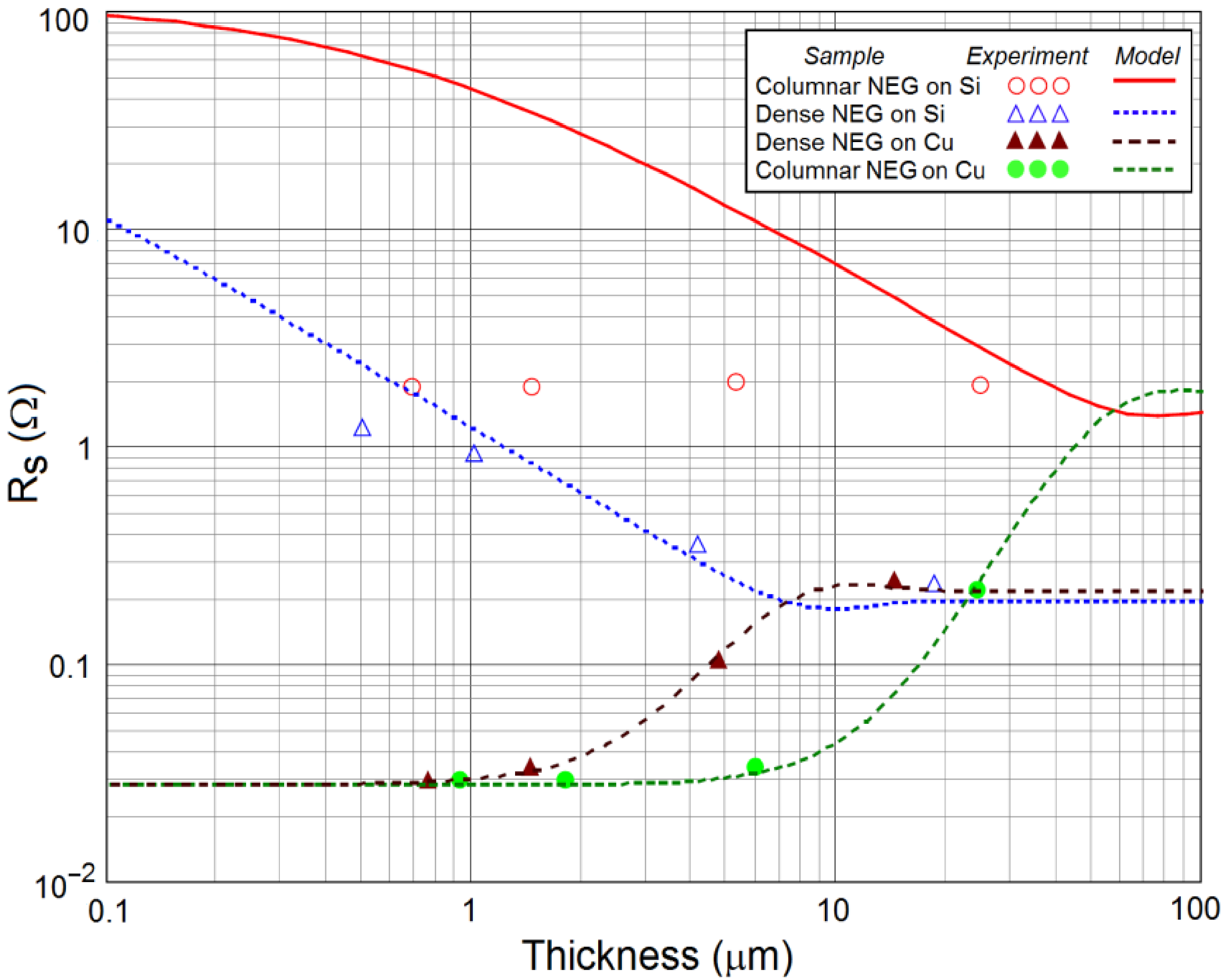
The surface resistance RS of dense and columnar NEG coatings on copper and silicon substrates as a function of film thickness



The bulk conductivity was obtained with the analytical model:

- σ_d = 1.4×10⁴ *S/m* for the columnar NEG coating
- σ_d = 8×10⁵ *S/m* for the dense NEG coating

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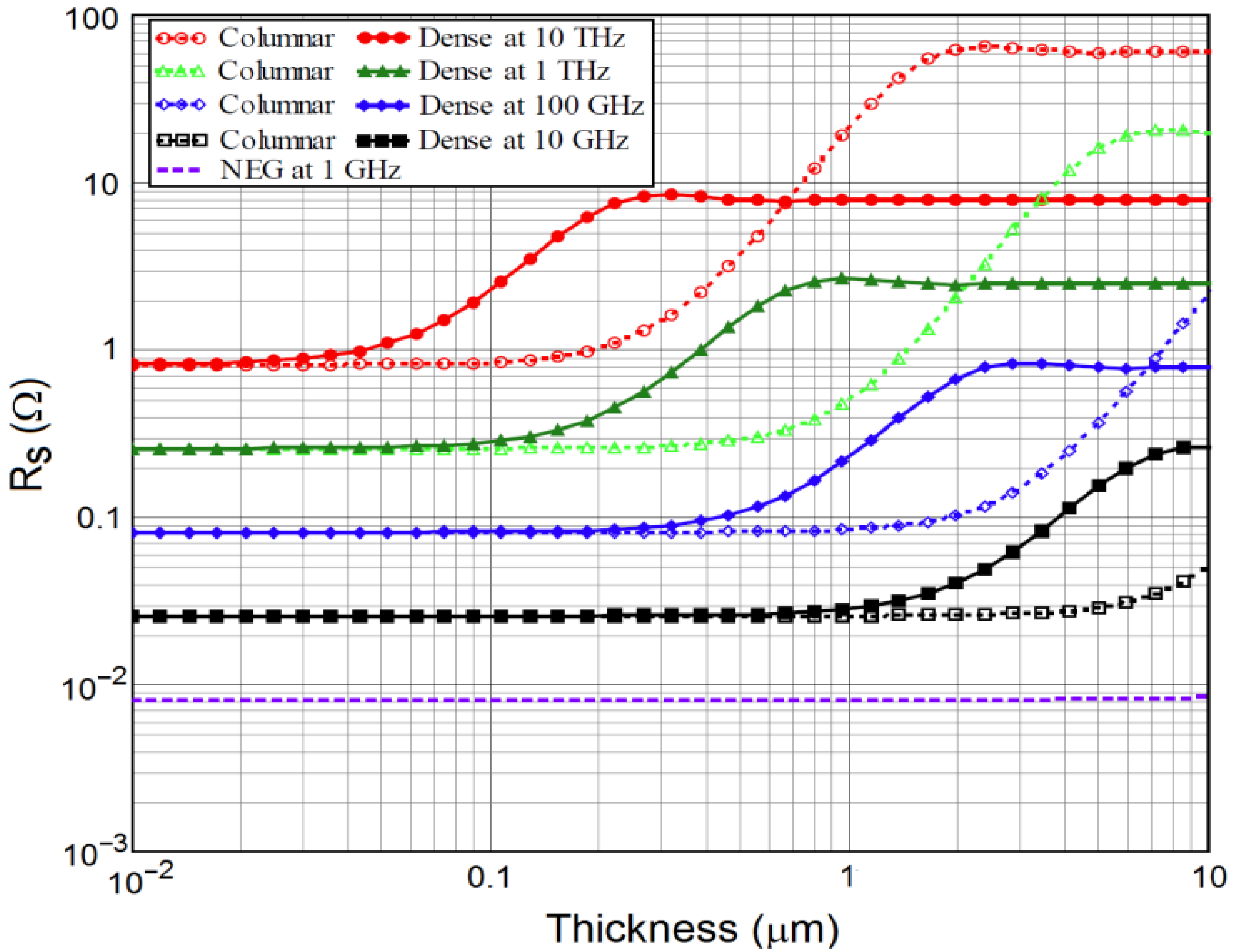
The surface resistance R_S as a function of NEG film thickness on copper at various frequencies



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Conclusion

- NEG coating is a technology that allows to meet **UHV/XHV** vacuum specification win long narrow vacuum chambers.
  - PSD and ESD After NEG activation at 180°C the initial η(316LN)/η(Ti-Zr-V) =
    - =20 for H_2, =1000 for CH_4 and =200 for CO.
    - Vacuum firing = an order of magnitude lower ESD
    - η(Ti-Zr-Hf-V) < η(Ti-Zr-V).
    - Best results is for the dense and dual layer NEG activated at 180 °C
  - Often the only vacuum solution
  - Lower cost of pumping system
- It require activation at 150-180 °C in stead of 250-300 °C usual bakeout:
  - Shorter or less bellows
  - Wider choice of material for vacuum chamber and components
- The bulk conductivity:
  - σd = 1.4×104 S/m for the columnar NEG coating
  - σd = 8×105 S/m for the dense NEG coating
- SEY < 1.1can be obtained after activation or by conditioning