Vacuum and e-cloud studies at DAFNE-TF

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on behalf of working team

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Outline

- Developing the e-cloud mitigation techniques at ASTeC
  - LASE
  - NEG coatings
- and studying their impact on accelerator systems
  - Surface resistance -> beam wakefield impedance -> beam parameters
  - Vacuum

Surface resistance

Surface resistance measurements: method

- The cavity geometry consists of two parts:
  - a body of the cavity
  - a planar sample,
  - separated by an air gap.
- Contactless

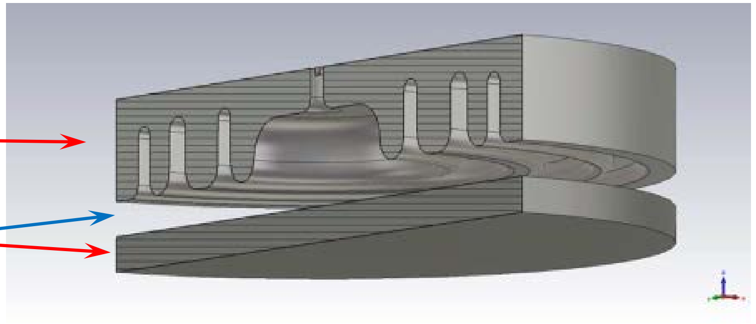
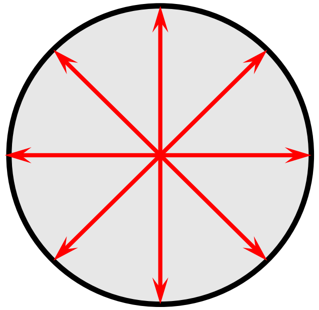
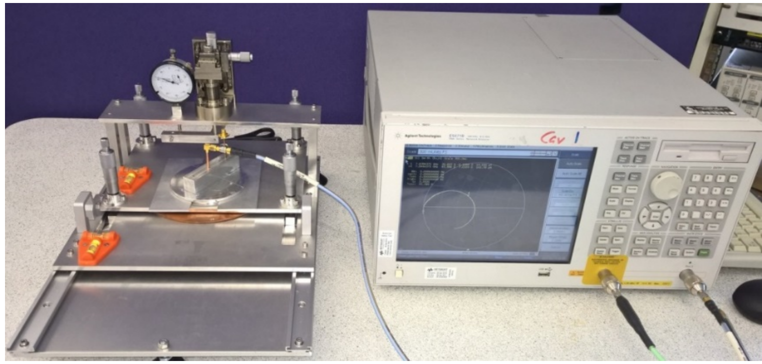


Fig. 1. A schematic of the triple choke RF cavity above a sample.



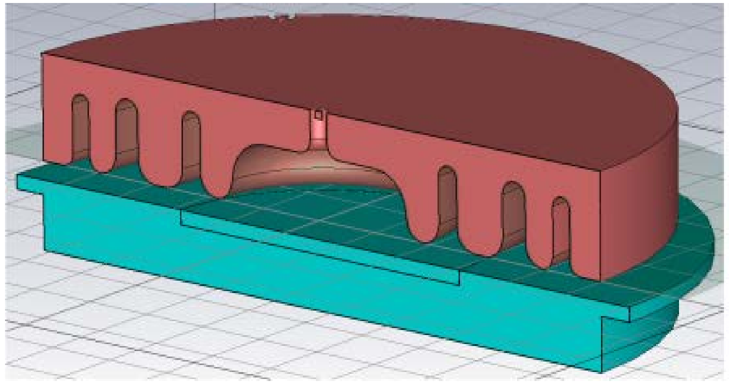
- RF chokes in order to keep the RF power within the cavity
- Operating in TM_{010} mode, has circular H field distribution hence Induces radial current.
- The surface resistance of the sample R_S^{sam} can be calculated for known
  - test cavity surface resistances R_S^{cav} and
  - measured Q_0,
- The magnetic field distribution in the cavity was calculated using CST Microwave Studio.
  - For our cavity, $G = 235\ \Omega$,
  - for a case using perfect electric conductor (PEC) boundary conditions, the field ratios are $p_c = 0.625$ and $p_s = 0.375$.

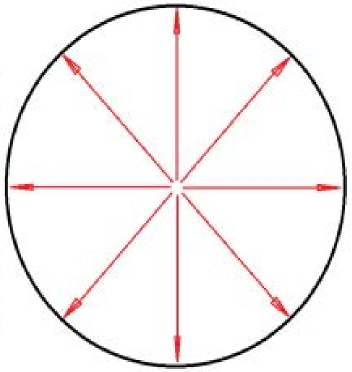
$$R_S^{sam} = \frac{G\,Q_0^{-1} - R_S^{cav}\,p_c}{p_s}$$



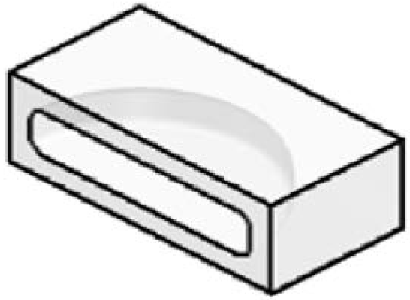
Surface resistance measurements

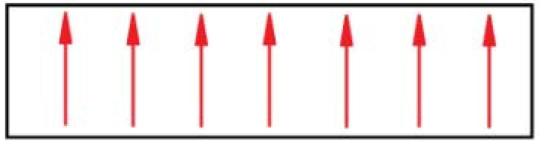
1st cavity – directionally averaged R_s





2nd cavity – R_s measurements along a selected direction





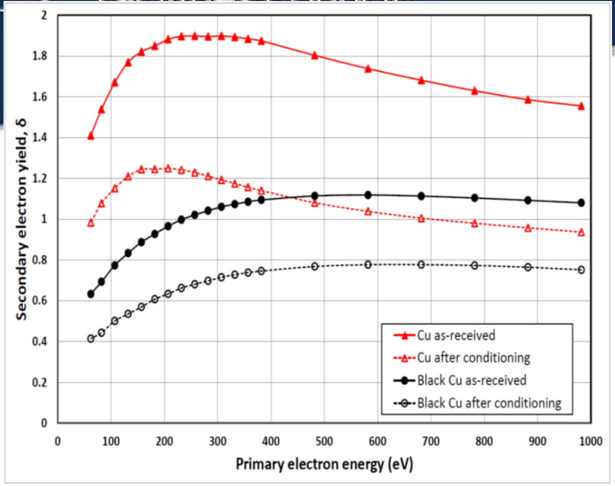
Test cavities (3.9 and 7.8 GHz):

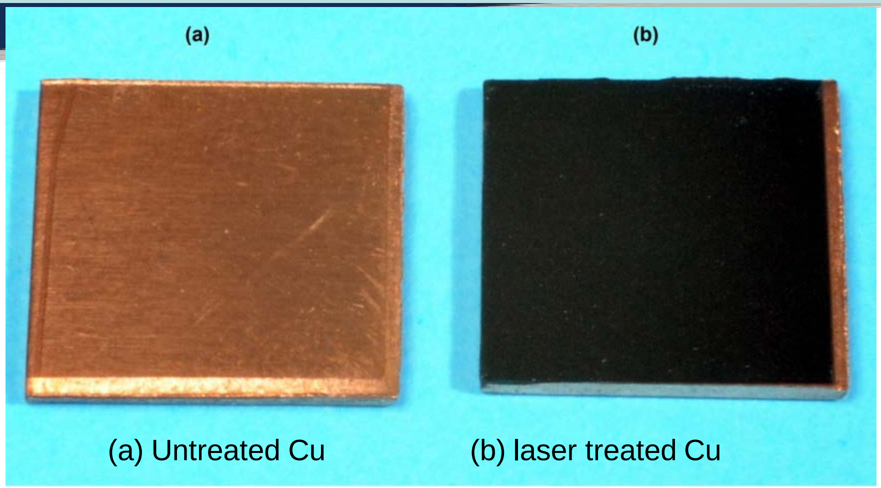
- The simulation results obtained with Microwave Studio
- Fabricated from Al.
- 3 choke cavity operating in TM_{010} mode, has circular H field distribution hence Induces radial current.
- Half pill box cavity operating in TM_{110} mode, has strong transverse H field hence induces axial electric current

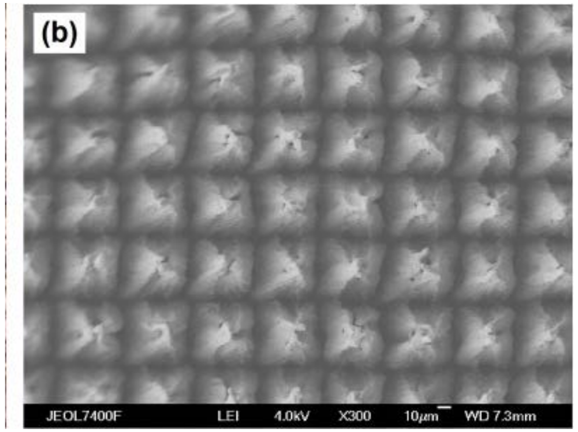
Samples:

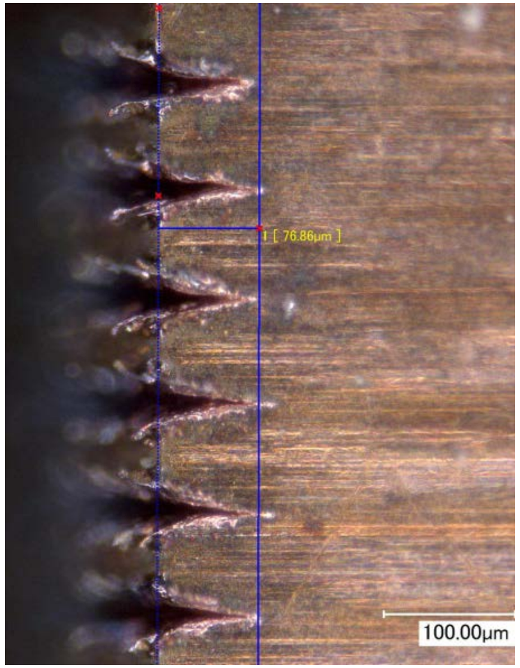
- 100 mm × 100 mm laser treated copper surface

Low SEY studies: First LASE results in 2014





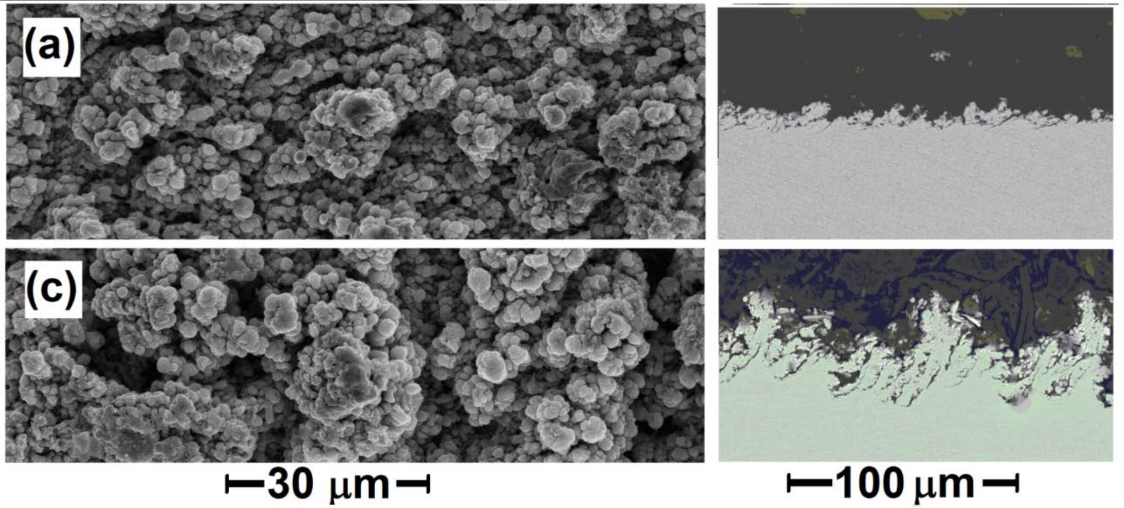




R. Valizadeh, O.B. Malyshev, S. Wang, et al. Low secondary electron yield engineered surface for electron cloud mitigation. Appl. Phys. Lett. 105, 231605 (2014); doi: 10.1063/1.4902993

- Nanostructuring of Material Surfaces by Laser Ablation is well established science and manufacturing
- The new is applying these surfaces to suppress PEY/SEY and to solve the e-cloud problem
- Main result: δ_{max} **< 1** can be achieved on Cu, Al and stainless steel
- Main question we had to ourselves and asked by other colleagues:
  - How **100-μm deep groves** affect surface resistance

Following low SEY studies



- Emphasis on physics:
    - How and why SEY is reduced on LASE surfaces
    - Further reduce SEY
    - Reduce surface resistance
    - Reduce particulate generation
    - Measure vacuum properties

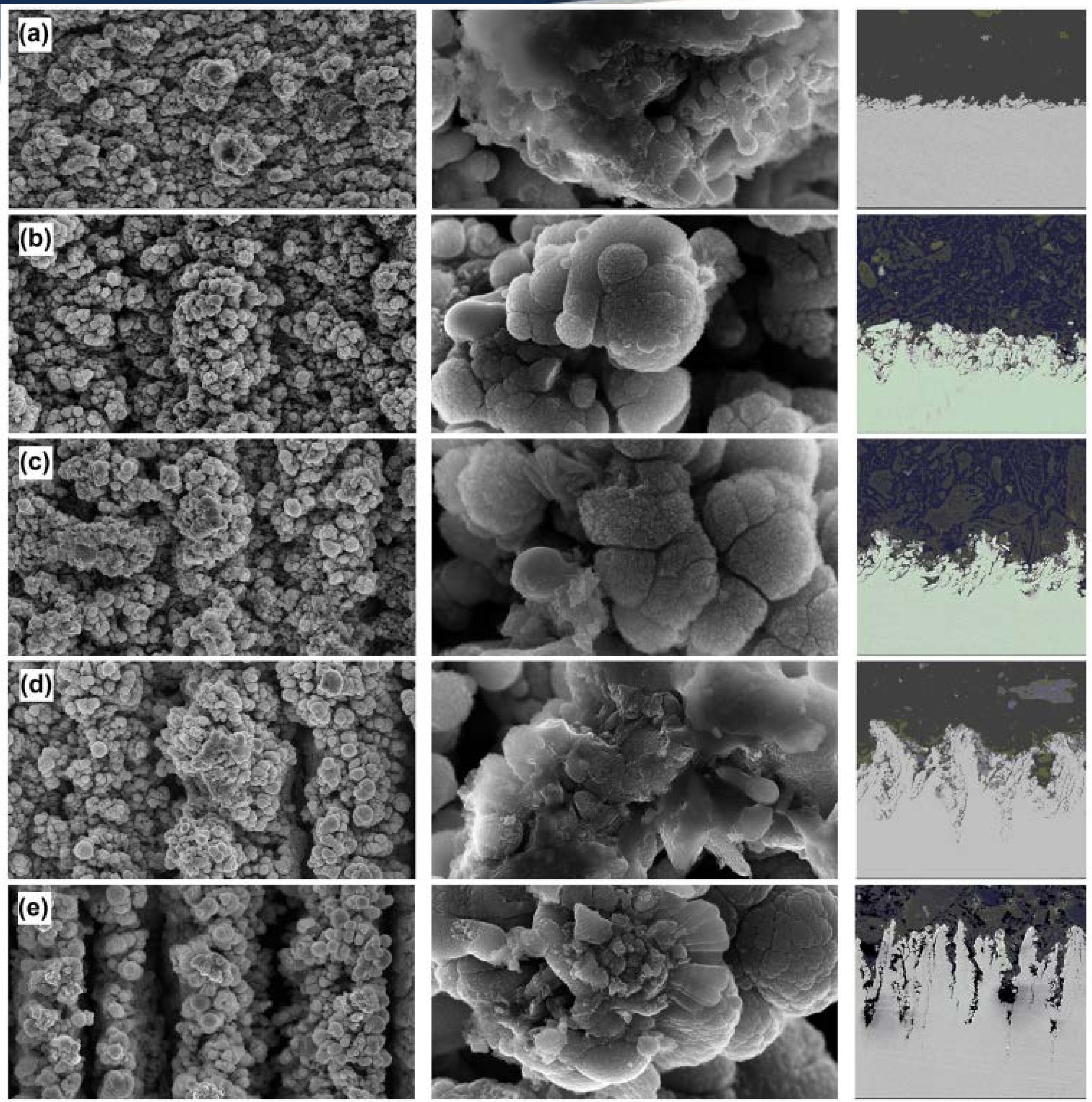
- R. Valizadeh, O.B. Malyshev, S. Wang, T. Sian, L. Gurran, P. Goudket, M.D. Cropper, N. Sykes. Low secondary electron yield of laser treated surfaces of copper, aluminium and stainless steel. In Proc. of IPAC'16, 8-13 May 2016, Busan, Korea (2016), p. 1089.
- R.Valizadeh, O.B.Malyshev, S.Wang, T.Sian, M.D.Cropper, N.Sykes. Reduction of Secondary Electron Yield for E-cloud Mitigation by Laser Ablation Surface Engineering, Applied Surface Science 404 (2017) 370-379. http://dx.doi.org/10.1016/j.apsusc.2017.02.013

Treatment of copper using a λ = 355 nm laser resulted in creation of three different scales structures as presented:

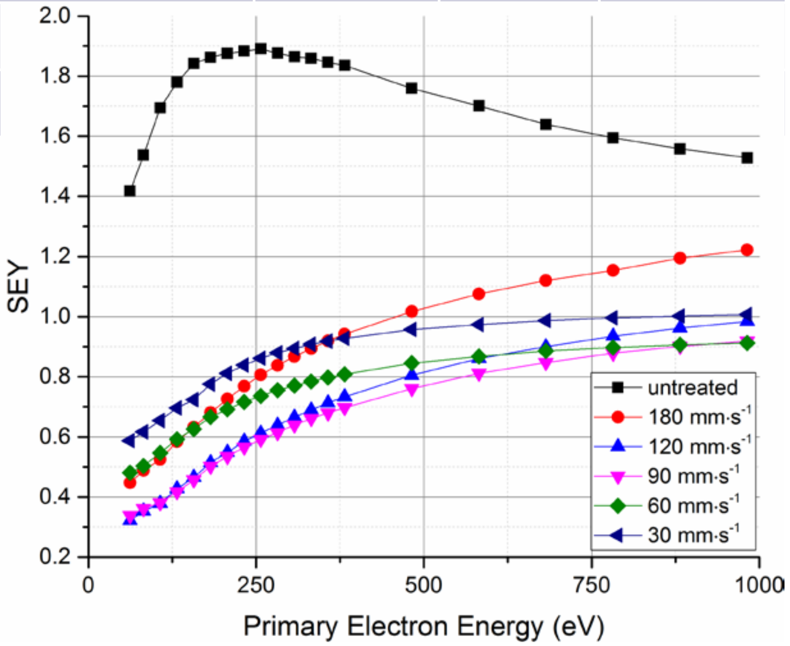
- microstructure grooves ranging from 8 to 100 µm deep,
- coral-like submicron particles superimposed on the grooves which is made of agglomeration of
    - nano-spheres

It was demonstrated that not only microstructure (groves) **but the nano-structures are playing a key role in reducing SEY.**
these surfaces can be produced using various lasers with different wavelength, such as λ=355 nm and λ=1064 nm.

LASE: A role of laser scan speed on copper samples



Sample	Scan speed [mm/s]	Groove depth [µm]	R_s [Ω]	R_s [Ω]		
			average	0°	45°	90°
Cu	untreated	-	0.033			
(a)	180	8	0.078	0.11	0.11	0.095
(b)	120	20	0.13			
(c)	90	35	0.14	0.15	0.19	0.20
(d)	60	60				
(e)	30	100				



Calculated and measured R_S at frequency f=7.8 GHz

Sample	Scan speed [mm/s]	Groove depth for LASE (Roughness for untreated metals) [μm]	Rs [Ω] measured with a 7.8-GHz cavity	Rs [Ω] calc with formula
Cu	untreated	0.4	0.028	0.029
(a)	180	8	0.078	~~0.046~~
(b)	120	20	0.13	~~0.046~~
(c)	90	35	0.14	~~0.046~~
(d)	60	60	–	~~0.046~~
(e)	30	100	–	~~0.046~~
Al	untreated	0.4	0.034	0.034
Nb	untreated	1.0	0.071	0.080
SS	untreated	1.4	0.17	0.16

Hammerstad and Bekkadal formula: $$R_s = \sqrt{\frac{\mu\omega}{2\sigma}}\left(1+\frac{2}{\pi}\arctan\left(0.7\,\mu\omega\sigma R_Q{}^2\right)\right);$$

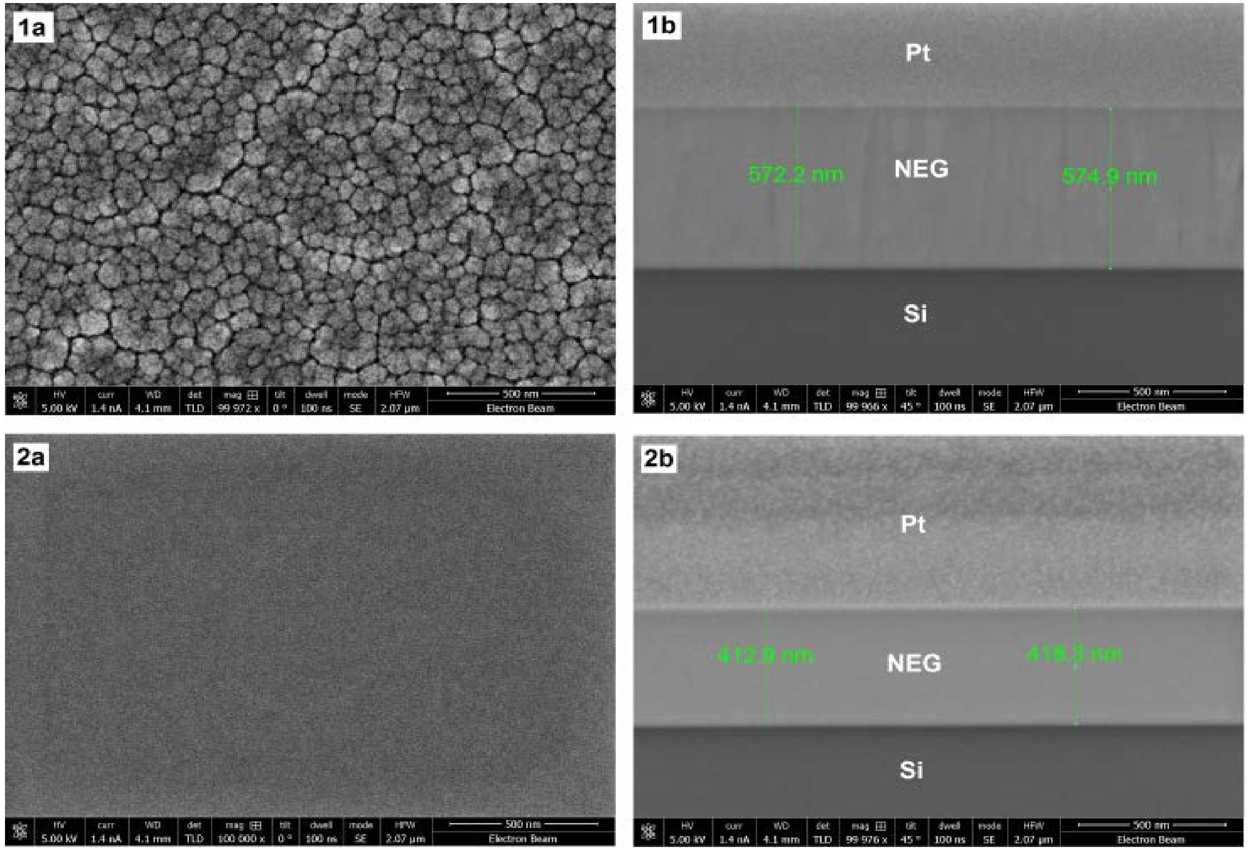
LASE samples

- More than 100 samples with different laser parameter were produced on:
  - copper,
  - stainless steel and
  - aluminium substrates
- SEY<1 on ~60%

➢ The following study is focused on meeting other specification than SEY<1

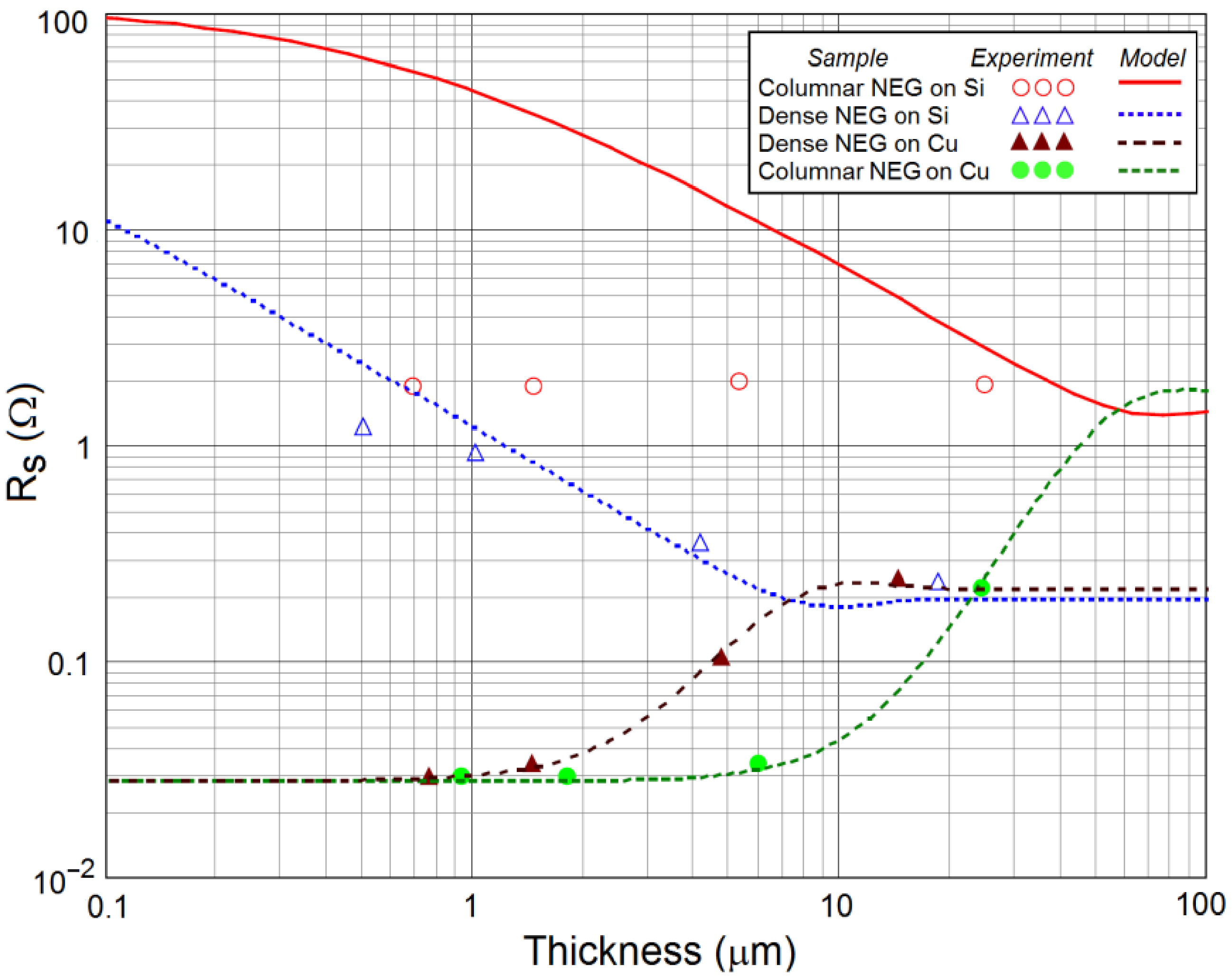
NEG coatings

- NEG coating is well-know for good vacuum properties
  - There are a variety of NEG films
- NEG film morphology:
  - 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



O.B. Malyshev, L. Gurran, P. Goudket, K. Marinov, S. Wilde, R. Valizadeh and G. Burt.. Nucl. Instrum. Methods Phys. Res., A 844, 99-107 (2017)

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



$$R_S = R_1 \frac{1-\exp(-4\kappa_1 d_1)+2\sin(2\kappa_1 d_1)\exp(-2\kappa_1 d_1)}{1+\exp(-4\kappa_1 d_1)-2\cos(2\kappa_1 d_1)\exp(-2\kappa_1 d_1)}$$

for NEG on Si substrate

$$R_S = R_1 \frac{1-\delta^2\exp(-4\kappa_1 d_1)-2\delta\sin(2\kappa_1 d_1)\exp(-2\kappa_1 d_1)}{1+\delta^2\exp(-4\kappa_1 d_1)+2\delta\cos(2\kappa_1 d_1)\exp(-2\kappa_1 d_1)}$$

for NEG on metal substrate

The bulk conductivity was obtained with the analytical model:

- **σ_d = 1.4×10^4 *S/m*** for the columnar NEG coating
- **σ_d = 8×10^5 *S/m*** for the dense NEG coating

O.B. Malyshev, L. Gurran, P. Goudket, K. Marinov, S. Wilde, R. Valizadeh and G. Burt. Nucl. Instrum. Methods Phys. Res., A 844, 99-107 (2017)

NEG coating studies – surface resistance

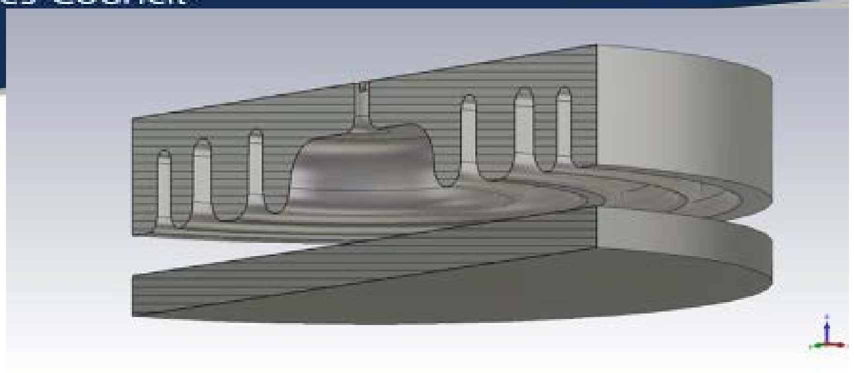


Fig. 1. A schematic of the triple choke RF cavity above a sample.

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

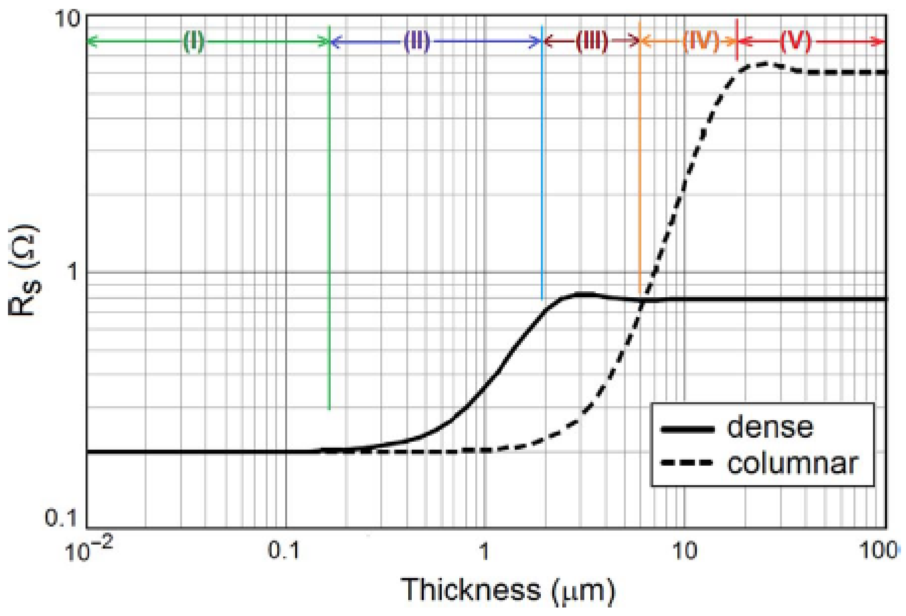


Fig. 7. A comparison of surface resistance of columnar (solid line) and dense (dashed line) NEG films, zones (I)–(V) as described in the text.

Five zones:

I. NEG coating's impact on the substrate surface resistance is negligible: **R_S(NEG) ≈ R_S(Cu);**

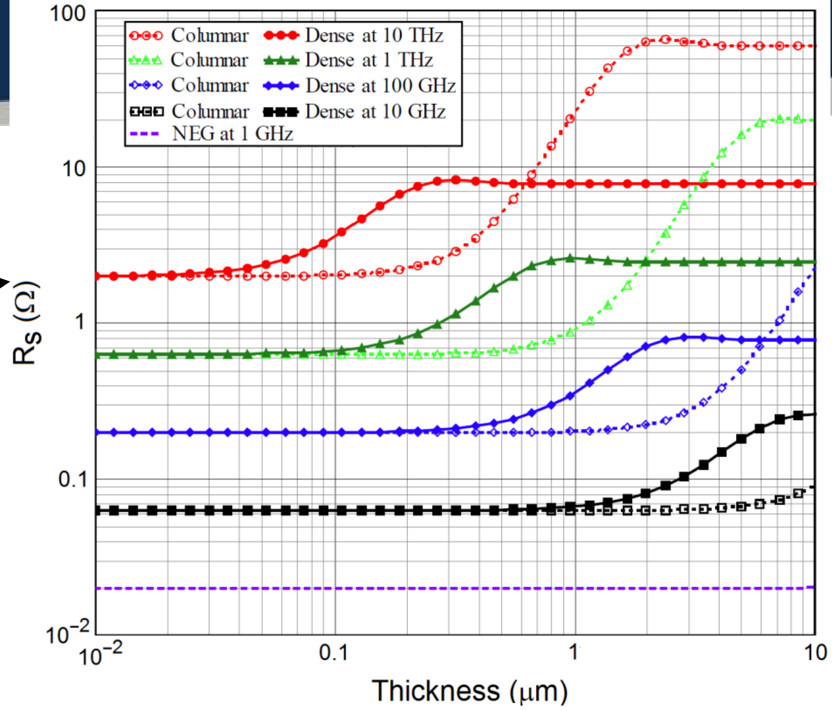
II. R_S of dense NEG coating steadily increases to its maximum, the columnar NEG impact on R_S is still negligible: **R_S(dense) > R_S(columnar) ≈ R_S(Cu)**;

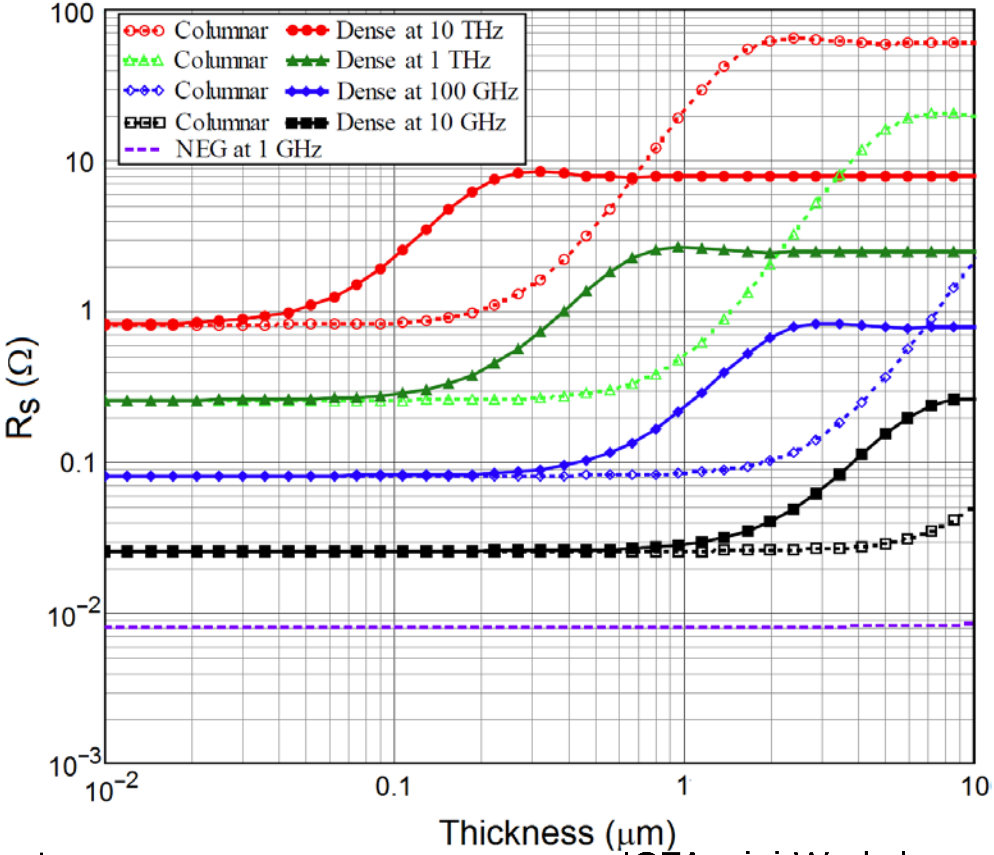
III. R_S of columnar NEG coating steadily increases and reaches a maximum value for dense NEG: **R_S(Cu) < R_S(columnar) < R_S(dense)**;

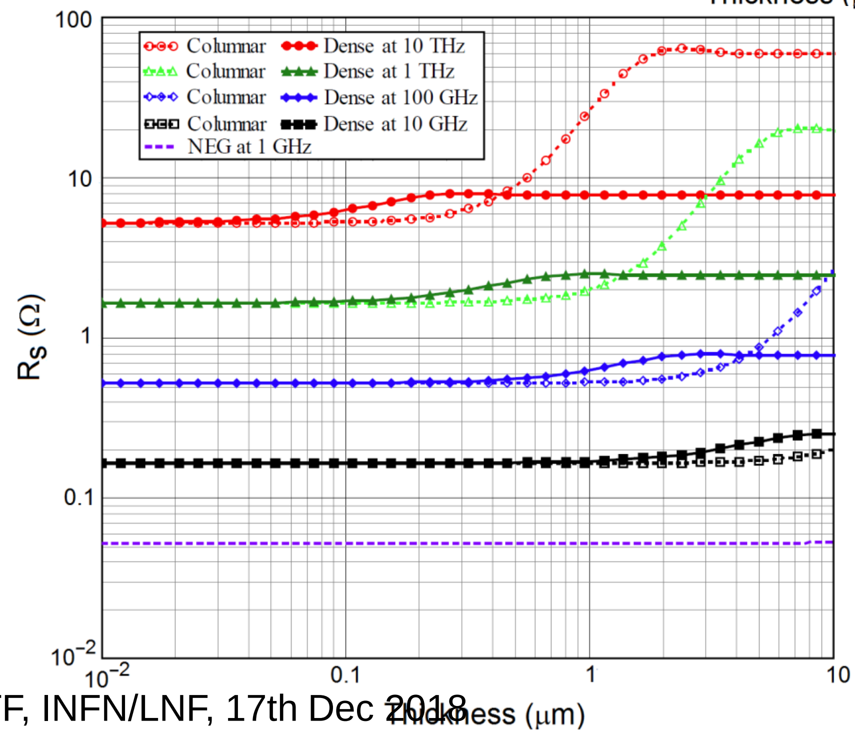
IV. R_S of columnar NEG coating steadily increases to its maximum: **R_S(Cu) < R_S(dense) < R_S(columnar)**;

V. R_S of both dense and columnar NEG do not increase further with thickness.

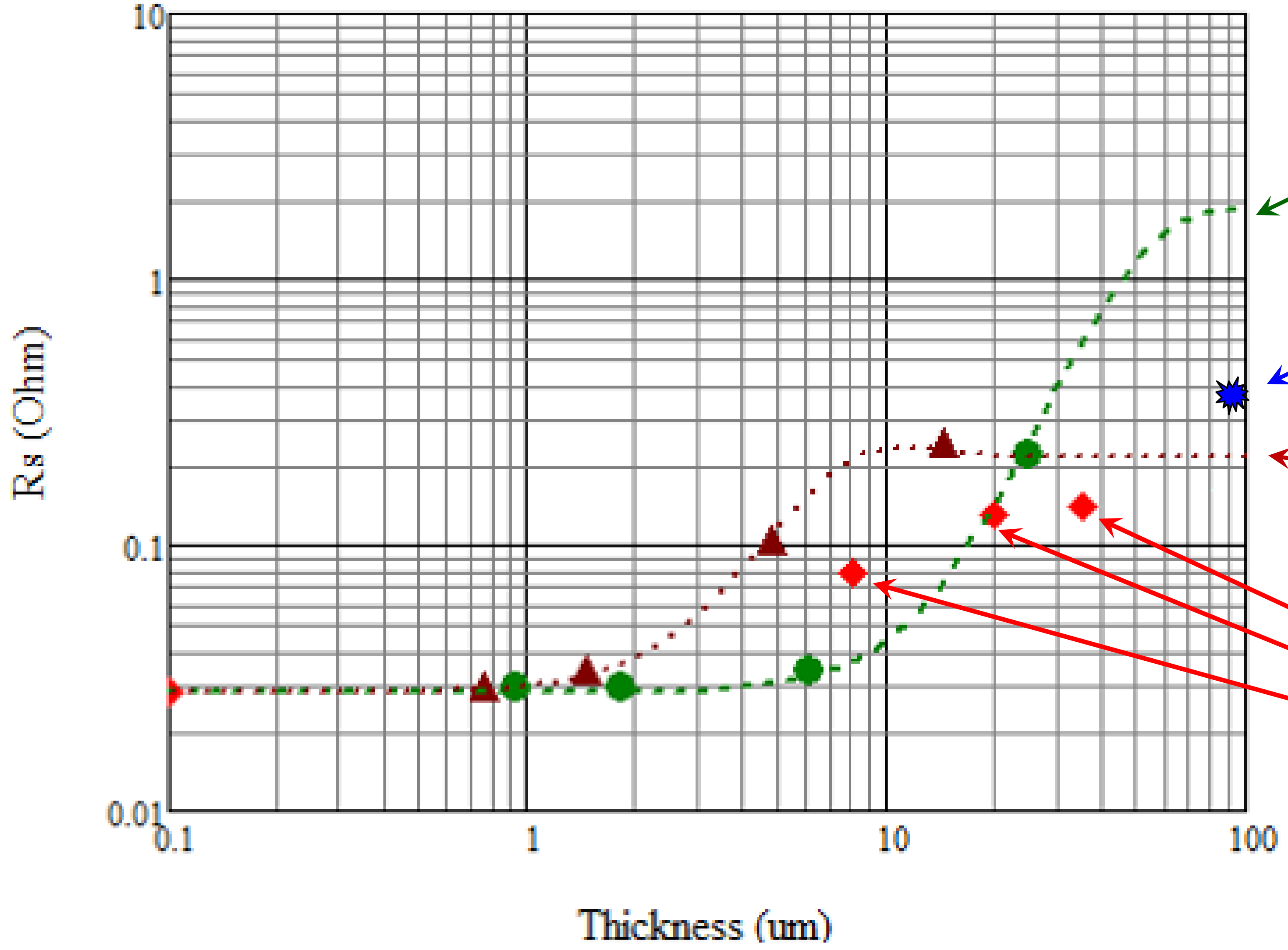
NEG coating studies – surface resistance at various frequencies on copper, aluminium and stainless steel







Surface resistance at 7.8 GHz for LASE and NEG coating



Columnar NEG coating

$\sigma_d = 1.4\times10^4\ S/m$

LASE:

pyramidal shape

Dense NEG coating

$\sigma_d = 8\times10^5\ S/m$

LASE:

(shallow) groves

Surface resistance

- An open question:
  - R_s as a function of RF frequency
  - R_s as a function of temperature
  - How relevant these data for the machine modelling and design?
- New materials with lower R_s have been developed in ASTeC:
  - What R_s is acceptable for each machine? How to specify?

➢ Machine tests are essential to bring more confidence to the lab results and to the applied models and parameters

Diamond II: the DDBA project (2013-2016)

PHYSICAL REVIEW ACCELERATORS AND BEAMS 21, 050701 (2018)

Double-double bend achromat cell upgrade at the Diamond Light Source: From design to commissioning

R. Bartolini,[1,2] C. Abraham,[1] M. Apollonio,[1] C. P. Bailey,[1] M. P. Cox,[1] A. Day,[1] R. T. Fielder,[1] N. P. Hammond,[1] M. T. Heron,[1] R. Holdsworth,[1] J. Kay,[1] I. P. S. Martin,[1] S. Mhaskar,[1] A. Miller,[1] T. Pulampong,[1] G. Rehm,[1] E. C. M. Rial,[1] A. Rose,[1] A. Shahveh,[1] B. Singh,[1] A. Thomson,[1] and R. P. Walker[1]

[1]*Diamond Light Source, Oxfordshire, OX11 0DE, United Kingdom*
[2]*John Adams Institute, University of Oxford, Oxford OX1 3RH, United Kingdom*

PHYSICAL REVIEW ACCELERATORS AND BEAMS 21, 060701 (2018)

Characterization of the double-double bend achromat lattice modification to the Diamond Light Source storage ring

I. P. S. Martin,* M. Apollonio, R. T. Fielder, E. Koukovini-Platia, and B. Singh
Diamond Light Source, Oxfordshire, OX11 0DE, United Kingdom

R. Bartolini
Diamond Light Source, Oxfordshire, OX11 0DE, United Kingdom and John Adams Institute, University of Oxford, Oxford OX1 3RH, United Kingdom

Lots of lesson learns on technology (magnets, vacuum, diagnostics, engineering)

General trust in AP simulations and commissioning tools

Worrisome increase in the impedance content of the ring – It is to be seen whether a full upgrade (*24 cells) will work with the solution used for the vacuum chamber

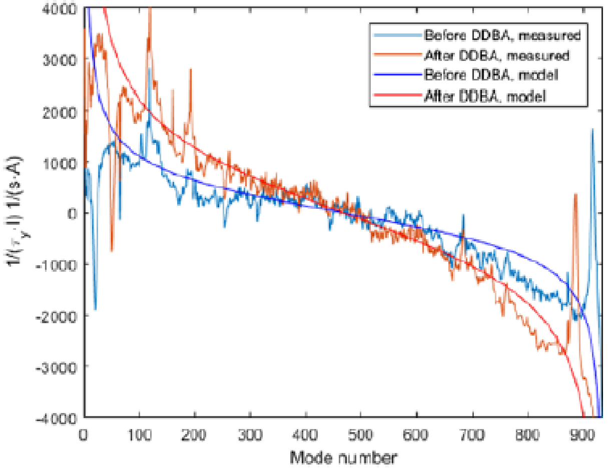


FIG. 17. Comparison of vertical multibunch modes growth rate before and after DDBA. All ID closed at 7 mm gap.

Prof. Riccardo Bartolini (DLS):

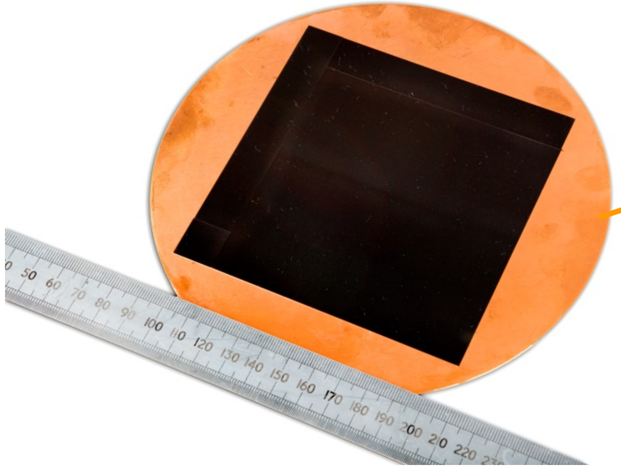
- Understanding the impedance due to smaller apertures + RW (and NEG contribution) is important for next rings and is a valid experimental test at DAFNE but also ANKA
- DLS is interested in participating to experimental activities in the characterisation of the NEG in view of Diamond II

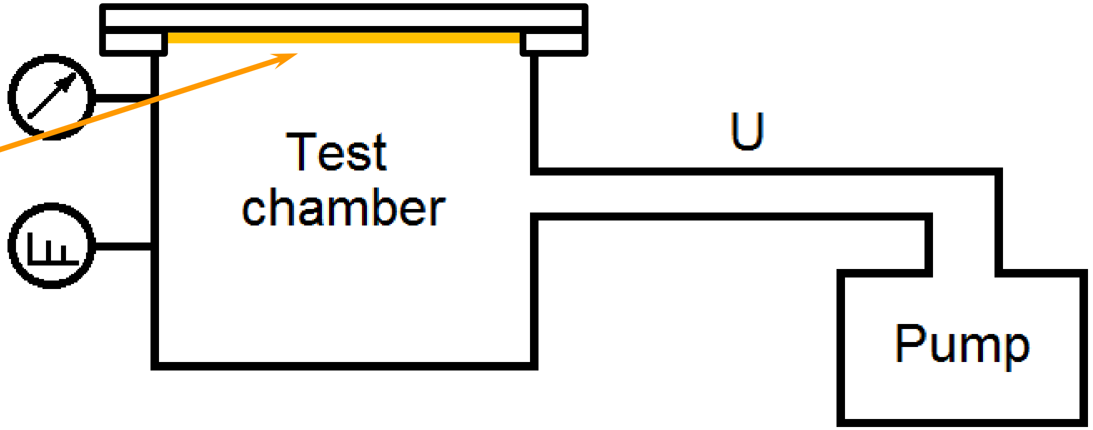
DLSR Workshop
Berkeley, 30 October 2018

Vacuum properties

LASE: thermal outgassing

- Sample:
  - a 100-mm diam. disk (copper gasket)
  - After LASE
- No difference in outgassing detected in a vacuum chamber without and with a sample

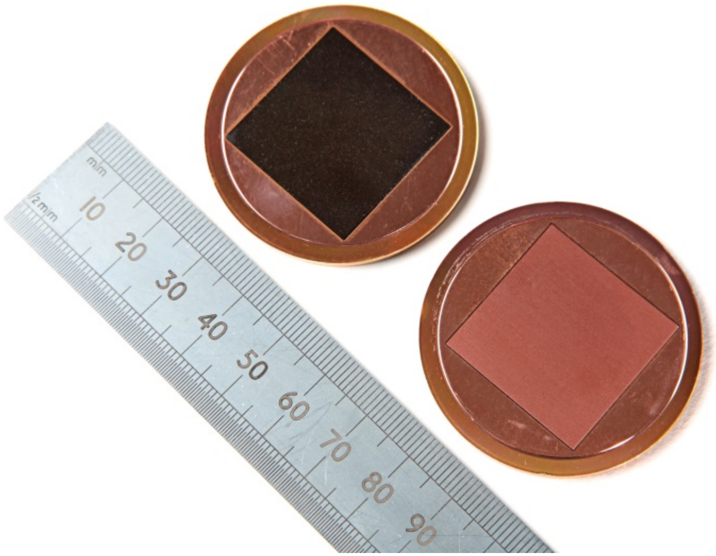


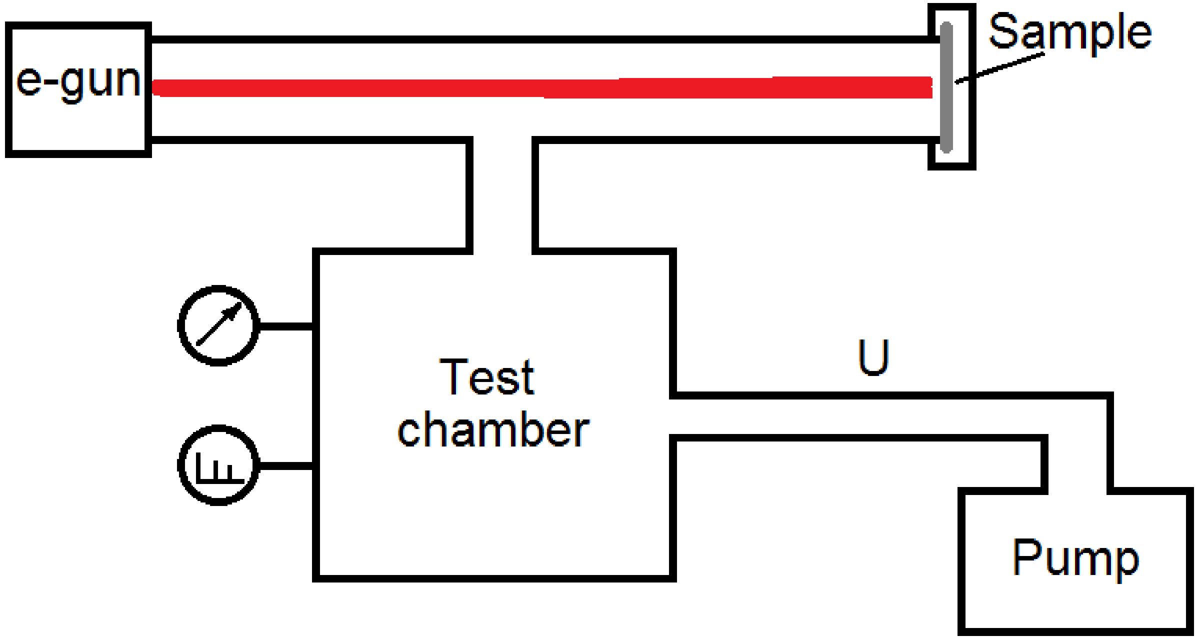


LASE: Electron Stimulated Desorption (ESD)

- 11 samples were tested:
  - Cu blank gaskets ∅48 mm
    - Untreated (3 samples)
    - Laser treated in air or Ar atmosphere
  - E_{e-} = 500 eV

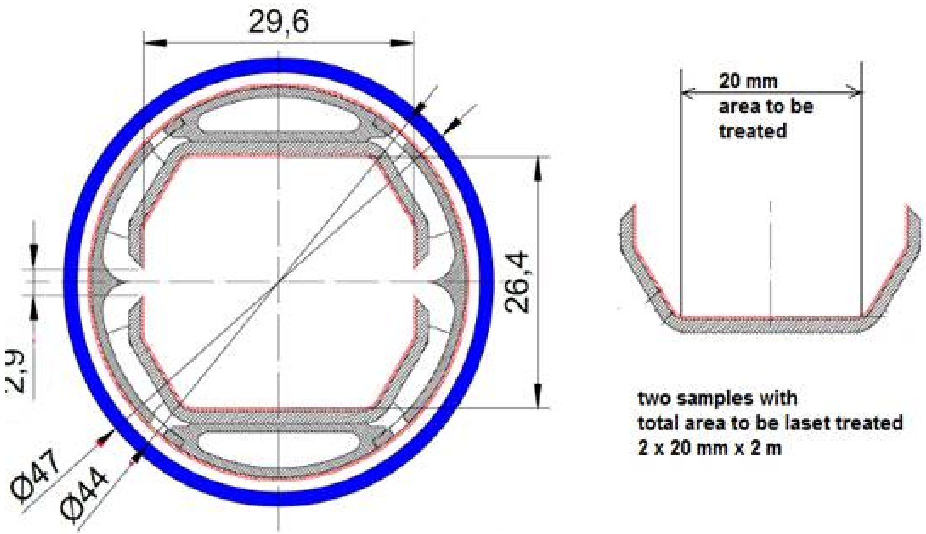
ESD of LASE of lower than for untreated copper by a factor >3-10

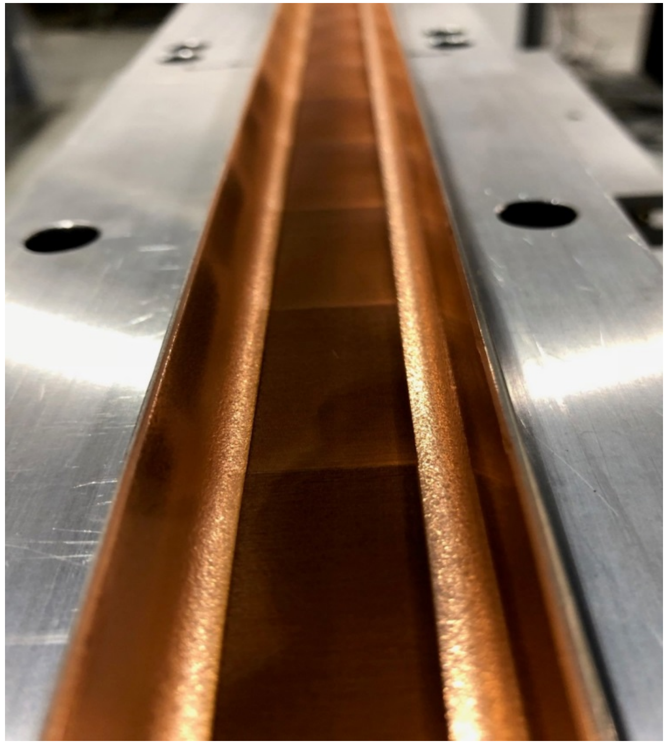




Photon Stimulated Desorption (PSD)

- KARA experiment in ANKA as a part of EuroCirCol WP4:
  - 2 m long porotype of the FCC-hh vacuum chamber
  - a tube in two halves, treated area of each half is 2 m x 20 mm.
  - Laser 1064 nm.
  - PSD measurements at room temperature





NEG coating vacuum properties

- 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,

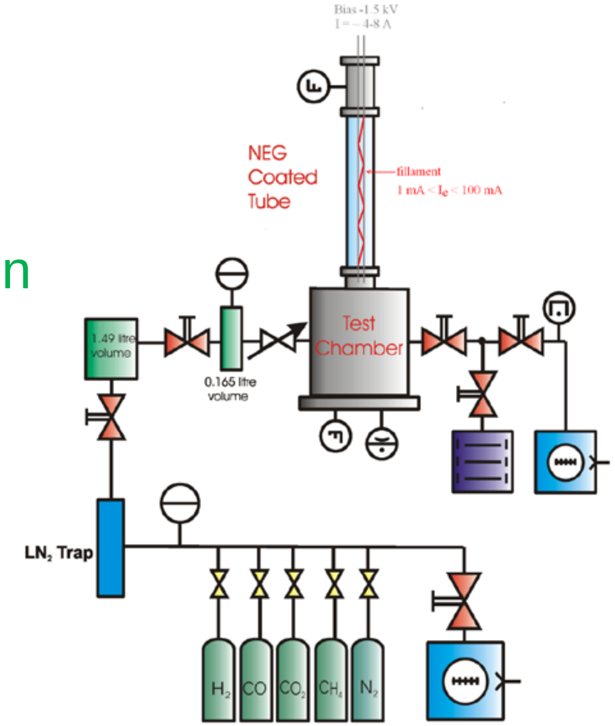
     A – surface area,

     v – mean molecular velocity

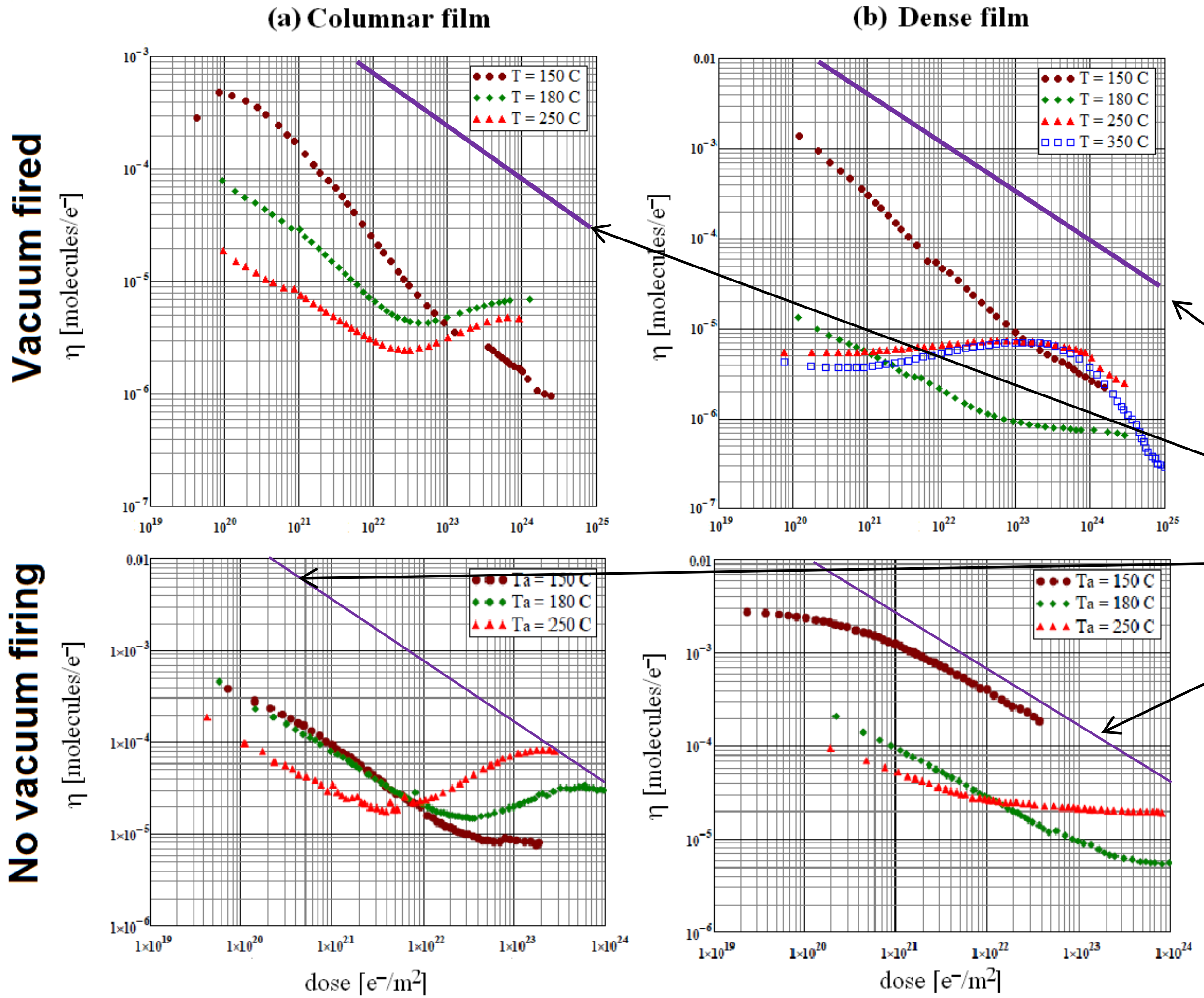
- Thermal outgassing is negligible
- Pumping:
  - $\alpha_{CO} \leq 0.4$, $\alpha_{CO2} \leq 0.6$, $\alpha_{H2} \leq 0.02$,
  - $\Theta_{CO} \leq 3$ ML, $\Theta_{CO2} \leq 10$ ML
- PSD and ESD lower than uncoated surface

ESD measurements:

- Various coatings on tubular samples
  - Composition,
  - Structure,
  - morphology
- $E_{e-} = 500$ eV



ESD of H_2 from NEG coating



$$P \propto \frac{\eta}{\alpha} = \frac{\text{desorption yield}}{\text{sticking probability}}$$

- H_2 ESD is much lower than for 316 LN
- Distributed pumping
  - => low pressure

316LN
T_b = 250 °C

- **O.B. Malyshev, R. Valizadeh, et al. JVST A 32, 061601 (2014)**
- **O.B. Malyshev et al. / Vacuum 86, 2035 (2012)**

Summary: Impact of ecloud mitigation on other systems

	LASE	NEG coating
E-cloud	• SPS and LHC machine tests • More data are required for different LASE and different conditions	• LHC operation • No systematic data for different types of NEG coating
SEY	δ_{max} **< 0.6**	δ_{max} **< 1**
PEY	• PEY? (scaled with SEY?) • Data are required	• PEY scaled with SEY (KEK data) • No data for different types of NEG coating
Vacuum		
Thermal outgassing	Low	Negligible
Photon stimulated desorption (PSD)	• To be studied (KARA experiment) • More data are required for different LASE and different conditions (cleaning, storage, bakeout, etc.)	Lower than for 316LN • BINP and ESRF data, • experience from many machines • No data for different types of NEG coating
Electron stimulated desorption (ESD)	Much lower than for Cu	Much lower than for 316LN
Bakeout/activation temperature	• Bakeable to 150 – 300 °C	• Can be activated to 140 – 250 °C • SR induced activation study needed
Beam wakefield impedance	• Low R_s LASE surface development • Machine tests are essential	• Low R_s NEG coating development • Machine tests are essential