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NEG coatings and Laser Ablation Surface Engineering (LASE) electron cloud mitigation techniques

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ASTeC

MANCHESTER 1824 The University of Manchester

Loughborough University

EuroCirCol Task 4.3: Mitigate beam-induced vacuum effects

ASTeC Vacuum Science Group,

STFC Daresbury Laboratory, UK

EuroCirCol

FCC Week 2018, 9-13 April 2018,

Beurs van Berlage, Amsterdam, Netherlands

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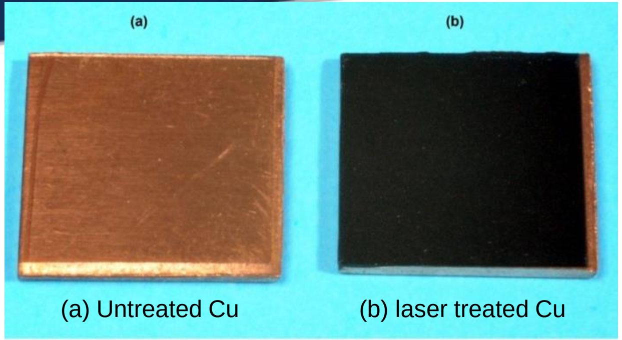
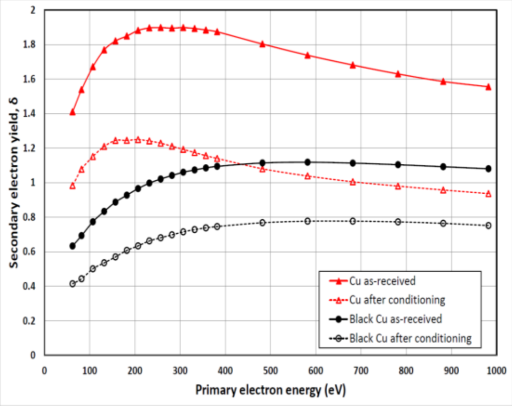
SEY studies:

e-cloud mitigation
by reducing Secondary Electron Yield (SEY)
Laser Ablation Surface Engineering (LASE)

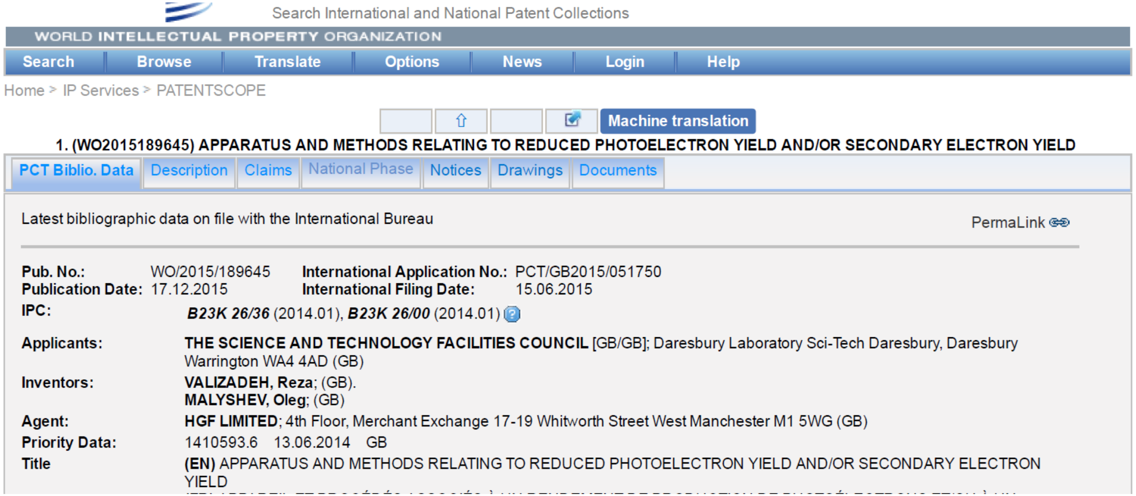
Discovery of LASE for SEY mitigation



(a) Untreated Cu (b) laser treated Cu



R. Valizadeh, et al. Appl. Phys. Lett. 105, 231605 (2014); doi: 10.1063/1.4902993



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1. (WO2015189645) APPARATUS AND METHODS RELATING TO REDUCED PHOTOELECTRON YIELD AND/OR SECONDARY ELECTRON YIELD

PCT Biblio. Data | Description | Claims | National Phase | Notices | Drawings | Documents

Latest bibliographic data on file with the International Bureau

PermaLink

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Publication Date: 17.12.2015 **International Filing Date:** 15.06.2015
IPC: ***B23K 26/36*** (2014.01), ***B23K 26/00*** (2014.01)
Applicants: **THE SCIENCE AND TECHNOLOGY FACILITIES COUNCIL** [GB/GB]; Daresbury Laboratory Sci-Tech Daresbury, Daresbury Warrington WA4 4AD (GB)
Inventors: **VALIZADEH, Reza**; (GB).
MALYSHEV, Oleg; (GB)
Agent: **HGF LIMITED**; 4th Floor, Merchant Exchange 17-19 Whitworth Street West Manchester M1 5WG (GB)
Priority Data: 1410593.6 13.06.2014 GB
Title **(EN)** APPARATUS AND METHODS RELATING TO REDUCED PHOTOELECTRON YIELD AND/OR SECONDARY ELECTRON YIELD

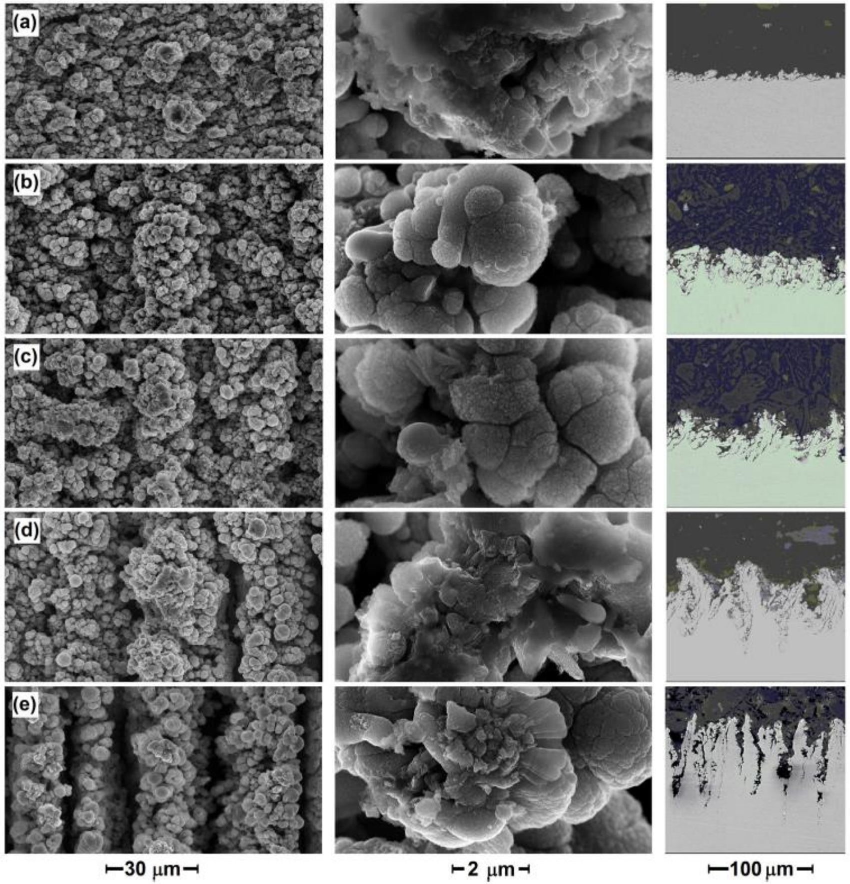
- Nanostructuring of Material Surfaces by Laser Ablation is well established science and manufacturing
- The new is applying these surfaces to suppress PEY/SEY and to solve the e-cloud problem
- Main result: SEY < 1 can be achieved on Cu, Al and stainless steel

Recent low SEY studies

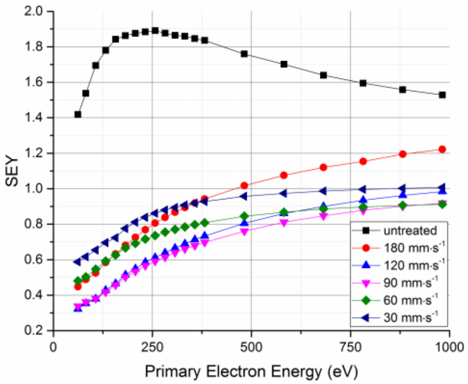
- Emphasis on the following problems:
  - How and why SEY is reduced on LASE surfaces
  - Reduce SEY with various lasers
  - Study an effect of cleaning
  - Study an effect of aging
  - Reduce surface resistance to minimise an impact on beam impedance
  - Reduce particulate generation
  - Apply for machine tests

- R. Valizadeh, O.B. Malyshev, S. Wang, et al. IPAC'16, p. 1089.
- R.Valizadeh, O.B.Malyshev, S.Wang, et al. Applied Surface Science 404 (2017) 370-379. http://dx.doi.org/10.1016/j.apsusc.2017.02.013

A role of laser scan speed on copper samples



Sample	Scan speed [mm/s]	Groove depth [µm]	Rs [Ω]
	untreated	-	0.033
(a)	180	8	0.078
(b)	120	20	0.13
(c)	90	35	0.14
(d)	60	60	–
(e)	30	100	–



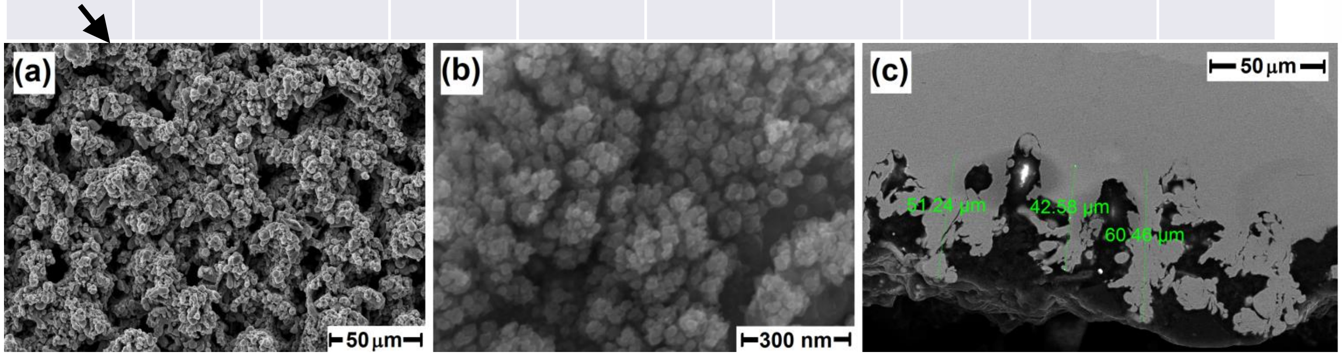
Treatment of copper using a λ = 355 nm laser resulted in creation of three different scales structures:

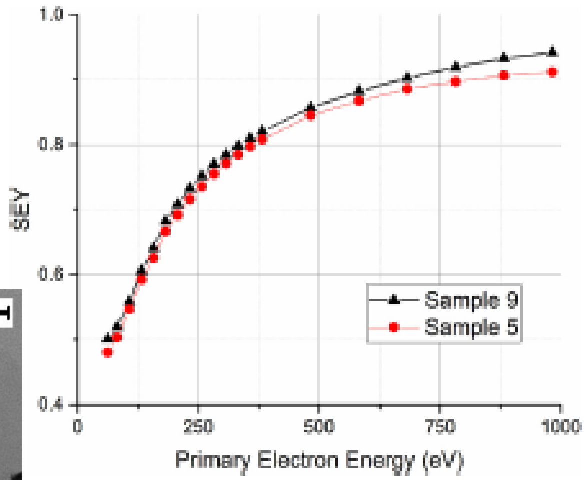
- microstructure grooves ranging from 8 to 100 µm deep,
- coral-like submicron particles superimposed on the grooves which is made of agglomeration of
- nano-spheres

A role of laser wavelength

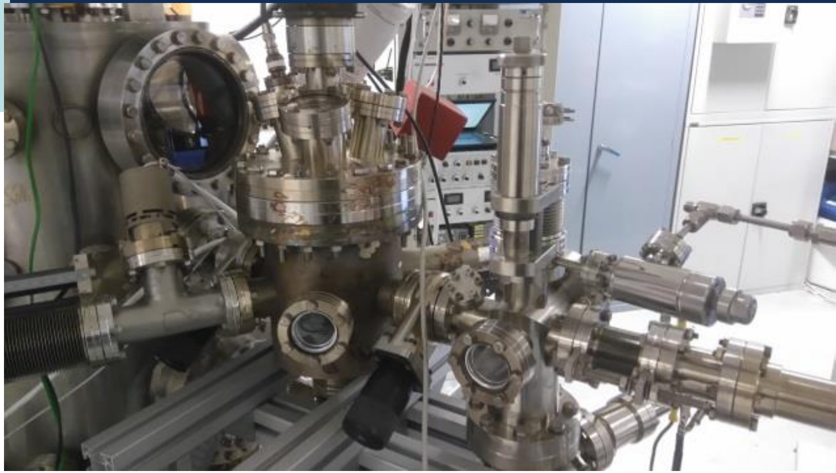
Similar surfaces with similar results for SEY can be can be produce using various lasers with different wavelength, such as λ=355 nm and λ=1064 nm.

Sample	λ (nm)	Av. power (W)	Spot size (μm)	Pulse duration (ns)	f (kHz)	Pitch width (μm)	Scan speed (mm/s)	Energy per pulse (μJ)	Fluence (J/cm²)
5	**355**	3	15	25	40	10	60	75	42
9	**1064**	3.6	25	70	10	20	30	360	73

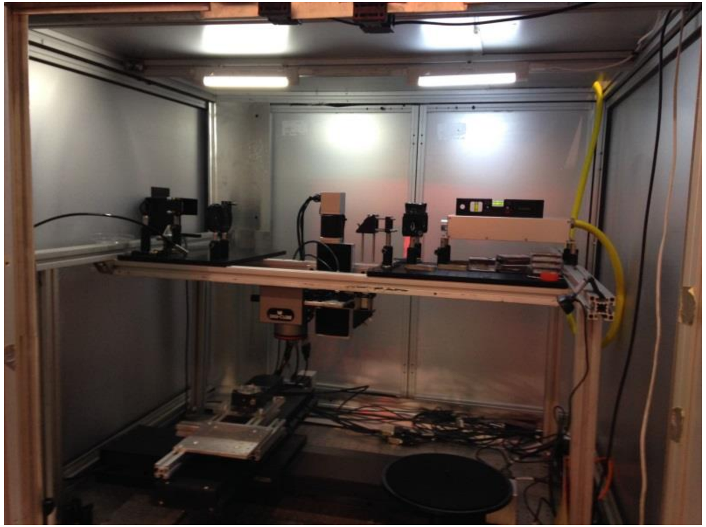




Current work:



- More samples produced at Micronanics, Liverpool and Manchester Universities:
  - and being characterised on SEY and particulates
  - See posters:
    - *Taaj Sian*. New LASE surfaces obtained with various lasers and their parameters
    - *Reza Valizadeh*. A progress with further developing of laser ablating surface engineering (LASE) for e-cloud eradication in particle accelerator
  - A new Laser treatment facility was built

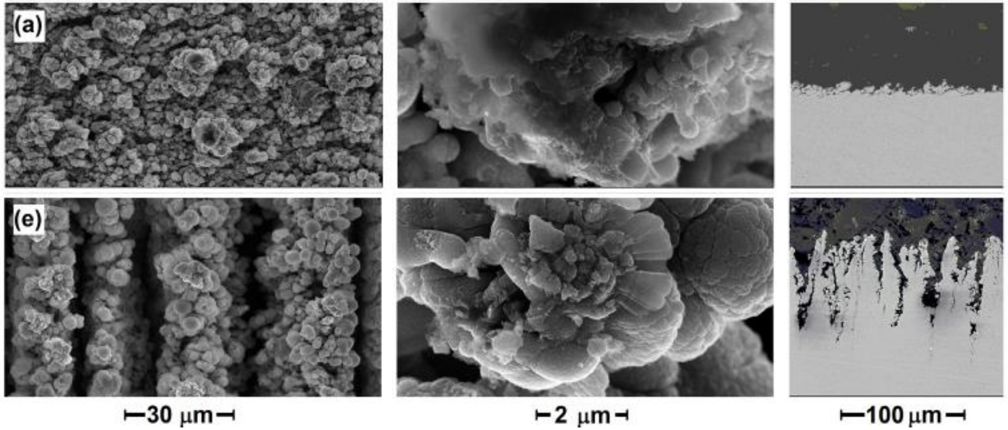


Samples produced with various lasers

Sample	λ (nm)	Average power (W)	Spot size (μm)	Pulse duration (ns)	Pulse repetition (kHz)	Pitch width (μm)	Scan speed (mm/s)	Energy per pulse (μJ)	Fluence (J/cm^2)
1	355	3	15	25	40	10	30	75	42
2	355	3	15	25	40	10	60	75	42
3	355	3	15	25	40	10	90	75	42
4	355	3	15	25	40	10	120	75	42
5	355	3	15	25	40	10	180	75	42
6	1064	1.9	25	70	2.5	20	125	760	154
7	1064	2.4	25	70	5.0	20	125	480	97
8	1064	3.6	25	70	10	20	30	360	73
9	1064	3	25	70	20	10	500	150	30
10	1064	1	25	70	100	10	500	10	2

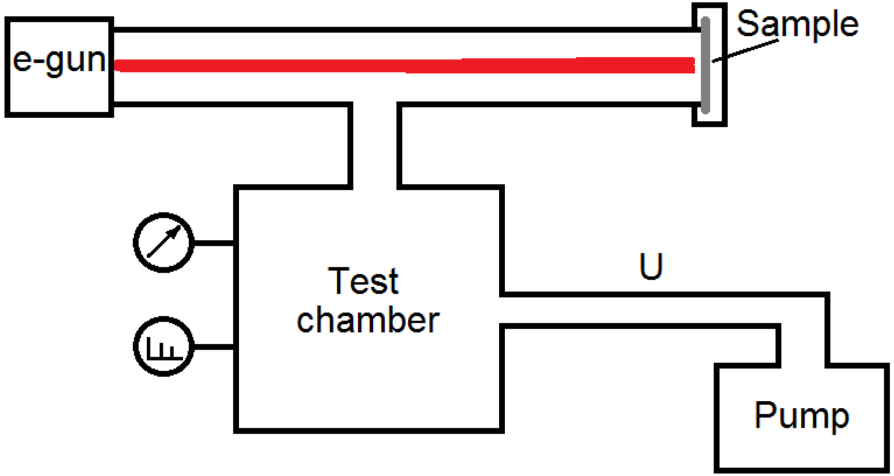
Date		Wavelength	power	spotsize	pulse duration	rep	pitch	speed	thickness		treatment	SEY
23/09/2015	Micronanics	355	3		2ns	40 kHz	5	120	50 micron thick			1.04
24/09/2016		355	3		2ns	40 kHz	5	120	100 micron thick			1.08
25/09/2016		355	3		2ns	40 kHz	5	90	100 micron thick			0.99
01/10/2016		355	3		2ns	40 kHz	5	90	50 micron thick			1.04
07/10/2015		355	3		2ns	40 kHz	5	90	50 micron thick		after acetone	1.01
08/10/2015		355				40 kHz		90				0.94
30/10/2015	Micronanics	355	3					90				0.815
02/11/2016		355	5					162				0.896
02/11/2015		355	5					216				1.125
03/11/2015		355	3					120				0.936
04/02/2016	Chester Uni	1064	5	15	>5ps	100 kHz	5	30				0.921
		1064	5	15	>5ps	100 kHz	5	30			after acetone	1.029
		1064	5	15	>5ps	100 kHz	5	5				0.922
		1064	5	15	>5ps	100 kHz	5	5			after acetone	0.925
29/03/2016		1064	5	15	>5ps	100 kHz	5	5	Argon atmosphere			0.872
14/02/2017	Micronanics	1064	5		70 ns	100 kHz	5	100				0.86
15/02/2017		1064	5		70 ns	100 kHz	10	100				0.94
20/02/2017		1064	5		70 ns	100 kHz	5	200				0.93
23/02/2017		1064	5		70 ns	100 kHz	10	200				1.06
	Micronanics with air flow											
08/03/2017	b	1064	6.6				10	30	air	no glass		1.01
	c	1064	6.6				10	30	pump flow (Flow of air)	glass		1.24
	d	1064	6.6				10	30	pump flow (Flow of air)	no glass		0.79
	e	1064	6.6				10	30	compressed air	no glass		0.99
	f	1064	6.6				10	30	compressed air	glass		1.31
20/06/2017	Manchester Uni	355nm	65	23 um	2ps	404 kHz	100	100				1.28
20/06/2017		355nm	65	23 um	2ps	404 kHz	100	200				1.59
21/06/2017		355nm	65	23 um	2ps	404 kHz	100	25				0.97
21/06/2017		355nm	65	23 um	2ps	404 kHz	100	50				1.09
22/06/2017		355nm	65	23 um	2ps	404 kHz	50	200				1.1
23/06/2017		355nm	65	23 um	2ps	404 kHz	25	100				0.82
23/06/2017		355nm	65	23 um	2ps	404 kHz	50	100				1.144
23/06/2017		355nm	65	23 um	2ps	404 kHz	25	200				1.135
23/06/2017		355nm	65	23 um	2ps	404 kHz	100	25				1.01
14/09/2017	IPG 40 kHz Miconanics	1064	20		2ns	40kHz	0.02	40				1.1
14/09/2017		1064	20		2ns	40kHz	0.02	80				1.17
19/09/2017		1064	10.5		2ns	40kHz	0.02	40				1.125

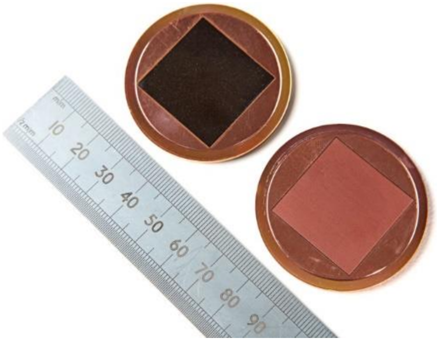
Main results



- SEY reduction due to a superposition of
  - microstructure (groves)
  - sub-micron and nano-structures
    - Groves are main source in surface resistance.
- Low SEY surfaces can be produced using various lasers with different wavelength, such as λ=355 nm and λ=1064 nm, different power, with a variety of other parameters.

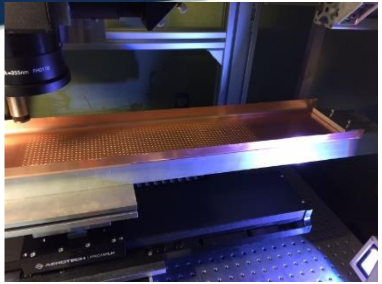
ESD measurements

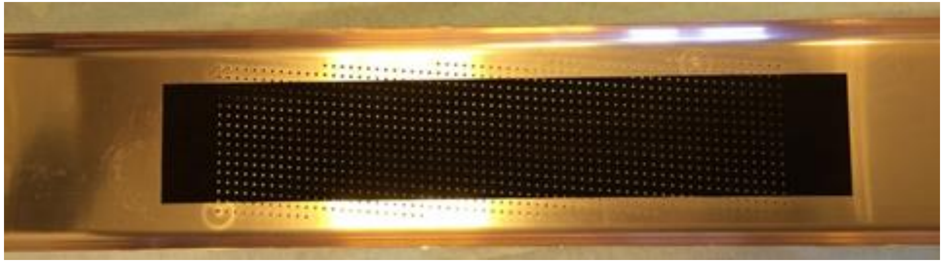


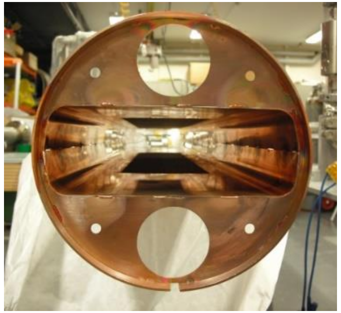


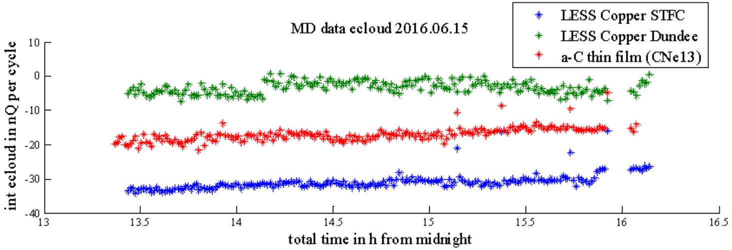
Particle counts

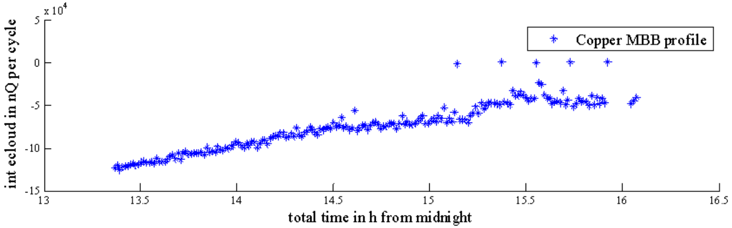
Test in SPS









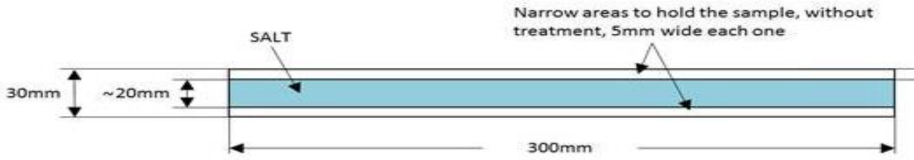


- **Electron cloud mitigation has based on LASE has been successfully demonstrated in particle accelerator for the first time**

- **S. Calatroni, et al. First accelerator test of vacuum components with laser-engineered surfaces for e-cloud mitigation. Phys. Rev. Acc. and Beams 20, 113201 (2017).**

Laser treated samples for WP4 partners

1) 10 samples for INFN to study an effect of cryogenic temperatures and cryosrbed gases on SEY
   - see a poster R. Cimino et al.
   - treated area 8 mm x 8 mm; Laser 355 nm or 1064 nm.
2) A sample for a reflectivity study at BESSY
   - See a poster E. La Francesca, R. Cimino. et al.)
   - Treated area 20 mm x 300 mm.
   - Laser 1064 nm.

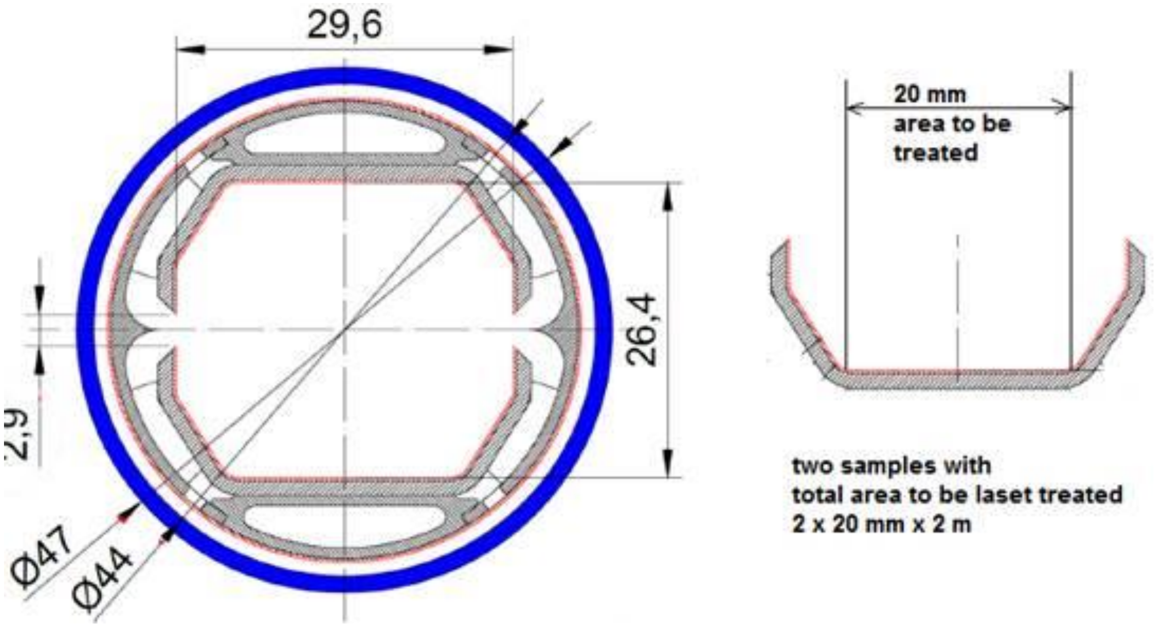


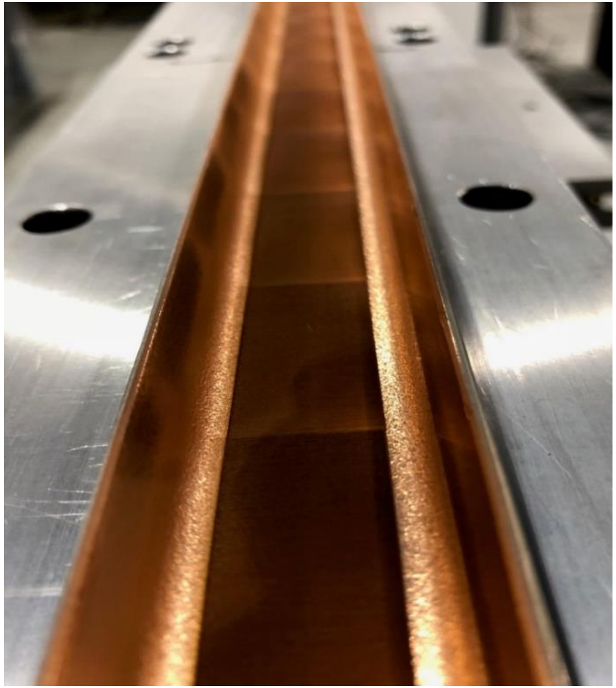
3) 4 samples for BINP, Novosibirsk (A. Krasnov)
   - 12 mm x 12 mm; Laser 355 nm or 1064 nm.

All samples have being laser treated at Micronanics

Laser treated samples for WP4 partners

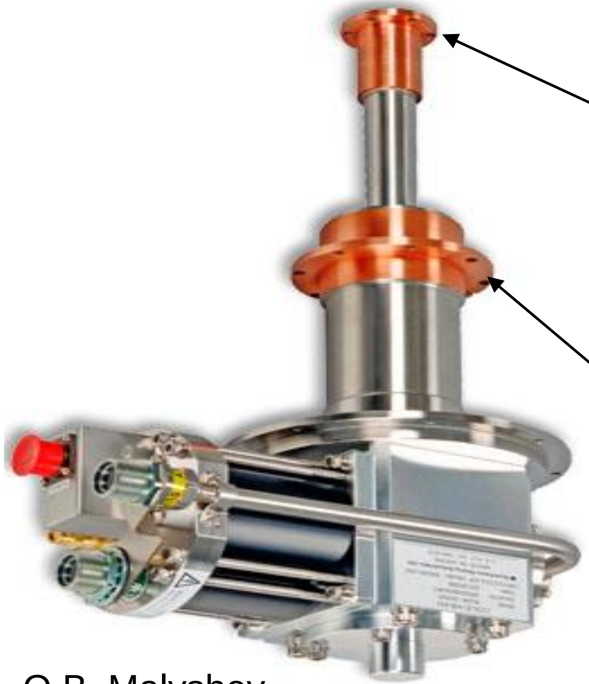
4) Sample for KARA experiment in ANKA (KIT) – 2 m long a tube in two halves, treated area of each half is 2 m x 20 mm. Laser 1064 nm.





A new cryogenic temperature facility

RDK-305D 4K Cryocooler (RDK-305D Cold Head with CNA-31C/D Compressor)



Bellows

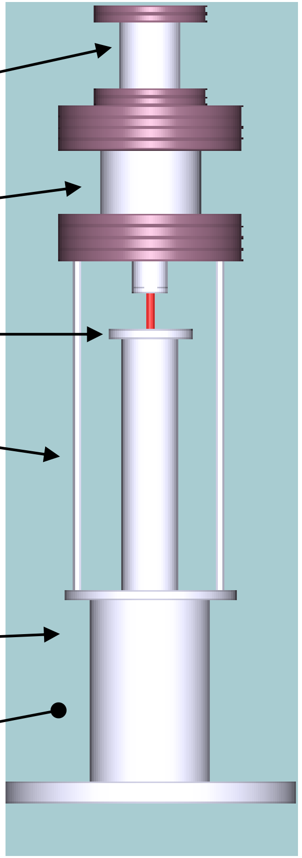
Test chamber

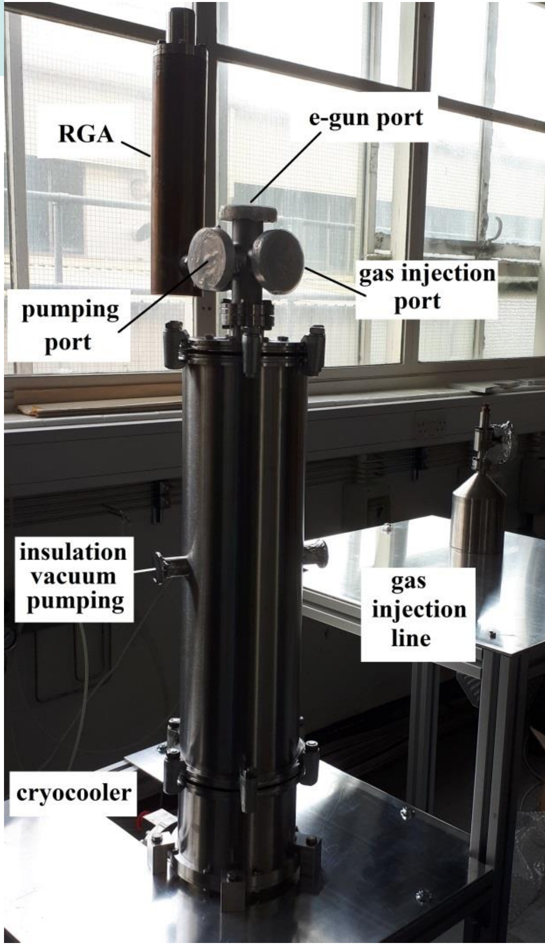
2nd stage

Conductor from 1st stage to heat shield

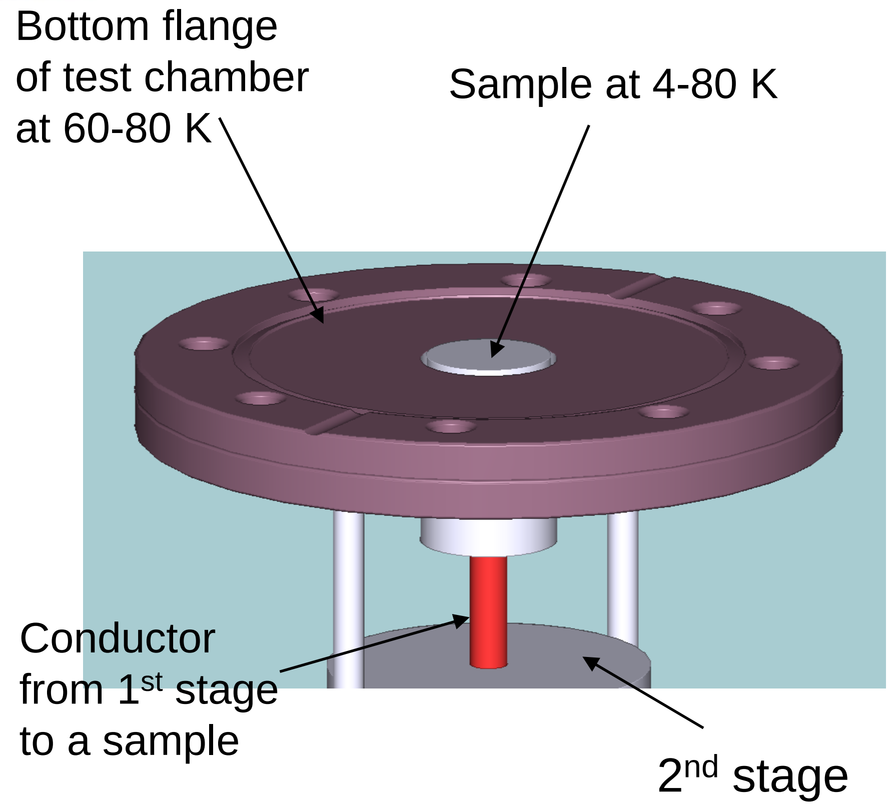
1st stage

Insulation vacuum





A new cryogenic temperature facility



- Current work:
  - Assembling a facility for cryogenic measurements
- Next Steps:
  - Completing assembly
  - Testing
  - Measurements at 4 K < T < 80 K
    - No condensed gas
    - With condensed gas
  - See a posters:
    - *Taaj Sian*. A facility for studying SEY from LASE surfaces at cryogenic temperatures

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NEG coating studies

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What NEG coating does

1) Reduces gas desorption:

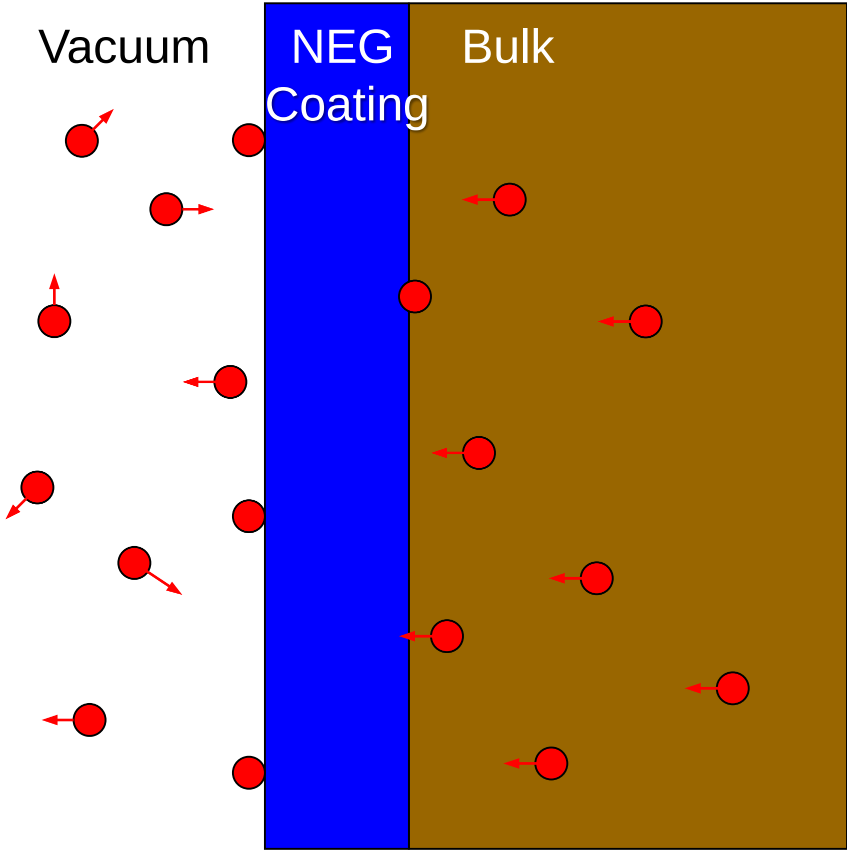
- A pure metal (Ti, Zr, V, Hf, etc.) film ~1-μm thick without contaminants.
- A barrier for molecules from the bulk of vacuum chamber.

2) Increases distributed pumping speed, *S*:

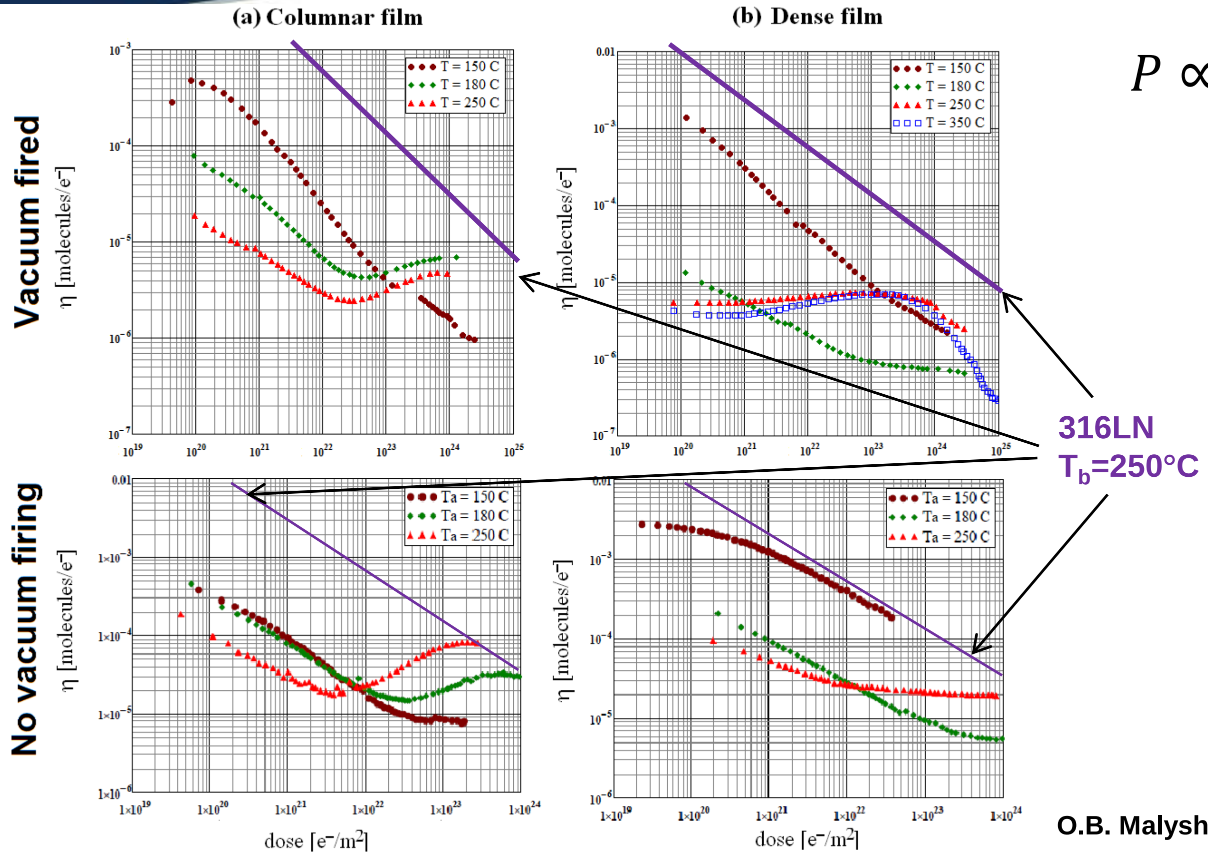
- A sorbing surface on whole vacuum chamber surface

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

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



Electron stimulated desorption of H_2



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

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

O.B. Malyshev, R. Valizadeh, et al. JVST A 32, 061601 (2014)

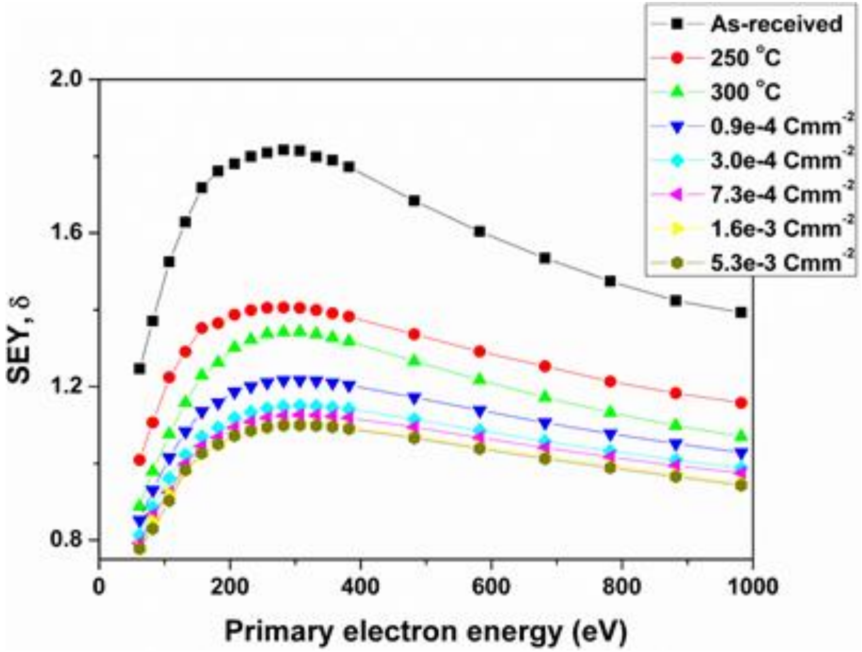
NEG coating for FCC-hh

- Looking for new materials
  - Lower activation temperature
    - It is 150 °C for columnar Ti-Zr-Hf-V.
  - Effect of photon and electron induced activation
    - It is possible to avoid NEG activation by heating?
- NEG coating at cryogenic temperatures
  - Reduced PSD and ESD
  - Impact on PEY and SEY
- NEG coating surface resistance
  - Developing new materials with higher electric conductivity
  - Effect of temperature

What NEG coating does

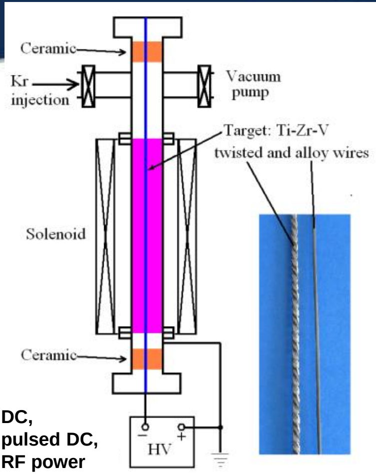
3) Reduces SEY:

- **After NEG activation**
- **After beam conditioning**

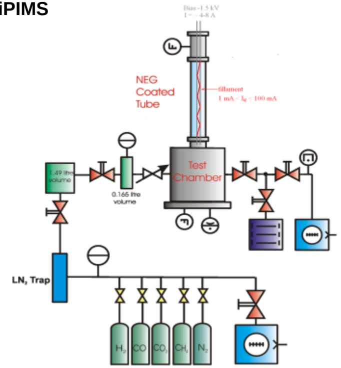


S. Wang. PhD Thesis

NEG coating studies



DC, pulsed DC, RF power supply, HiPIMS



- Current work:
  - Studying pure Zr film on a sample tubes, ESD and pumping measurements
    - Three samples (dense and columnar film) measurements and data analysis completed.
      - See a poster of Ruta Sirvinskaite. Singe metal Zr NEG coating, its pumping properties and electron stimulated desorption
  - Four other sample with different materials have been deposited
    - One sample – pumping properties completed
    - Others will be studied over next two months
- Next Steps:
  - Assemble a facility for cryogenic (LN_2) measurements and start a cryogenic study
  - Design of a facility for cryogenic (dry system 4 K < T < 80 K) measurements
  - Analysis of the experimental results

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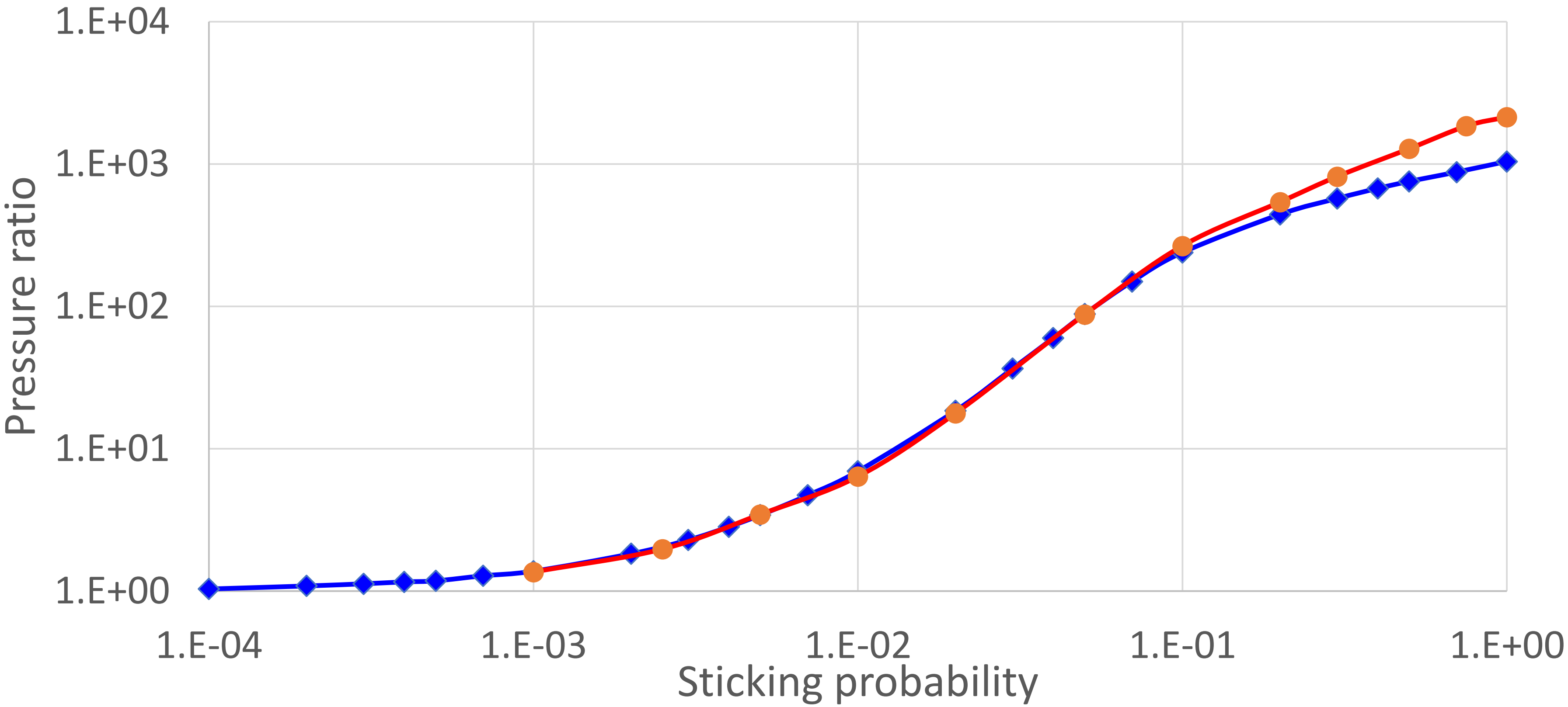
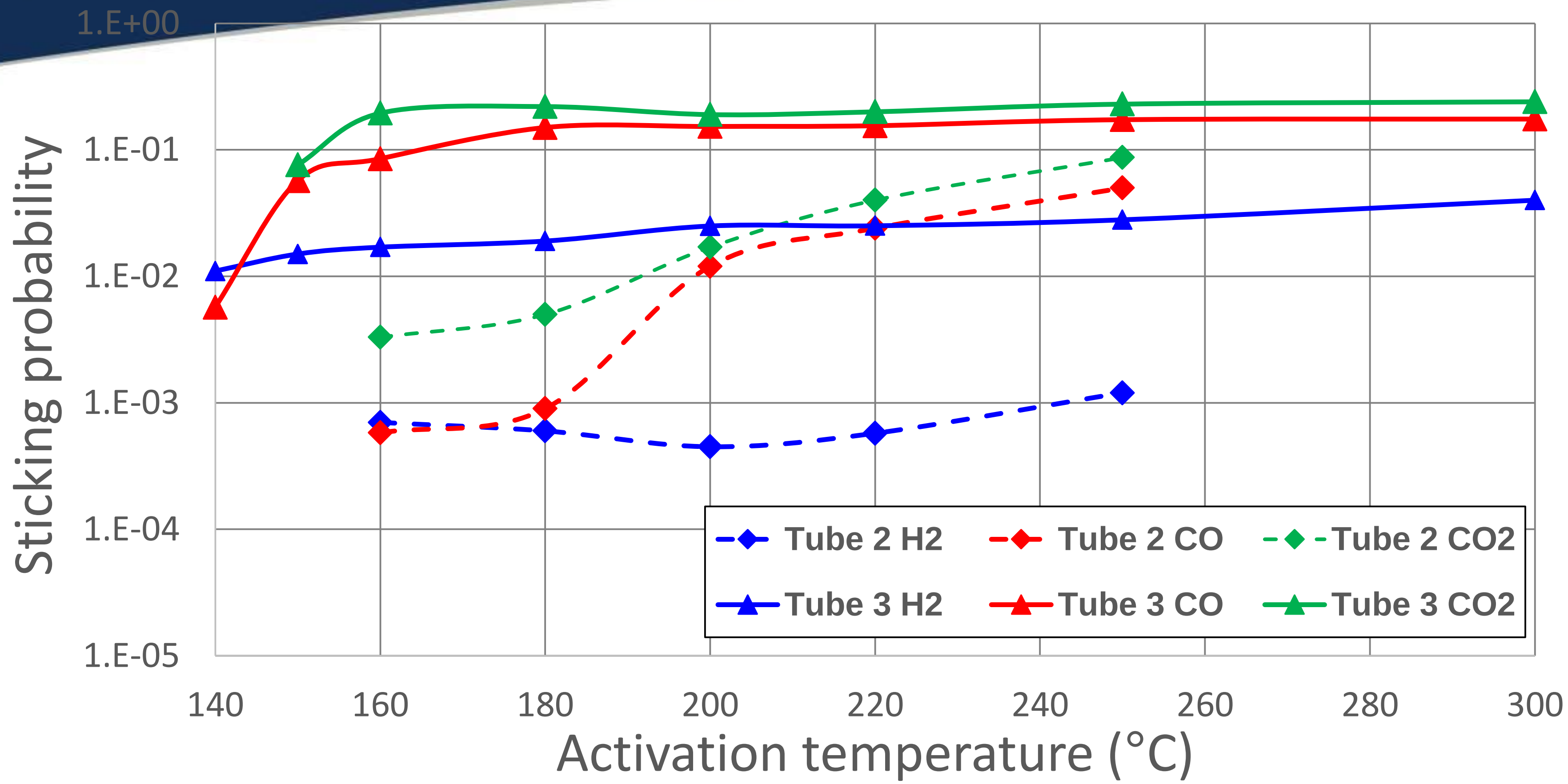
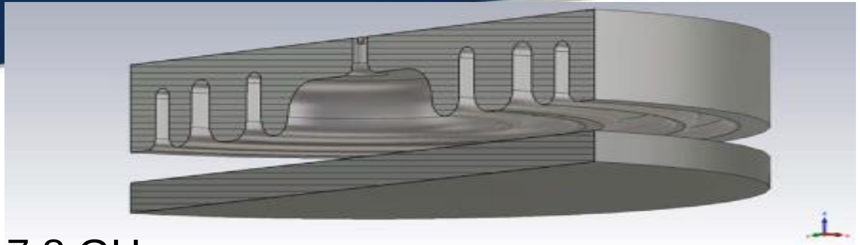
Modelled pressure ratio vs. sticking probability



Sample 2 - dense Zr, sample 3 - columnar Zr



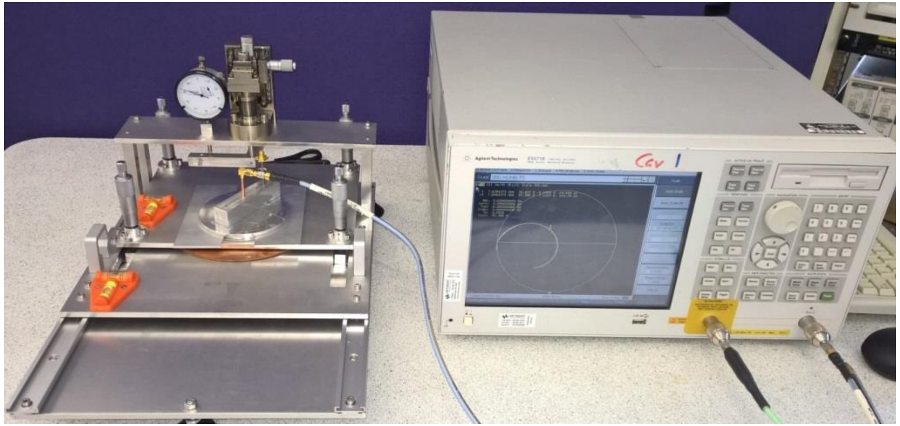
How do we measure the surface resistance



f = 7.8 GHz

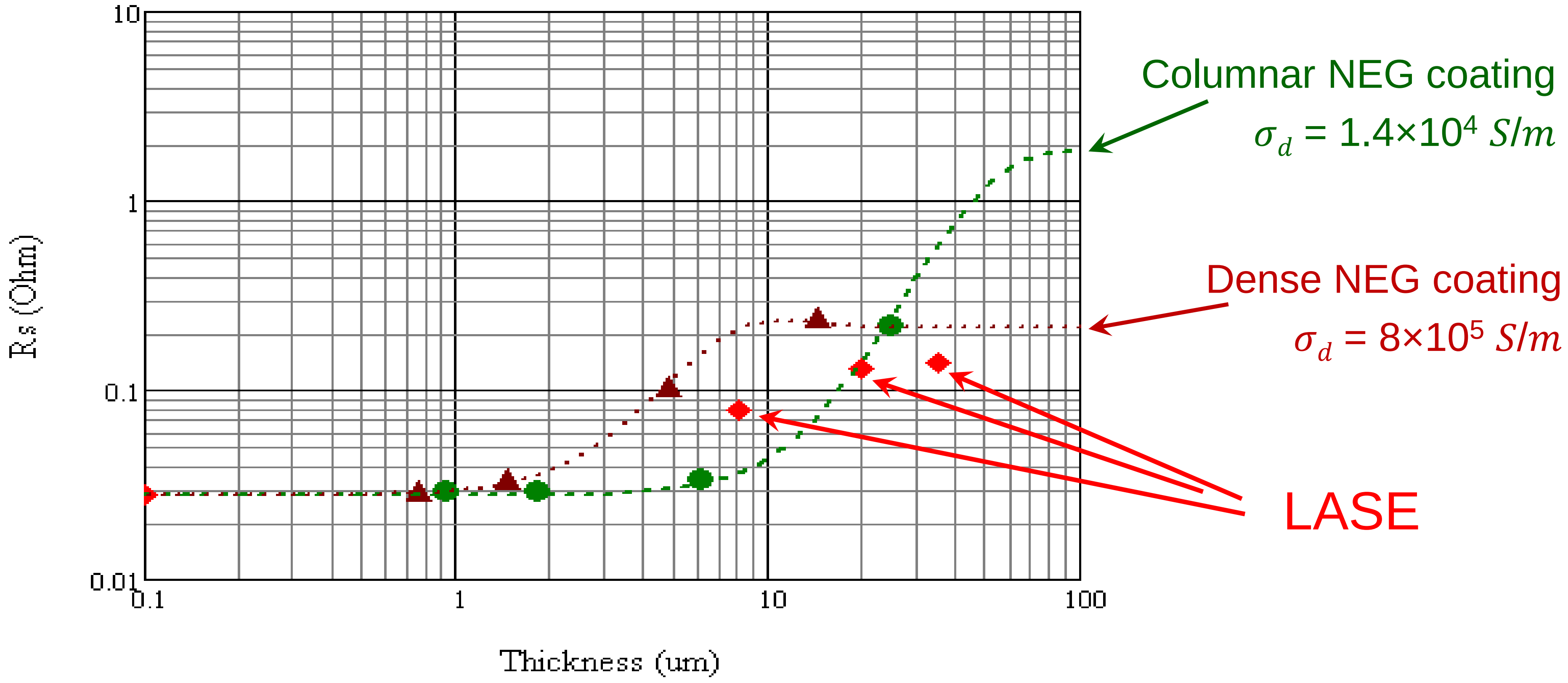
Fig. 1. A schematic of the triple choke RF cavity above a sample.

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

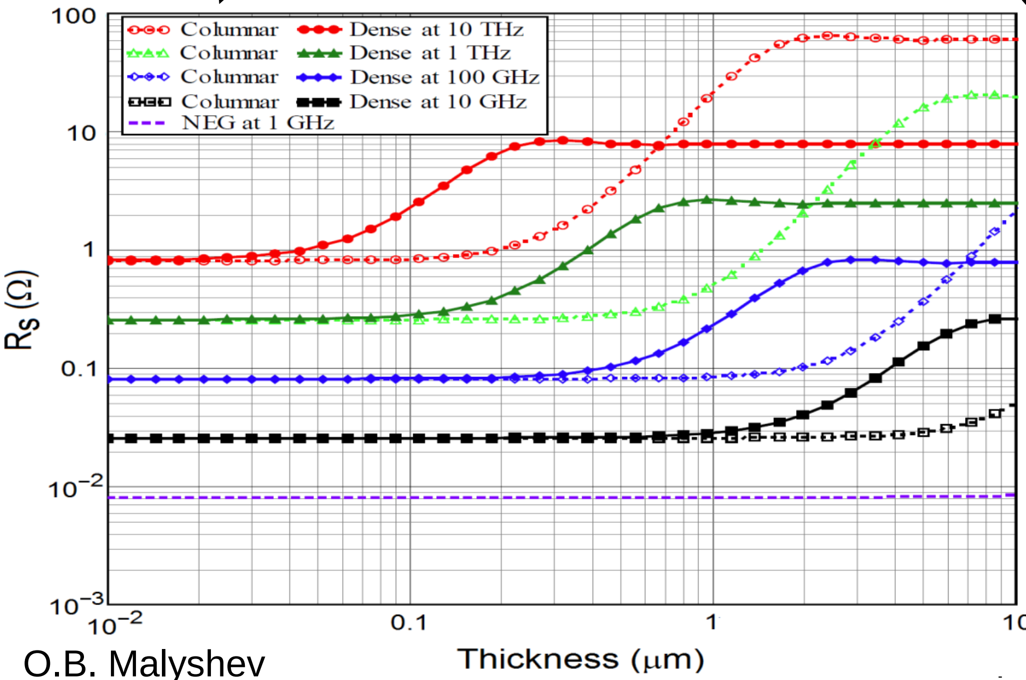


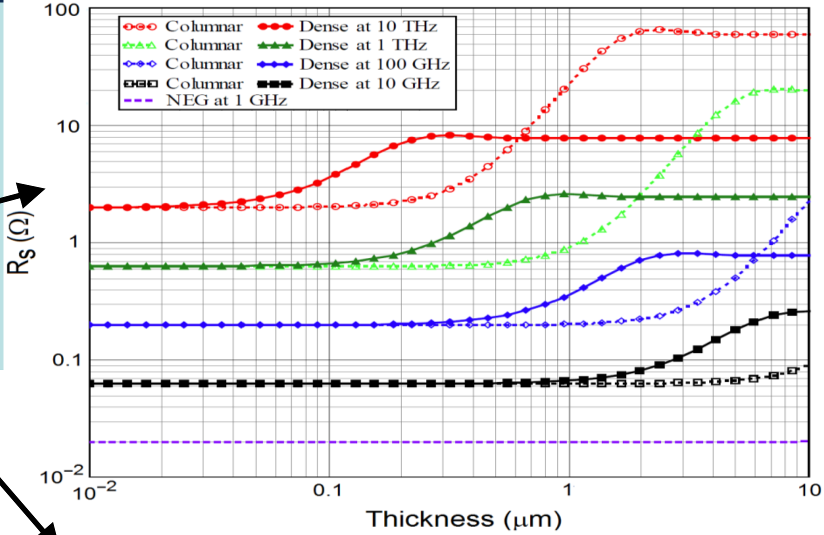
- The surface resistance of the sample R_S^{sam} can be calculated for known
  - test cavity surface resistances R_S^{cav} and
  - measured Q_0,
- The magnetic field distribution in the cavity was calculated using CST Microwave Studio.
  - For our cavity, G = 235 Ω,
  - for perfect electric conductor (PEC) boundary conditions, the field ratios are p_c = 0.625 and p_s = 0.375.

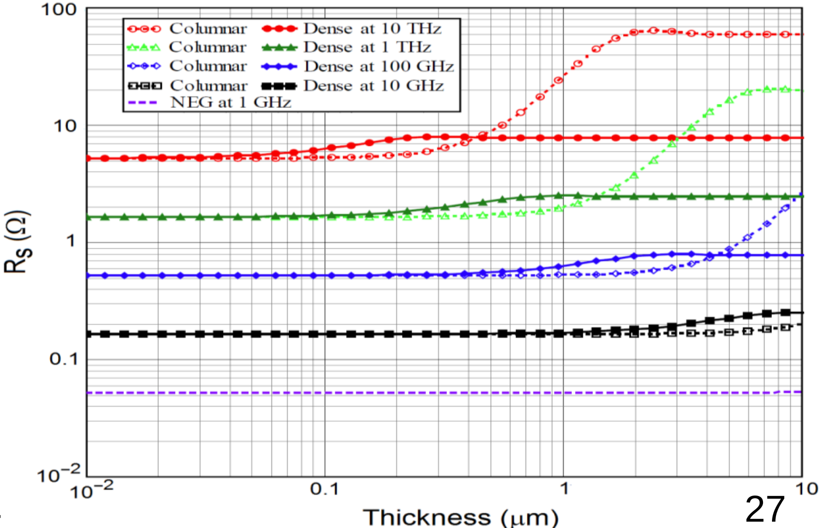
Surface resistance at 7.8 GHz for LASE and NEG coating



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







Surface resistance

- A possibility for R_s measurement on a tubular samples on a dedicated facility are under investigation

- An open question:
  - R_s as a function of temperature
    - To be addressed in future
      - Planar samples could be studied in a few months
      - Tubular sample can be considered later

Acknowledgements

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