LASE surface:
low SEY vs. surface resistance

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31st March 2017

Existing e-cloud mitigation methods

Active means:

- Weak solenoid field (10-20 G) along the vacuum chamber
- Biased clearing electrodes
- Charged particle beam train parameters
  - Bunch charge and sizes
  - Distance between bunches

Advantages:

- Solenoids can be installed on existing facilities (if there is a space for them)
- Beam parameters have some flexibility

Disadvantages:

- Requires:
  - Controllers
  - Power supplies
  - Cables
  - Vacuum compatible electric feedthroughs

Passive means:

- Low SEY material
- Low SEY coating
- Grooved surface
- LASE surfaces
- Special shape of vacuum chamber
  - An antechamber allows reducing PEY

Advantages:

- No Controllers,
- No power supplies,
- No cables

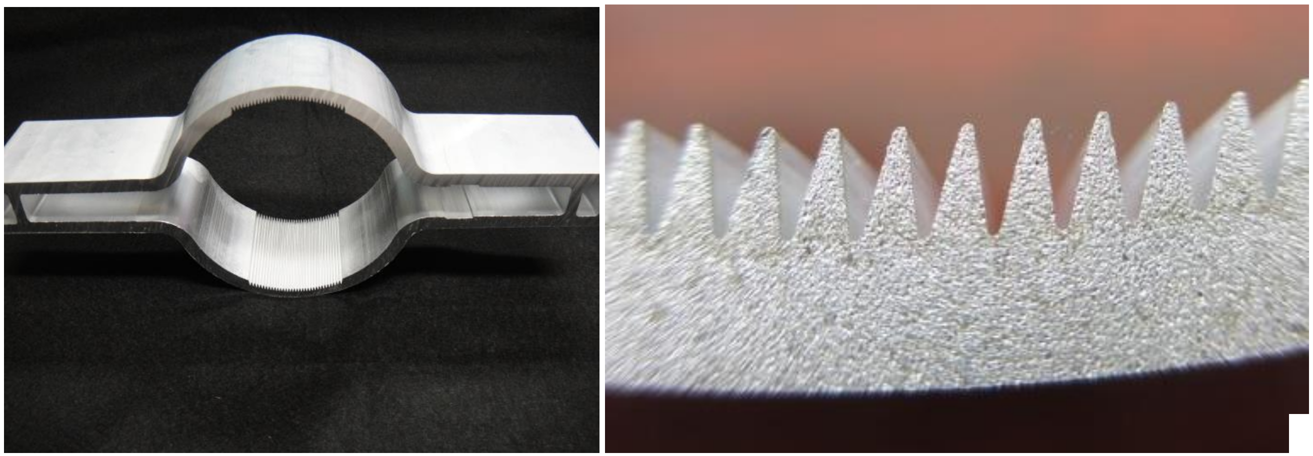
Disadvantages:

- In-vacuum deposition
- Difficult to apply on existing facilities
- Durations of surface treatments
- Cost

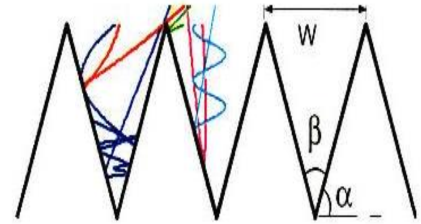
All these methods work solving e-cloud problems in many accelerators. So the task is to choose one (or a few) which suit a machine the best.

Modifying the surface geometry

- Modifying the surface geometry
    - making mechanical grooves

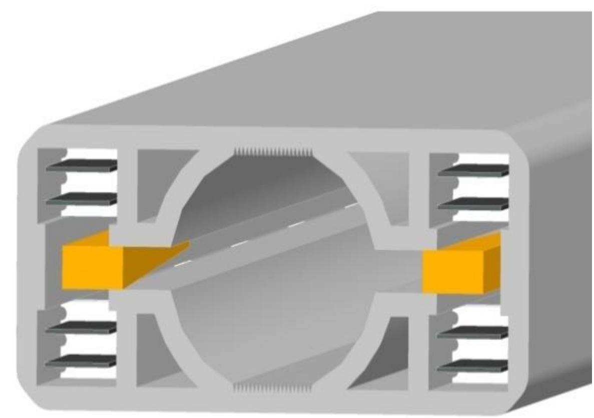


KEKB vacuum chamber (by courtesy of Y. Suetsugu)



By A. Krasnov and
By L Wang et.al

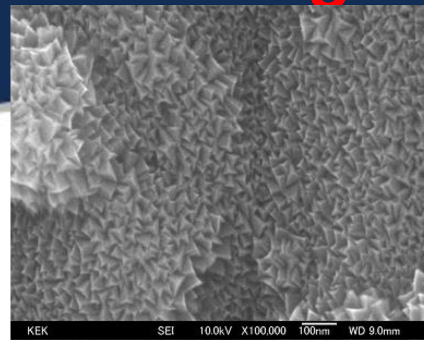
- Modifying the vacuum chamber geometry
    - making an antechamber



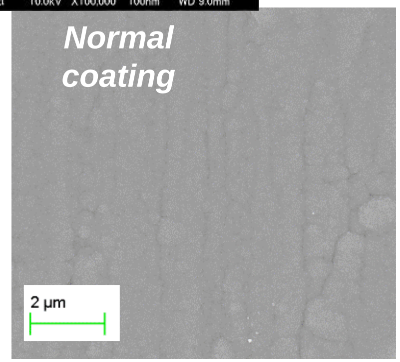
ILC wiggler vacuum chamber

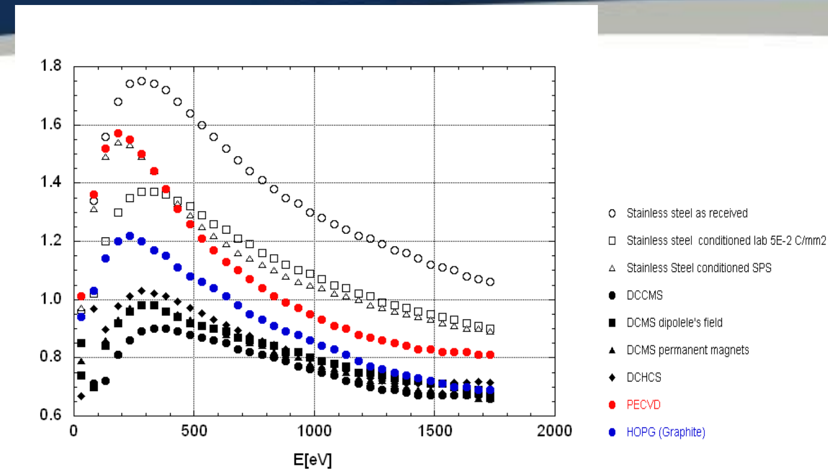
Coating with low SEY Materials

- TiN coating (KEK)

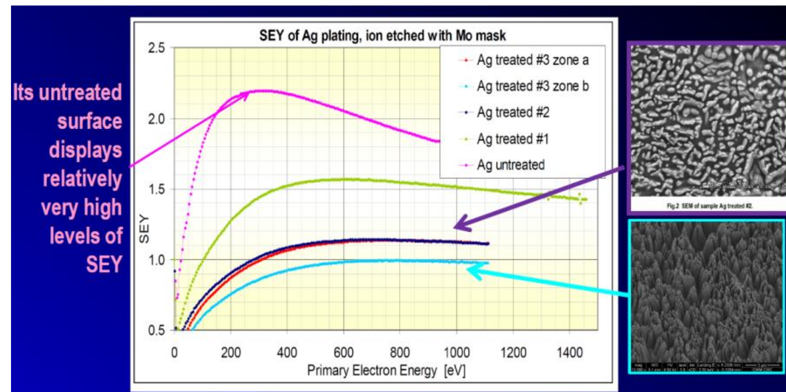


- a-Carbon (CERN)

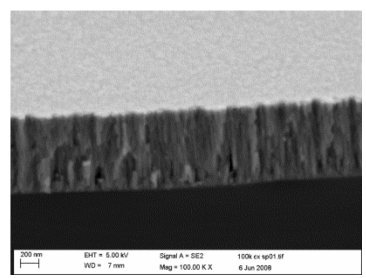


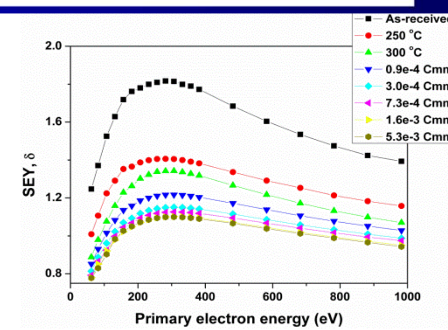


- Ag plating, ion etched with Mo Mask (I. Montero et.al, Proc. e-Cloud12)



- NEG coating (ASTeC)





- ➢ **It was well known that surface topography is often a key to low SEY**
- ➢ **Such surfaces look dark or black**

Discovery of LASE for SEY mitigation

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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

Pub. No.: WO/2015/189645 **International Application No.:** PCT/GB2015/051750
Publication Date: 17.12.2015 **International Filing Date:** 15.06.2015
IPC: ***B23K 26/36*** (2014.01), ***B23K 26/00*** (2014.01)

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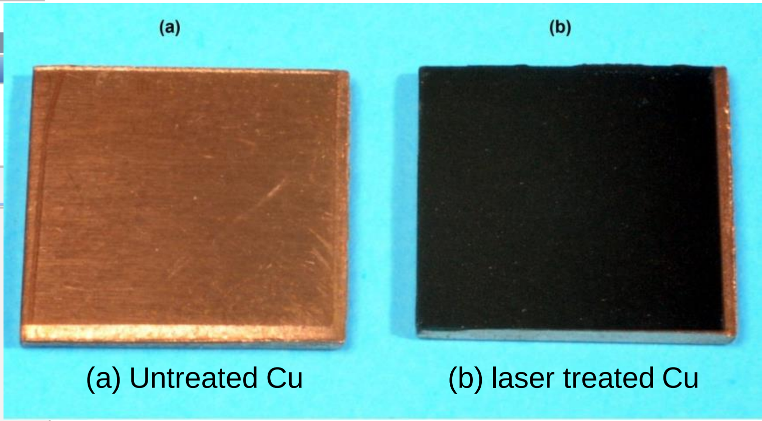
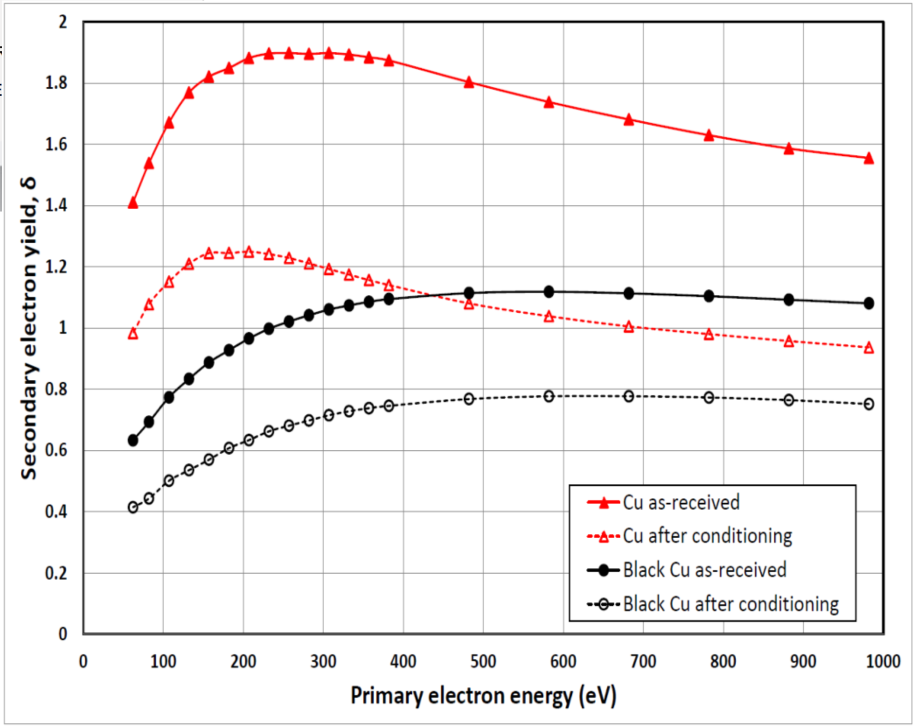
Priority Data: 1410593.6 13.06.2014 GB

Title **(EN)** APPARATUS AND METHODS RELATING TO REDUCED PHOTOELECTRON YIELD AND/OR SECONDAR YIELD
(FR) APPAREIL ET PROCÉDÉS ASSOCIÉS À UN RENDEMENT DE PRODUCTION DE PHOTOÉLECTRONS E RENDEMENT DE PRODUCTION D'ÉLECTRONS SECONDAIRES RÉDUITS

Abstract: **(EN)**A method of reducing the photoelectron yield (PEY) and/or the secondary electron yield (SEY) of at least part of an apparatus, the method comprising the steps of providing an apparatus, and ablating material from a metal surface of the apparatus using a pulsed laser to produce an array of periodic structures in the metal surface and thereby reducing the PEY and/or SEY of the metal surface.

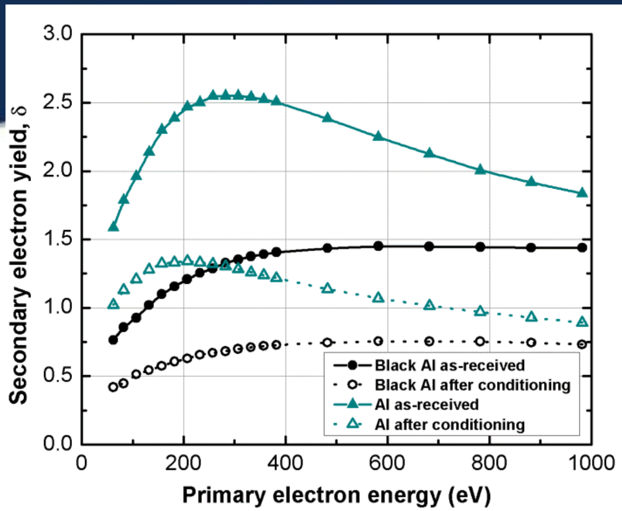


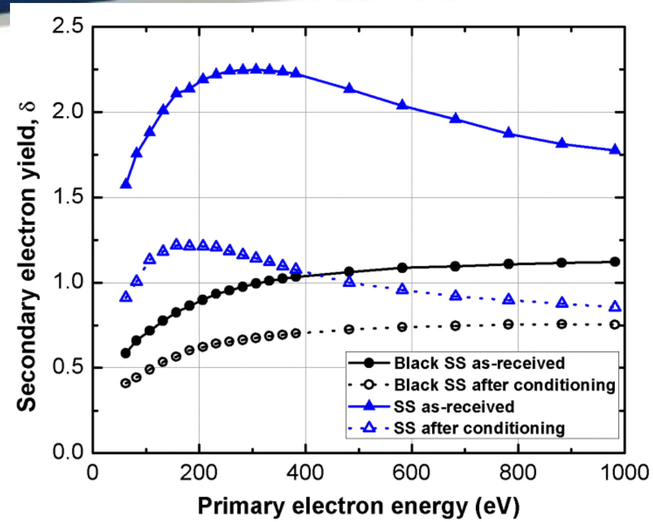
(a) Untreated Cu (b) laser treated Cu

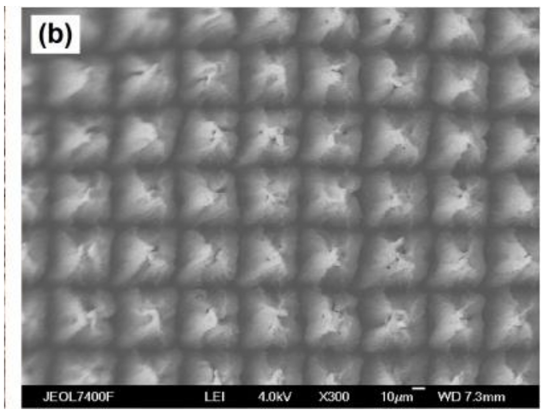


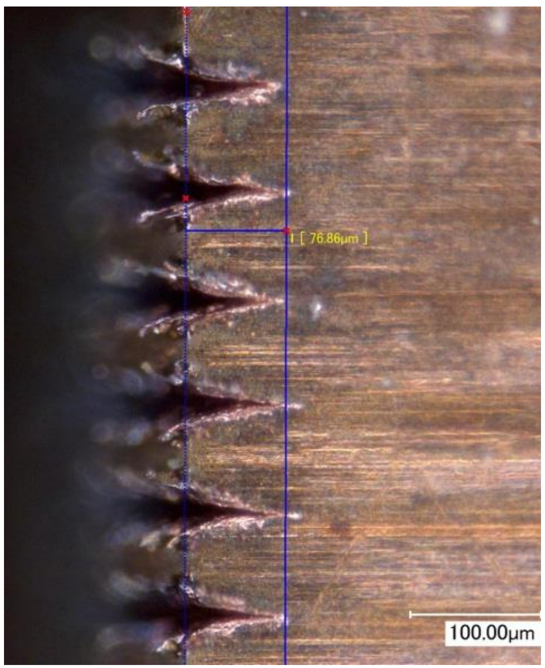
- Nanostructuring of Material Surfaces by Laser Ablation is well established science and manufacturing
- The new is applying these surfaces to suppress PEY/SEY and to solve the e-cloud problem

Low SEY studies: First results









- **R. Valizadeh, O.B. Malyshev, S. Wang, S.A. Zolotovskaya, W.A. Gillespie and A. Abdolvand. Low secondary electron yield engineered surface for electron cloud mitigation. Appl. Phys. Lett. 105, 231605 (2014); doi: 10.1063/1.4902993**

- Main result: **SEY < 1** can be achieved on Cu, Al and stainless steel
- Main question we had to ourselves (and which was asked by other colleagues):
  - How **100-μm deep groves** affect surface impedance

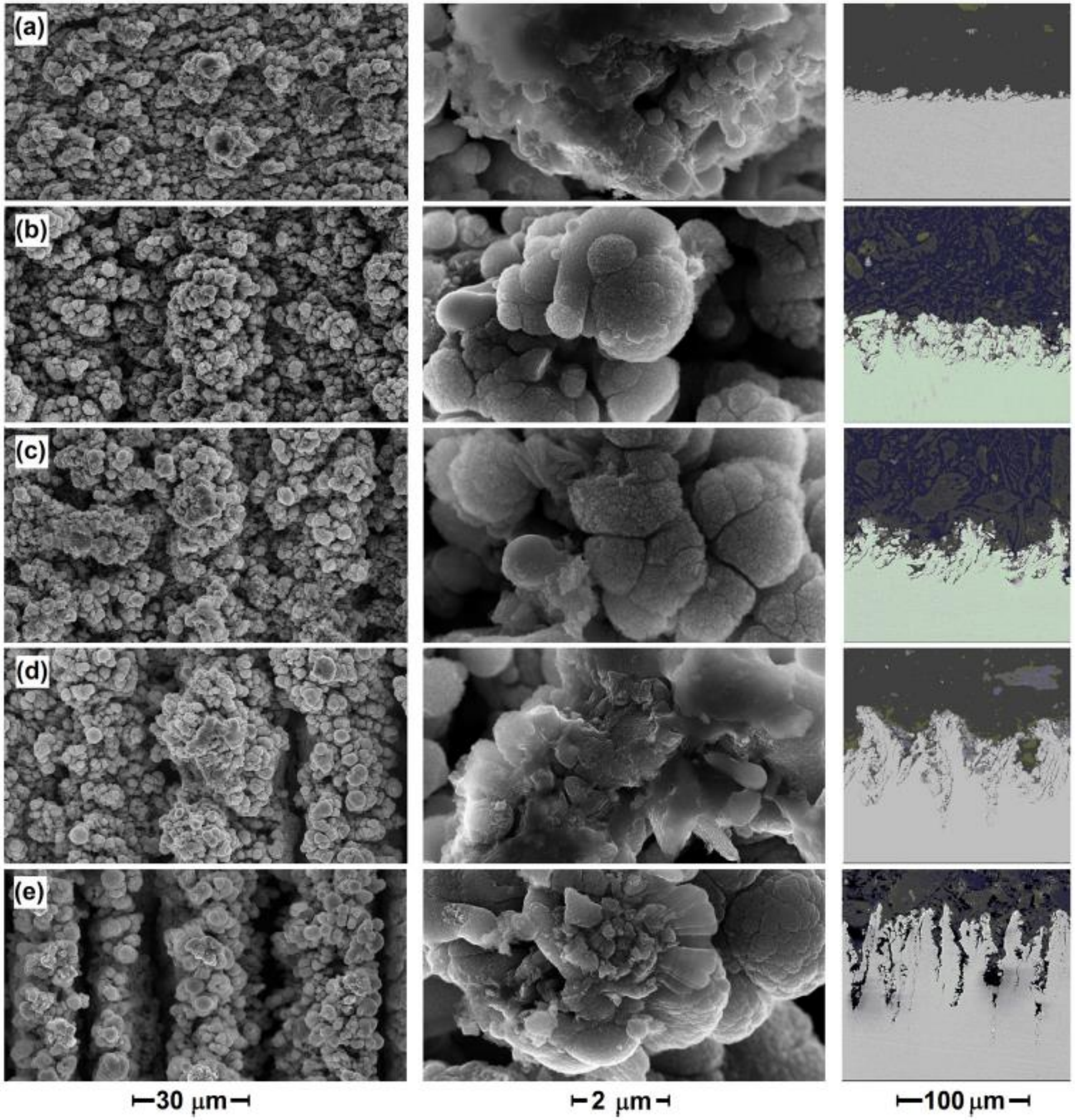
Recent low SEY studies

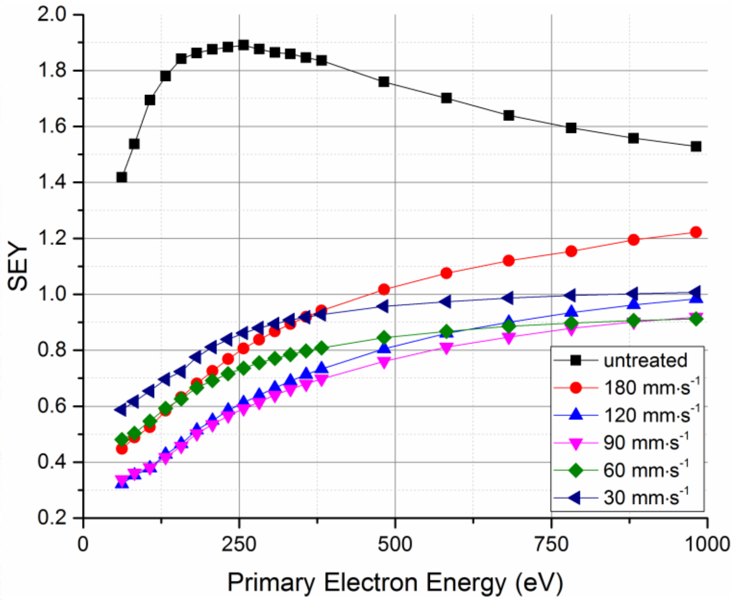
- Emphasis on physics:
  - How and why SEY is reduced on LASE surfaces
  - To further reduce SEY
  - To reduce impedance
  - To reduce particulate generation

- **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**

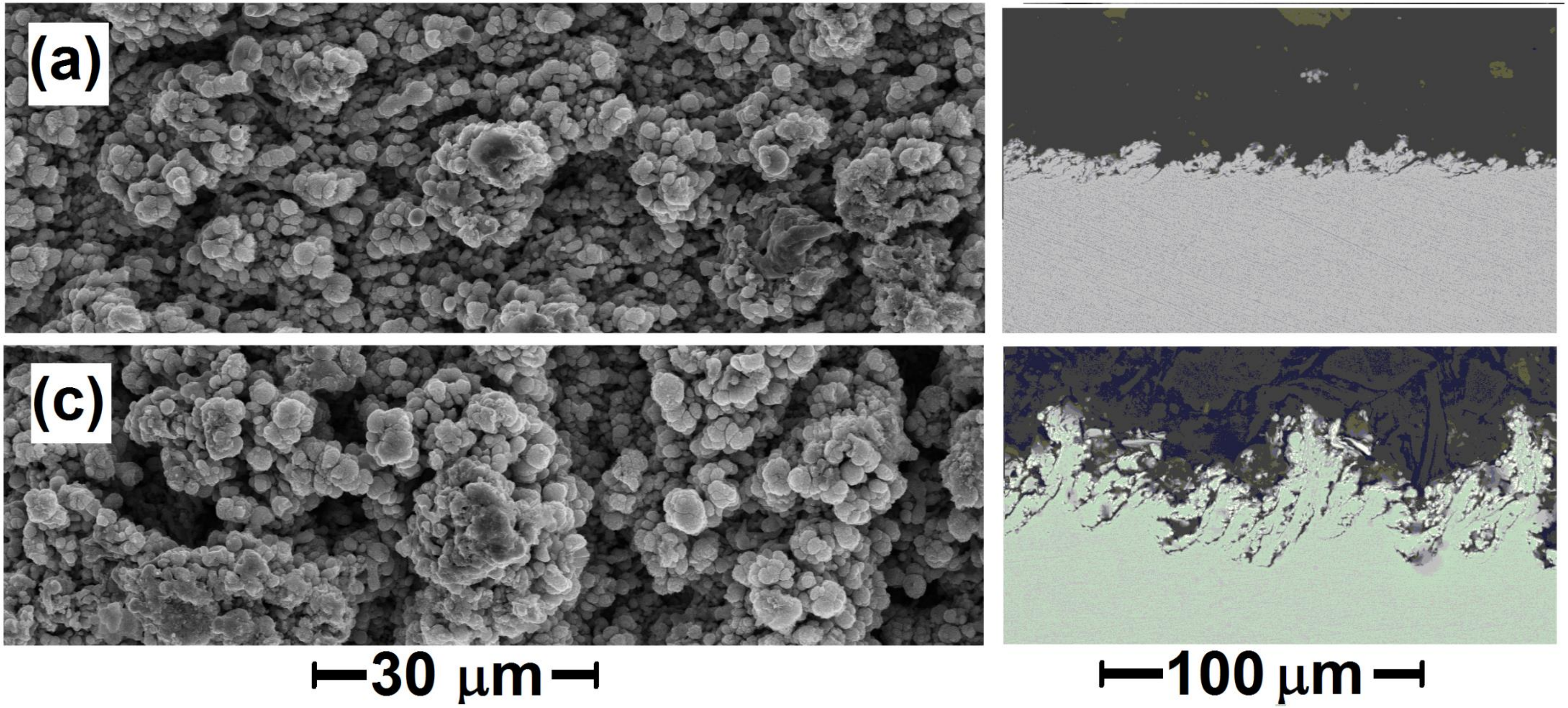
A role of laser scan speed on copper samples





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

Surface in more details



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

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Calculated and measured R_S at frequency f=7.8 GHz

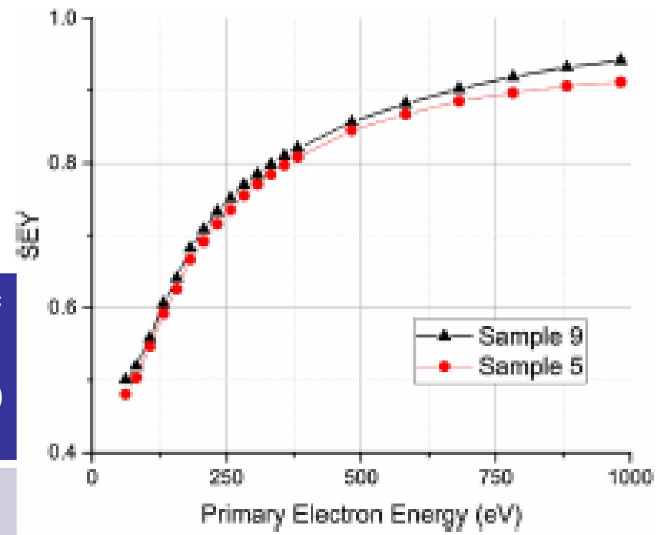
Sample	index	Scan speed [mm/s]	Groove depth for LASE (Roughness for untreated metals) [μm]	Rs [Ω] measured with a 7.8-GHz cavity	Rs [Ω] calc with formula
1		untreated	0.4	0.028	0.029
2	(a)	180	8	0.078	~~0.046~~
3	(b)	120	20	0.13	~~0.046~~
4	(c)	90	35	0.14	~~0.046~~
5	(d)	60	60	–	~~0.046~~
6	(e)	30	100	–	~~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:

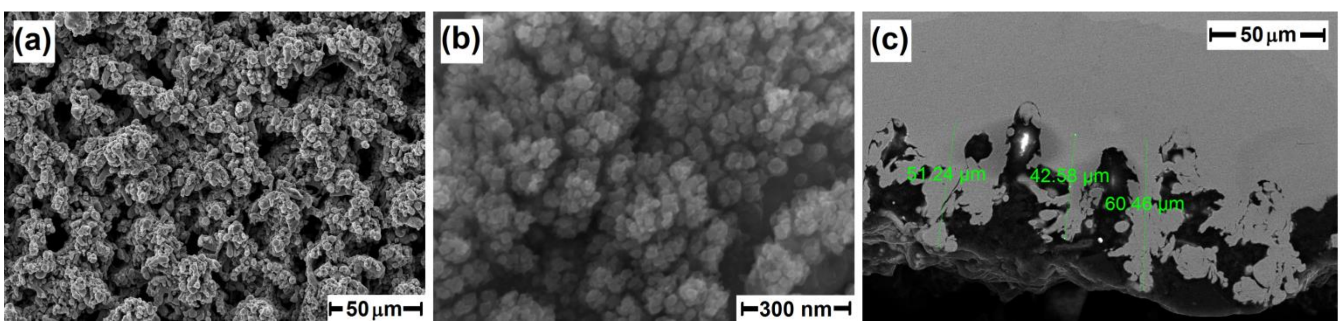
$$R_s = \sqrt{\frac{\mu\omega}{2\sigma}}\left(1+\frac{2}{\pi}\arctan\left(0.7\,\mu\omega\sigma R_Q^{\ 2}\right)\right);$$

A role of laser wavelength

- Similar surfaces with similar SEY can be obtained with different laser wavelength after optimising the laser parameters:



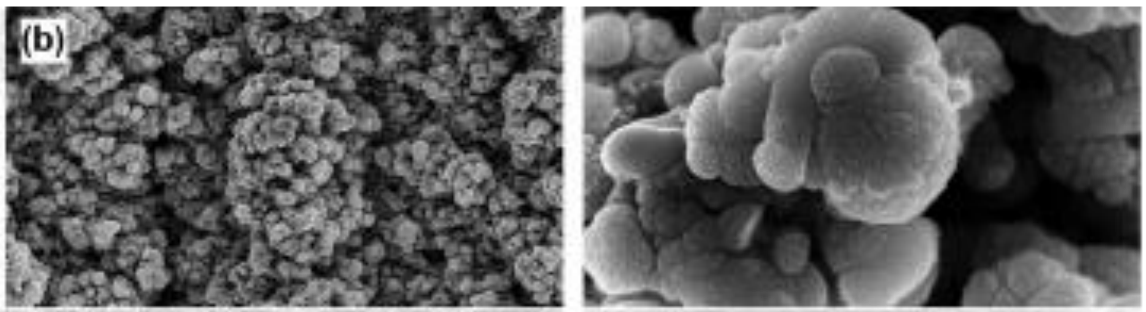
Sample	λ (nm)	Av. power (W)	Spot size (μm)	Pulse duration (ns)	f (kHz)	Pitch width (μm)	Scan speed (mm/s)	Energy per pulse (μJ)	Fluence (J/cm^2)
5	**355**	3	15	25	40	10	60	75	42
9	**1064**	3.6	25	70	10	20	30	360	73

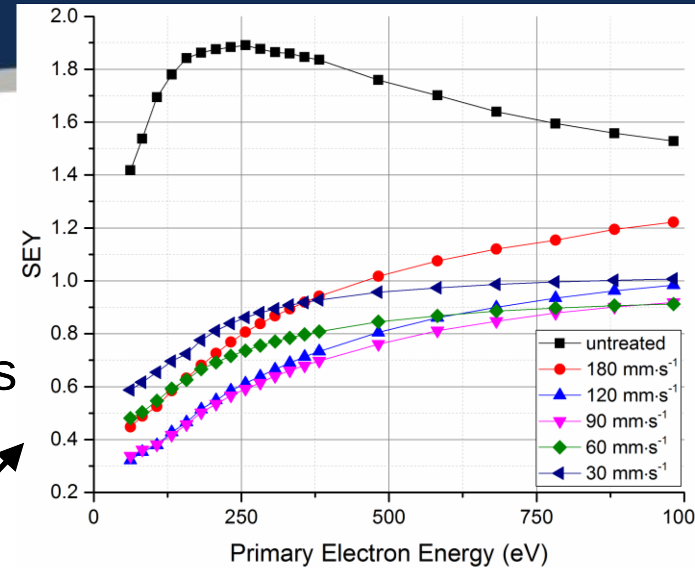


Similar surfaces with similar results for SEY can be can be produce using various lasers with different wavelength, such as λ=355 nm and λ=1064 nm.

A role of submicron and nanostructures

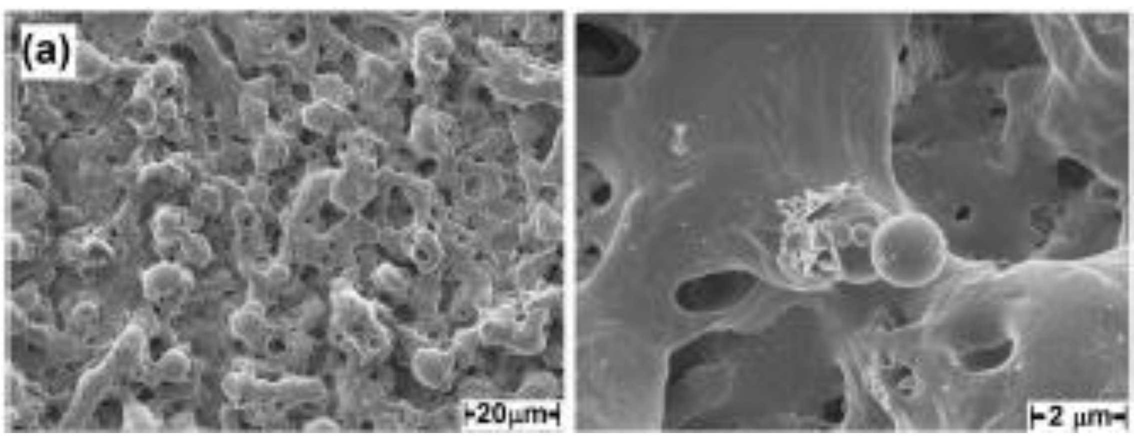
Sample 2 (180 mm/s). The topography of the surface consists of submicron structures and nanospheres superimposed on 8 μm deep grooves





Removal of submicron and nanostructures lead to SEY increase

Sample 2* after second laser treatment which removes submicron and nanostructures



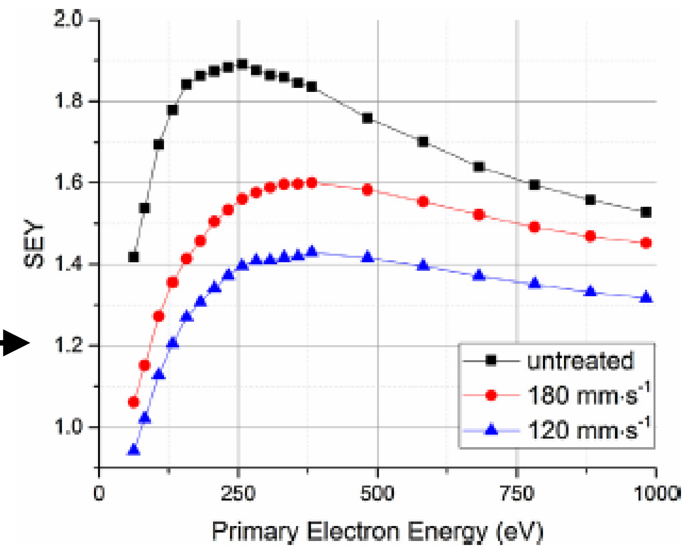
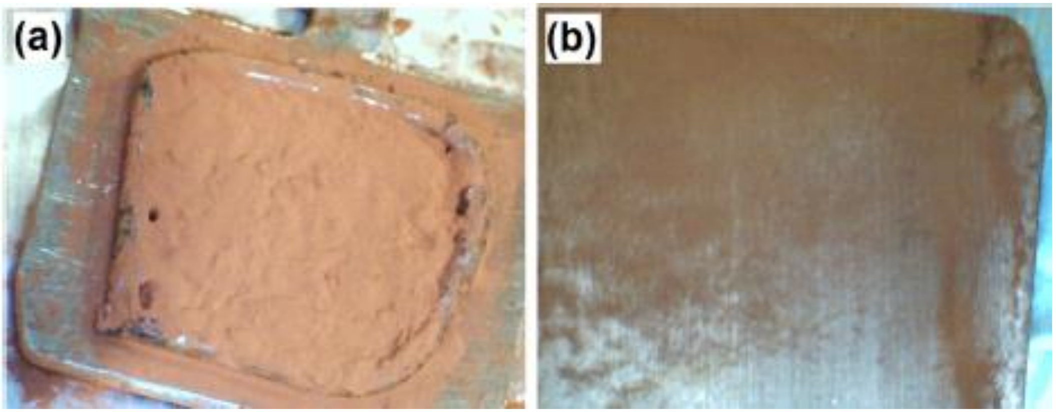


Fig. 12. SEY as function of primary electron energy of Samples 2* and 3* twice lase[r] treated (in comparison to untreated Sample 1).

A role of micro and nanostructures

SEY reduced by copper powder to ~1.



Samples 10 and 11 were covered with 5-μm copper powder.
No groves.

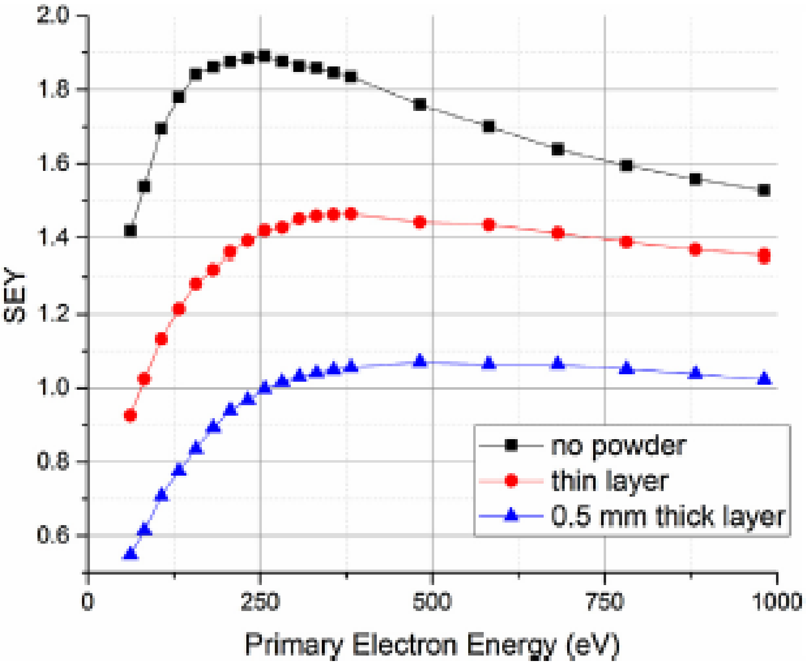


Fig. 13. SEY as function of primary electron energy of copper substrate (Sample 1) and copper powder with different thickness (Samples 10 and 11).

LASE conclusions

- It was demonstrated that not only microstructure (groves) but the nano-structures as well are playing a role in reducing SEY. It was found that the most efficient nano-structure for SEY reduction is submicron and nano-spheres, which allows to keep SEY<1 even at much reduced groove depth.
- It was also demonstrated that these surfaces can be produce using various lasers with different wavelength, such as λ=355 nm and λ=1064 nm, with optimised laser parameters such as pulse length, repetition rate, power, fluence, beam size, scan speed and distance between scanned lines.
- There is a clear evidence that SEY < 1 can be obtained with LASE with very reduced surface resistance

How do we measure the surface resistance

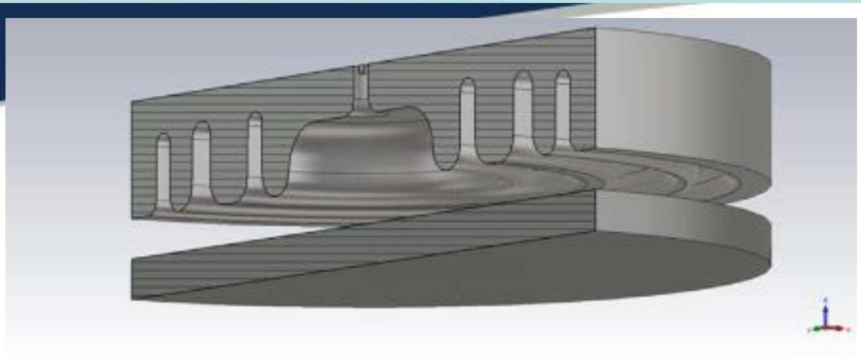
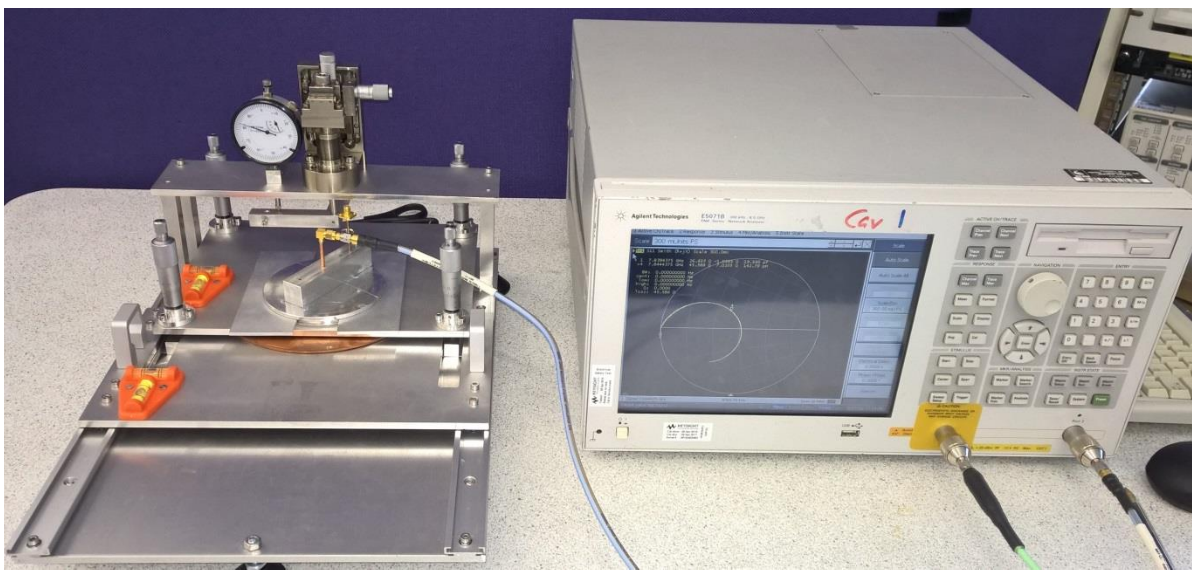


Fig. 1. A schematic of the triple choke RF cavity above a sample.

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

- 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 a case using perfect electric conductor (PEC) boundary conditions, the field ratios are p_c = 0.625 and p_s = 0.375.

f = 7.8 GHz

Calculation of surface resistance

- A multilayer structure (metal-insulator-metal) was modelled
- By applying transmission line theory it can be shown that the surface impedance of this multi-layer structure is given by

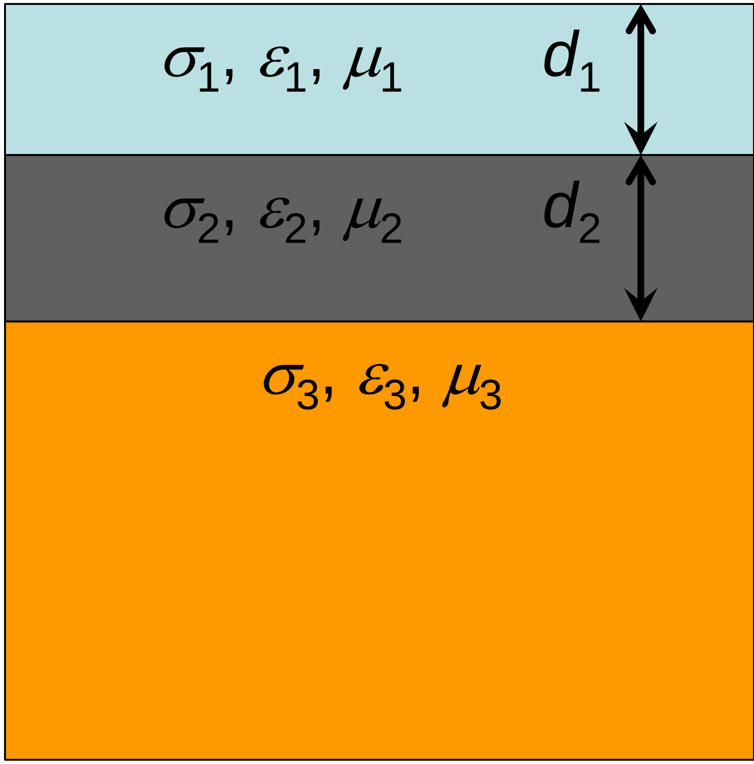
$$Z_S = Z_1 \frac{(Z_1 + Z_{23}) - (Z_1 - Z_{23})\exp(2ik_1 d_1)}{(Z_1 + Z_{23}) + (Z_1 - Z_{23})\exp(2ik_1 d_1)}$$

- In case of metal-metal structure (d_2 = 0) it gives

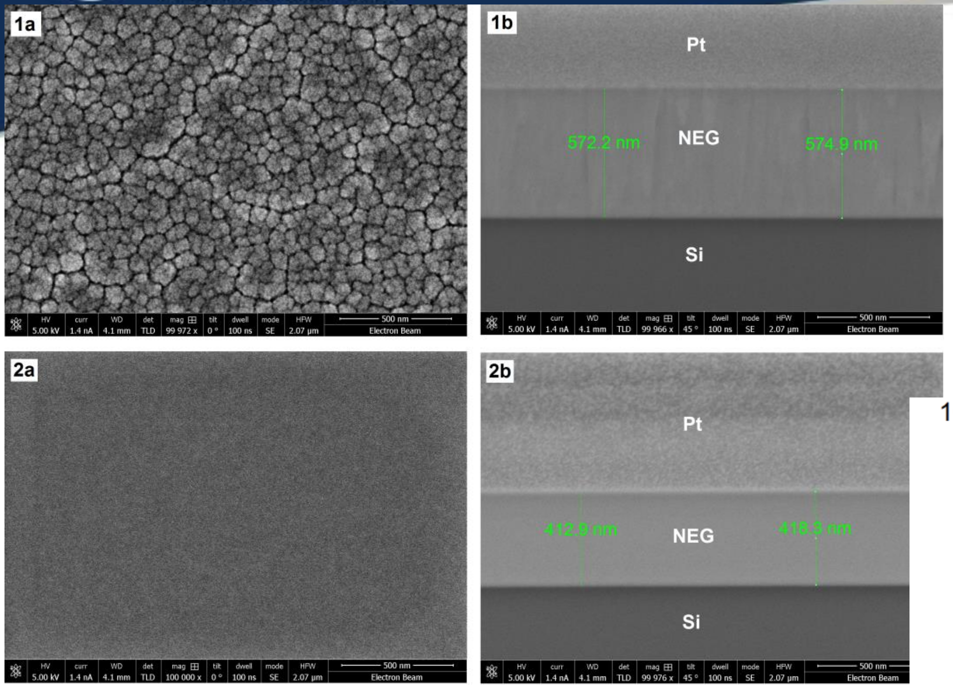
$$R_S = R_1 \frac{1 - \delta^2 \exp(-4\kappa_1 d_1) - 2\delta \sin(2\kappa_1 d_1)\exp(-2\kappa_1 d_1)}{1 + \delta^2 \exp(-4\kappa_1 d_1) + 2\delta \cos(2\kappa_1 d_1)\exp(-2\kappa_1 d_1)};$$

- In case of metal-insulator structure ($d_2 >> d_1$) it gives

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

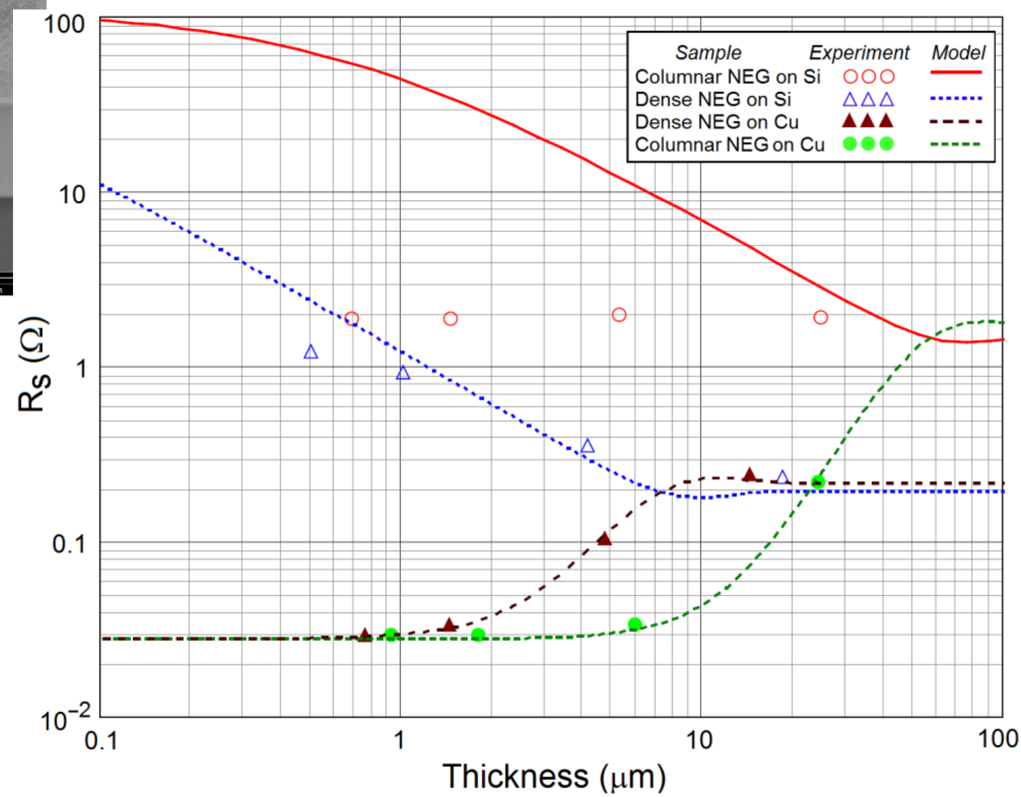


NEG coating studies – surface resistance



Columnar and Dense NEG coating

- 16 NEG coated samples deposited
- Columnar and Dense (8+8)
- Thickness: 0.7-18 μm
- On two substrates: Cu and Si



The bulk conductivity was obtained with the analytical model:

- $\sigma_d = 1.4\times10^4\ S/m$ for the columnar NEG coating
- $\sigma_d = 8\times10^5\ S/m$ for the dense NEG coating.

NEG coating studies – surface resistance

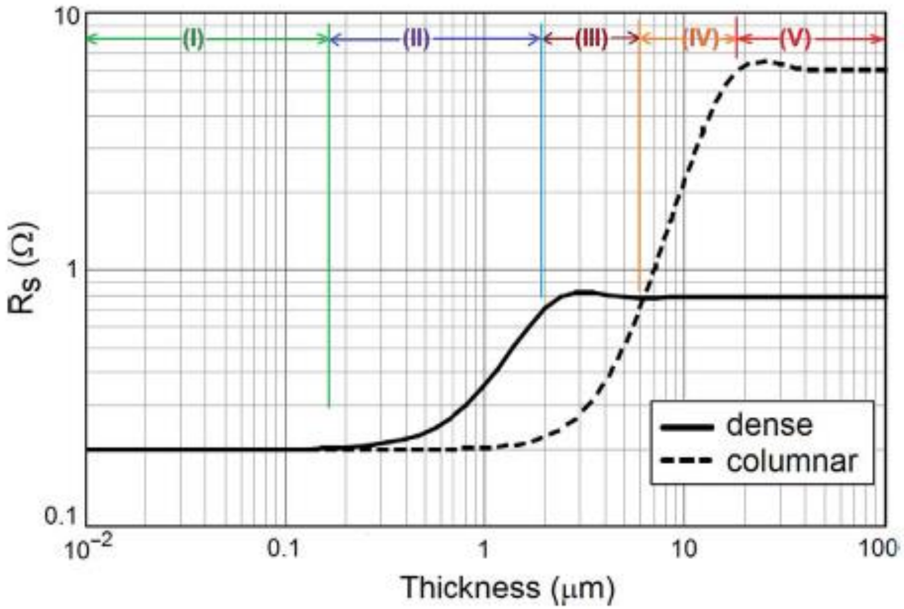


Fig. 7. A comparison of surface resistance of columnar (solid line) and dense (dashed line) NEG films, zones (I)–(V) as described in the text.

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)**;

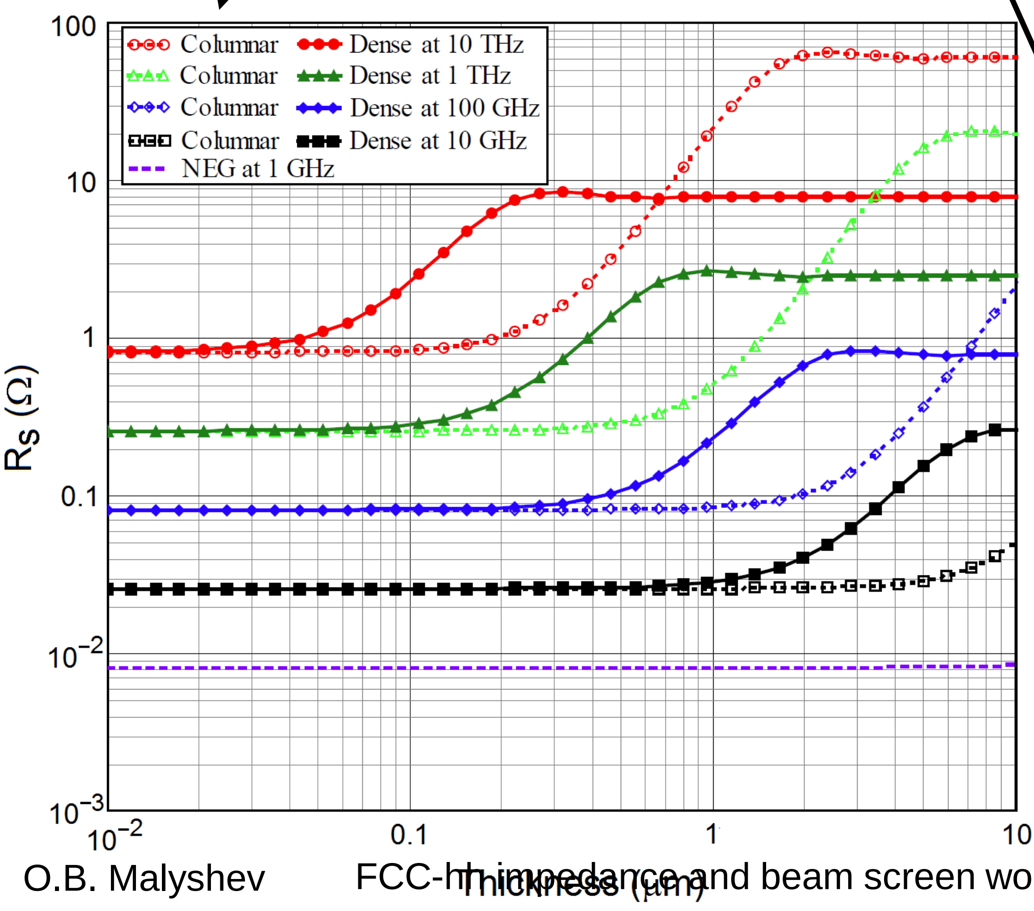
III. R_S of columnar NEG coating steadily increases and reaches a maximum value for dense NEG: **R_S(Cu) < R_S(columnar) < R_S(dense)**;

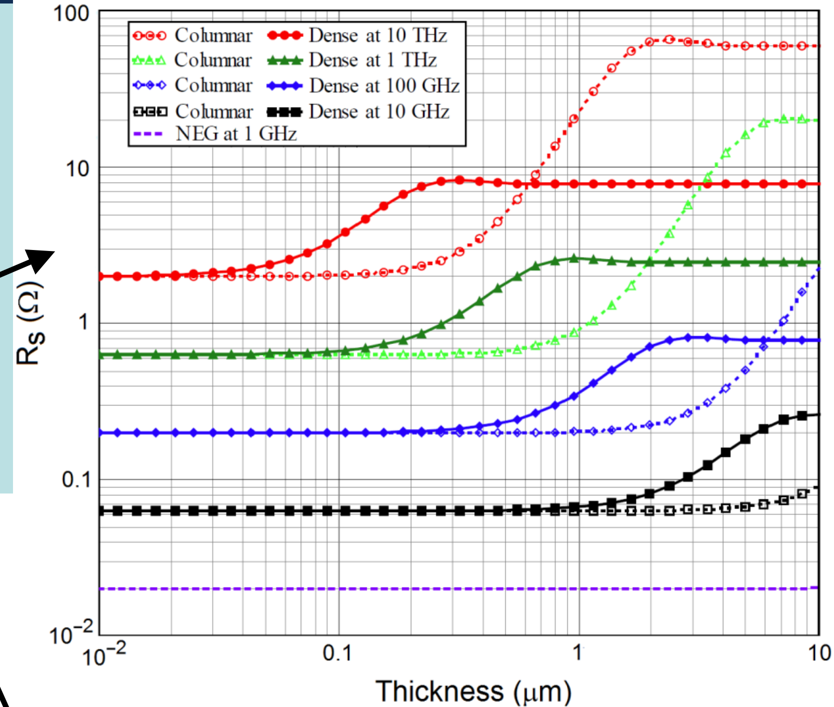
IV. R_S of columnar NEG coating steadily increases to its maximum:

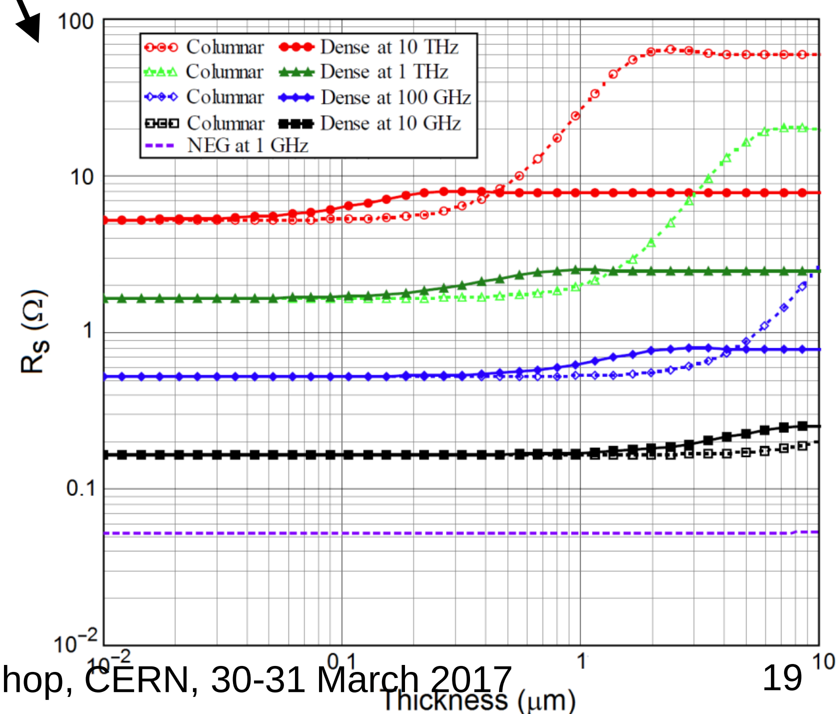
R_S(Cu) < R_S(dense) < R_S(columnar);

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







NEG coating studies – surface resistance

For more details please refer to:

Nuclear Instruments and Methods in Physics Research A 844 (2017) 99–107

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RF surface resistance study of non-evaporable getter coatings

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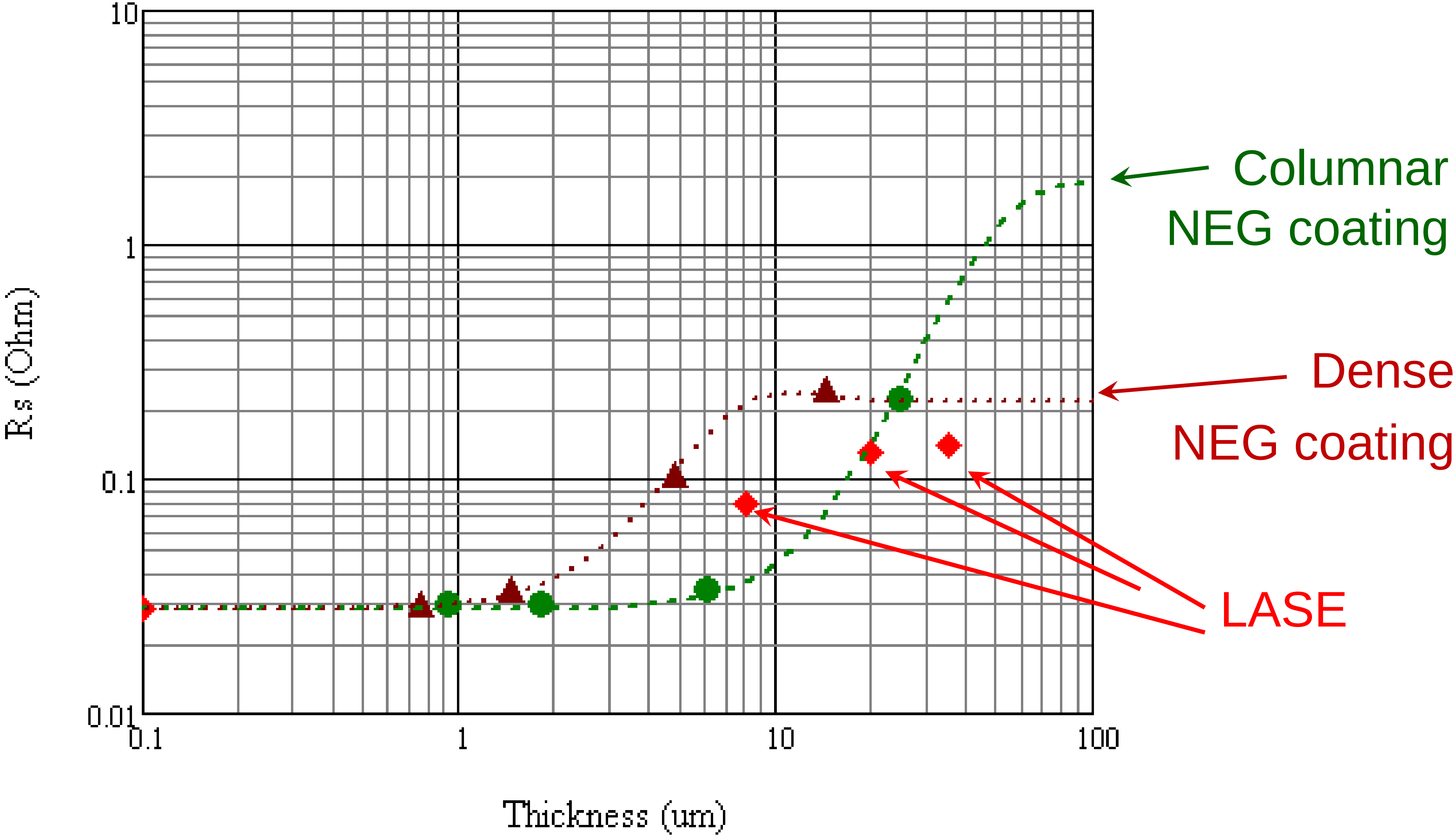
Surface resistance at 7.8 GHz for LASE and NEG coating



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Surface resistance summary

- The RF surface resistance of metal surfaces can be studied with a three-choke test cavity
  - **Contactless method**
  - Realised at 7.8 GHz
- Surface resistance of **LASE** surface was studied
  - To reduce R_s the depth of damaged layer should be reduced
- Surface resistance can be calculated for dense and columnar **NEG coating** as a function of:
  - Film thickness
  - RF frequency
- An open question:
  - R_s as a function of temperature
    - To be addressed in future
      - Possibilities for a dedicated facility are under investigation