THEORY OF FIELD EMISSION THROUGH DIELECTRIC PORES IN THE METAL SURFACE LAYER

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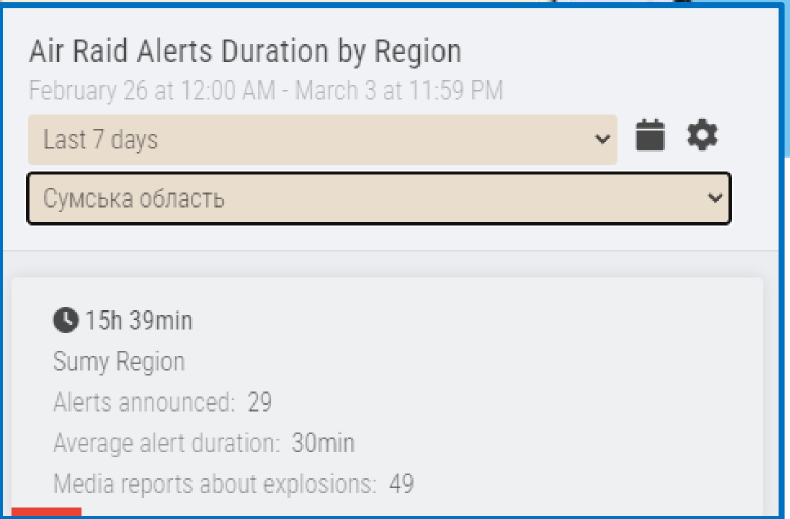

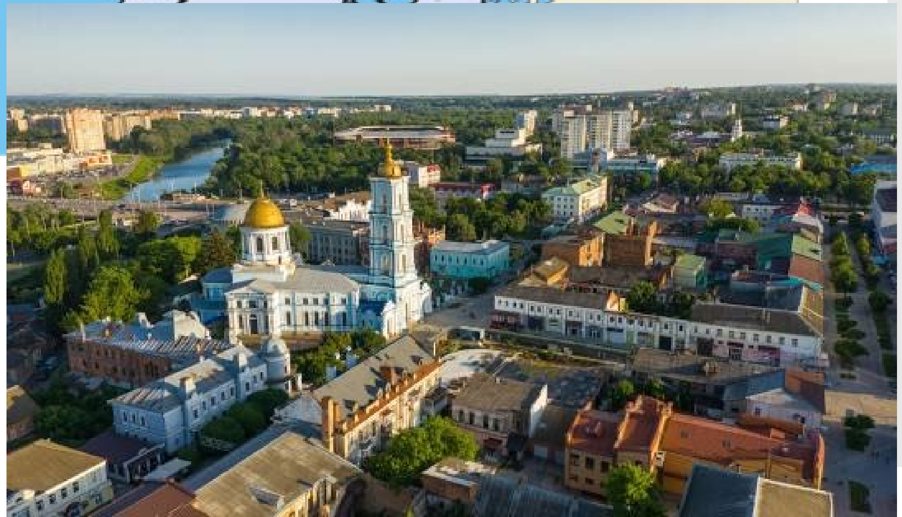

Institute of Applied Physics, National Academy of Sciences of Ukraine

The staff amounts to 146 persons. Investigations are performed by 95 researchers including 11 Doctors of Science and 43 PhDs.

<u>The main areas of research:</u>

- Study of ion, electrons and photons interactions with matter (including biological objects) and fields.

- Development of nuclear and physical research methods for structure and composition of materials and electrostatic accelerators

Main building

Laboratory building

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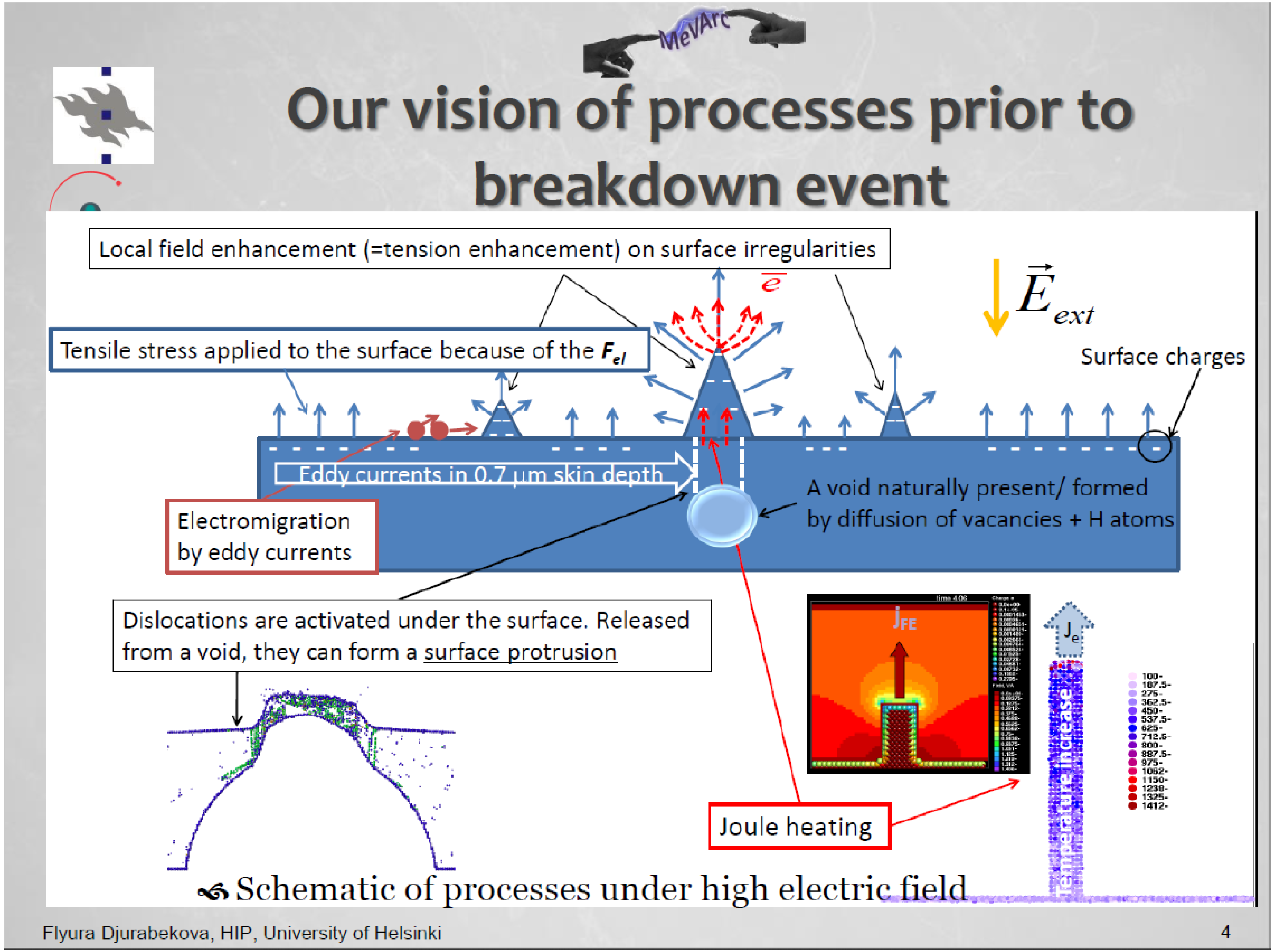
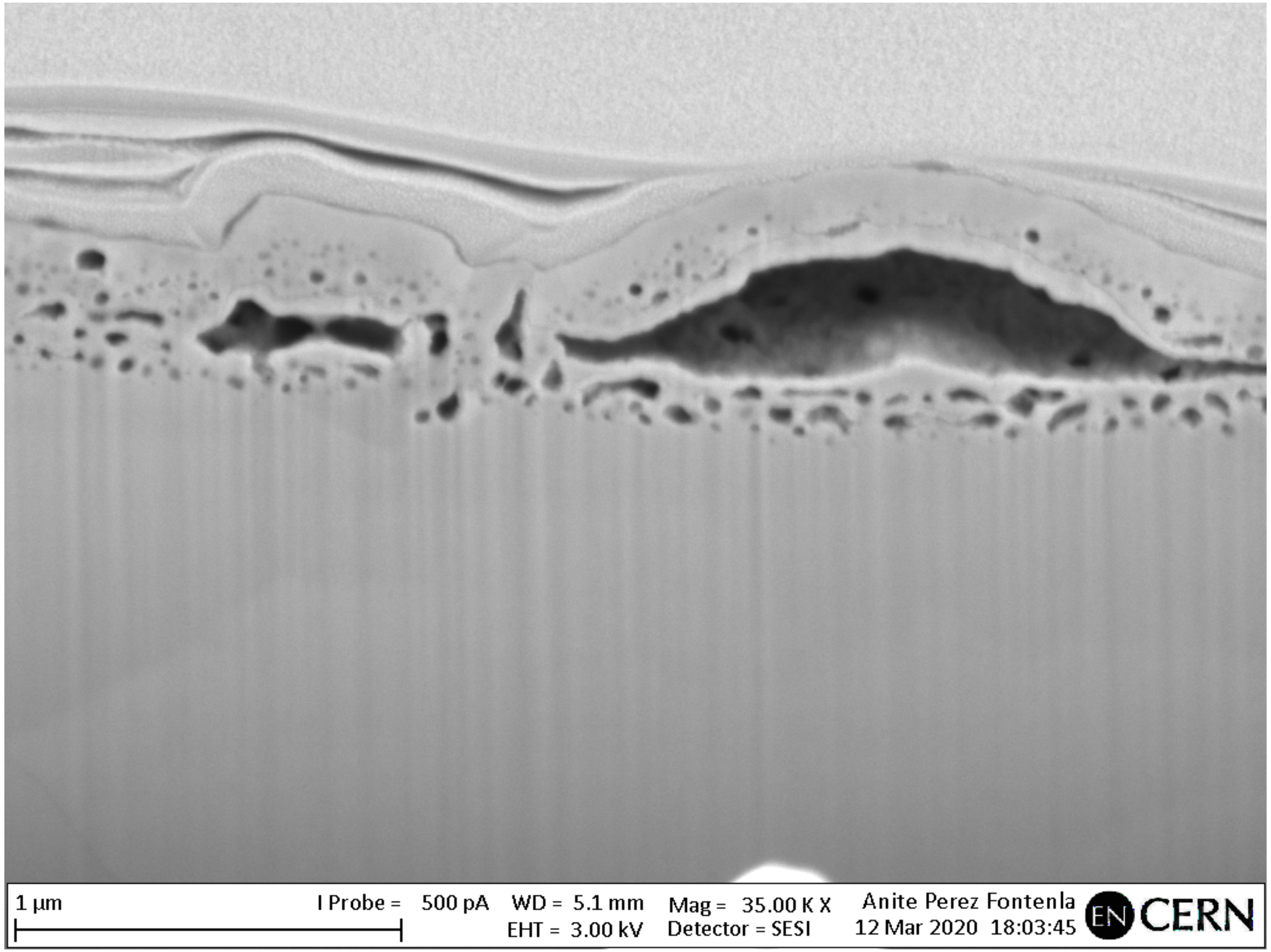


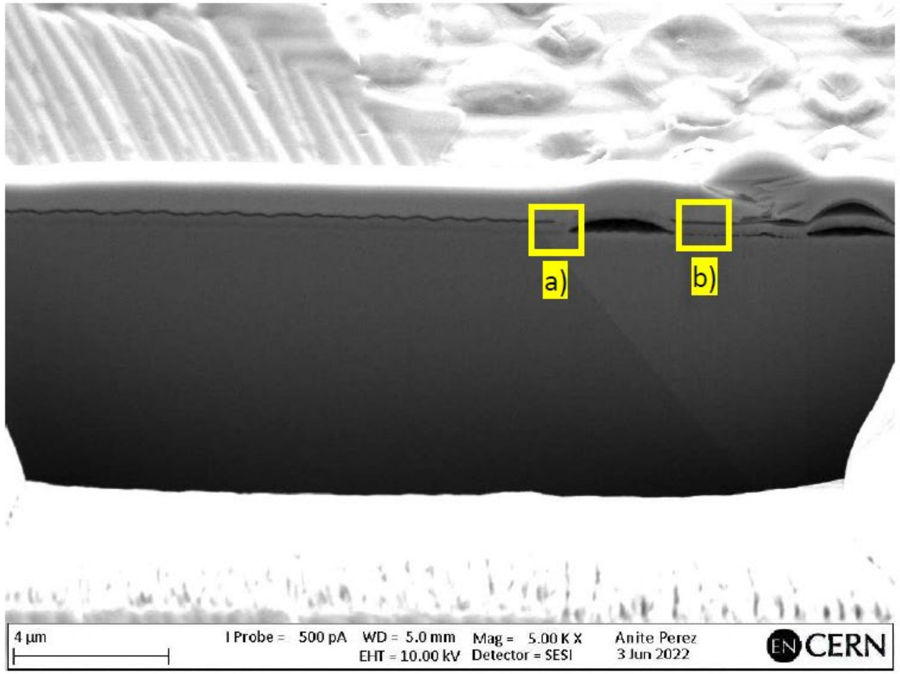
Flyura Djurabekova (MeVArc 2013)

Computer simulations of Cu surface behavior before and after a breakdown event

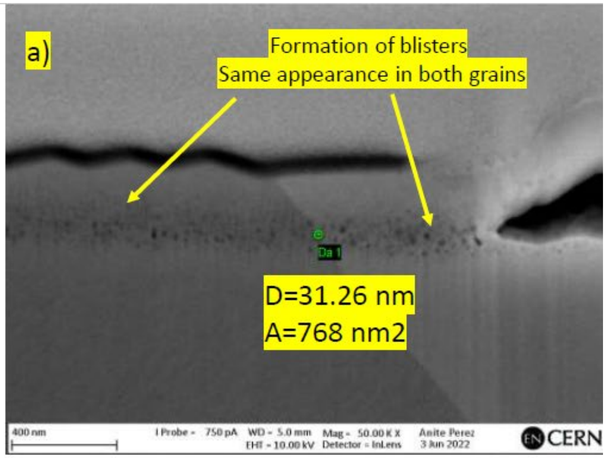


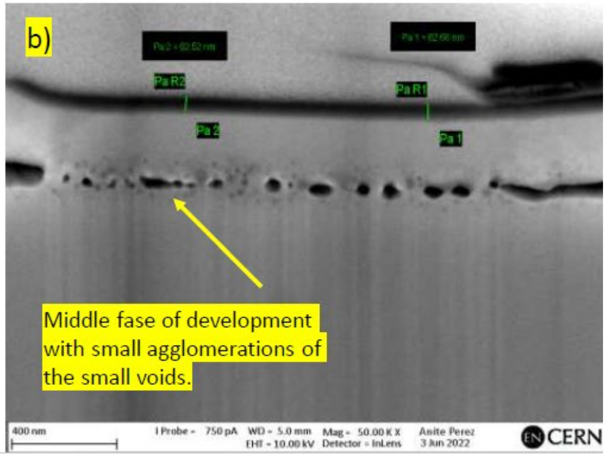
A. T. Fontenla (MeVArc 2021)

Microscopy investigation of the surface behaviour of different materials after H- irradiation in different conditions



The process of formation of blistering seems to occurs in the two different grains, at the depth between 260-280 nm. With a slower development on the blue grain 111.



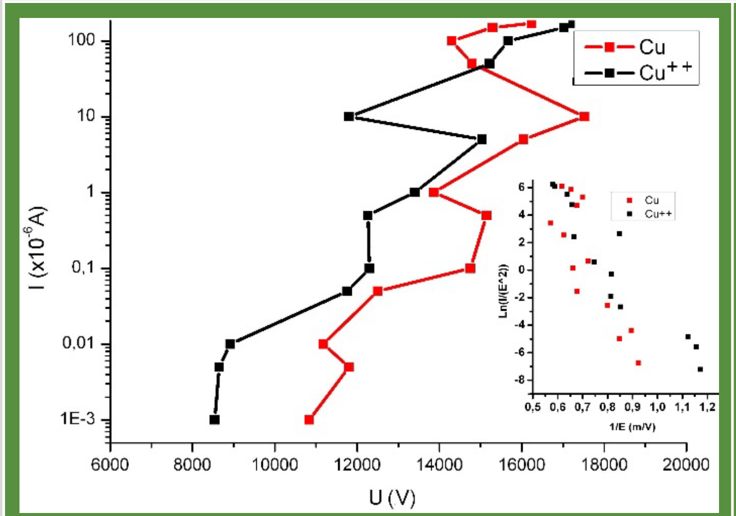


CATARINA SERAFIM
(Mini MeVArc 2023)

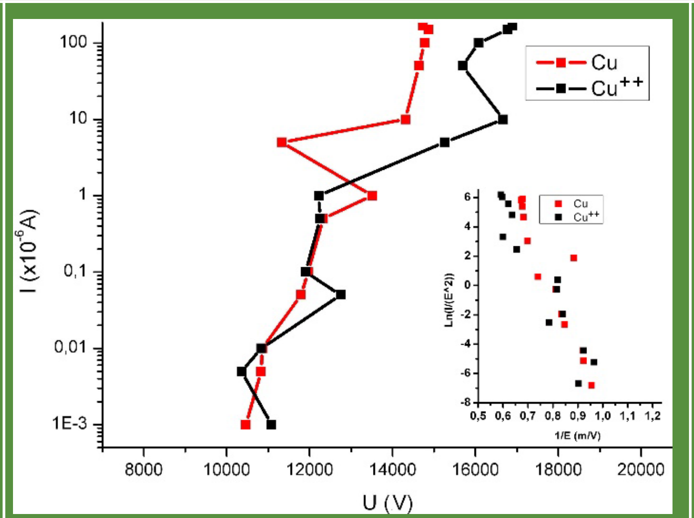
Part I – Experimental Study

Discussion concerning the effect of low H- beam irradiation on Cu sample

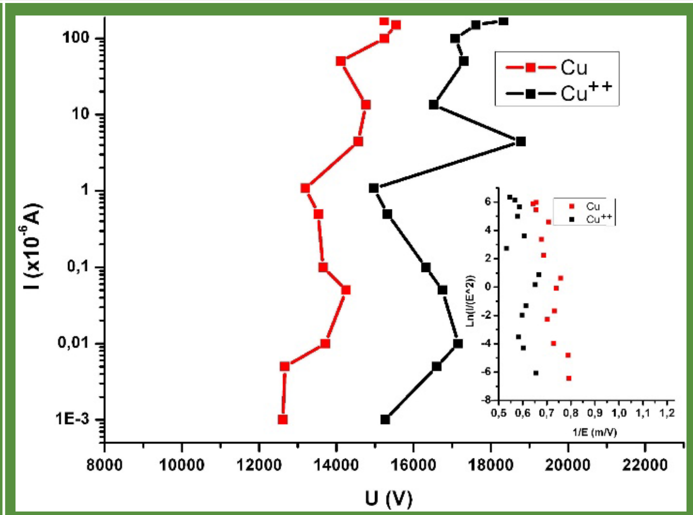
Ion implantation at IAP NASU



Breakdown characteristics for samples irradiated with Cu2+ ions with an irradiation dose of D=7•10^{15} cm^{-2} in conventional and Fowler-Nordheim coordinates



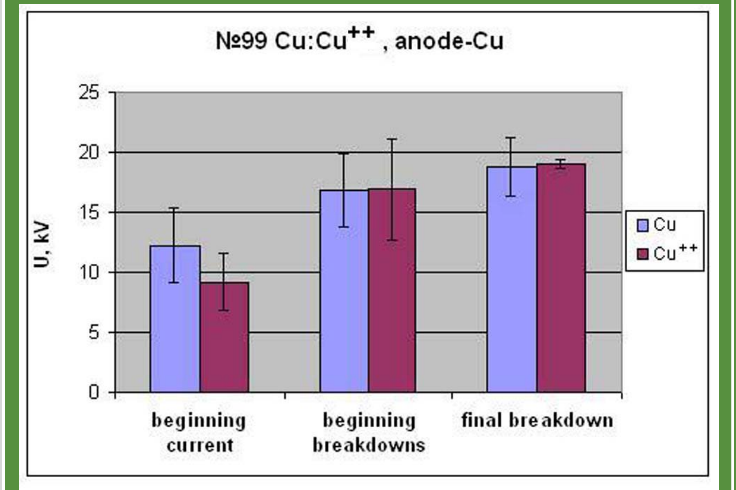
Breakdown characteristics for samples irradiated with Cu2+ ions with an irradiation dose of D=1.3•10^{16} cm^{-2} in conventional and Fowler-Nordheim coordinates



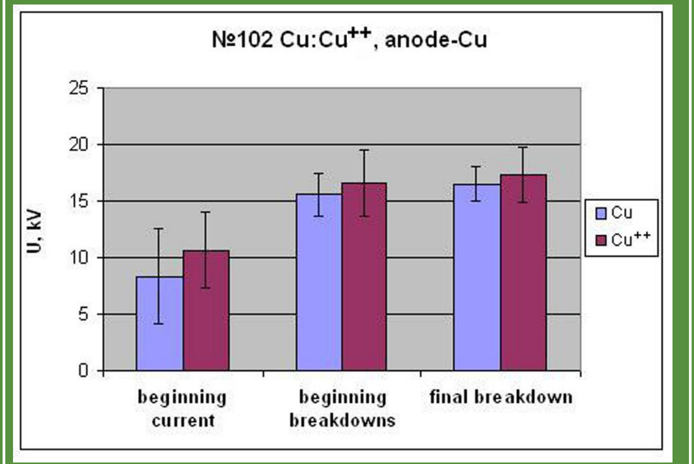
Breakdown characteristics for samples irradiated with Cu2+ ions with an irradiation dose of D=3.5•10^{16} cm^{-2} in conventional and Fowler-Nordheim coordinates

Study of vacuum high-gradient breakdowns from the ion-modified surface of copper electrodes
https://doi.org/10.46813/2023-145-103

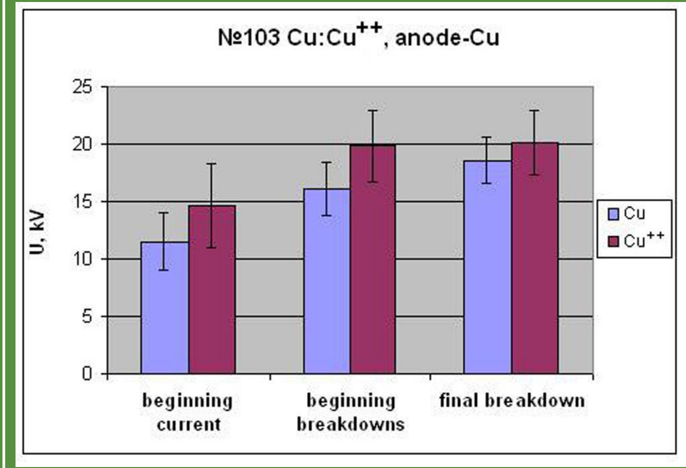
Ion implantation at IAP NASU



Breakdown characteristics for samples irradiated with Cu2+ ions with an irradiation dose of $D=7 \bullet 10^{15}$ cm^{-2} in conventional and Fowler-Nordheim coordinates



Breakdown characteristics for samples irradiated with Cu2+ ions with an irradiation dose of $D=1.3 \bullet 10^{16}$ cm^{-2} in conventional and Fowler-Nordheim coordinates



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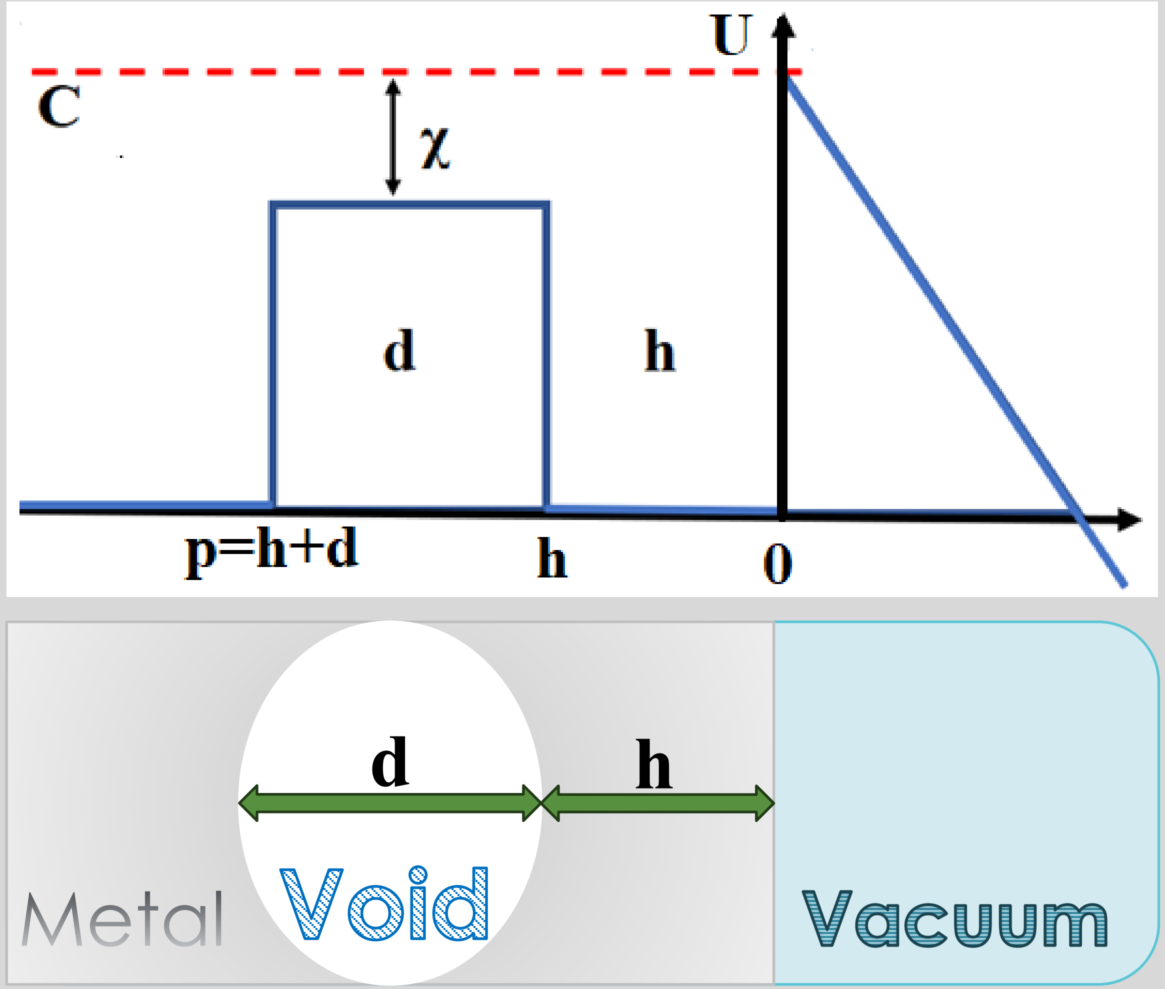
Potential barrier model



Schematic representation of the potential barrier for the metal-dielectric-metal-vacuum system

- ✓ h is the depth of the nanoscale void in the metal surface layer
- ✓ d is the diameter of the nanoscale void
- ✓ χ is the electron affinity for the dielectric
- ✓ C is the height of the potential barrier

Transmission coefficient

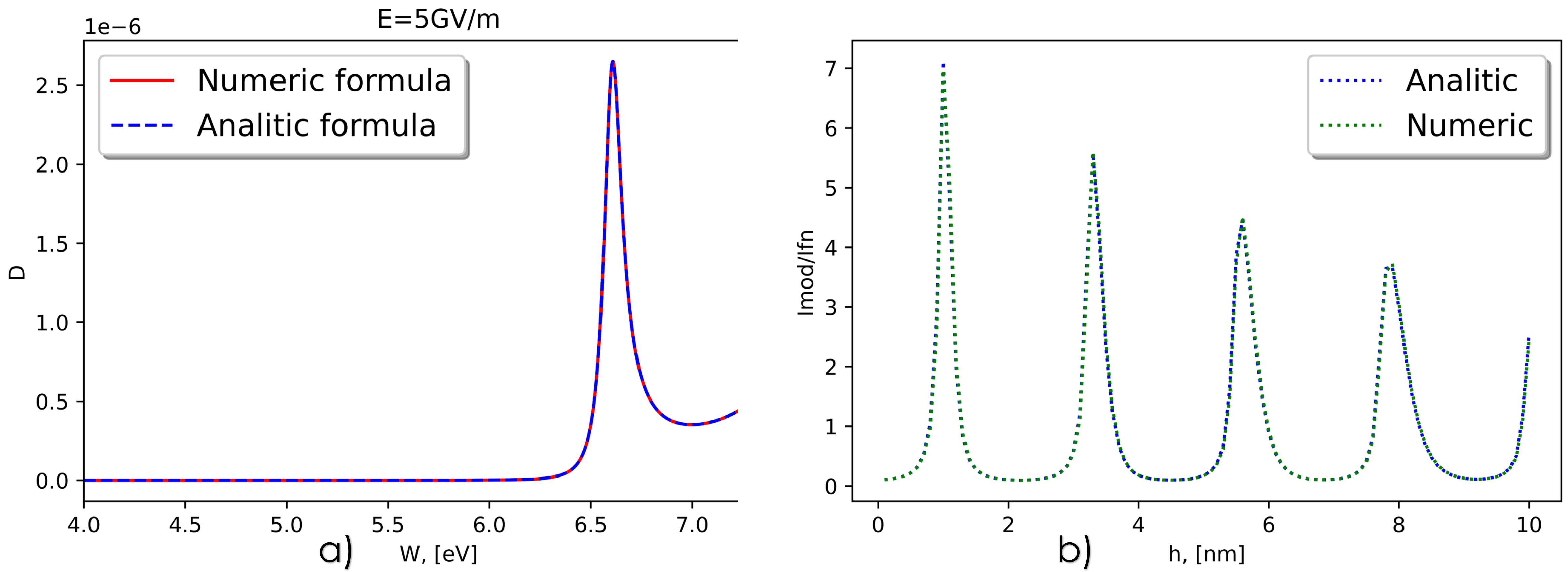
- Imposing the conditions of continuity of the wave function at the metal-dielectric, dielectric-metal, and metal-vacuum boundaries and using typical values of the metal yield work and electric field strength allows us to obtain an analytical expression for the transparency coefficient of the potential barrier:

$$D = \frac{4(C-\chi-\mathrm{W})\mathrm{W}^{\frac{3}{2}} e^{-\frac{4k(C-\mathrm{W})^{\frac{3}{2}}}{3eE}} \sqrt{C-\mathrm{W}}}{(C-\chi)\left(\left(\sinh(\beta d)\Upsilon\sqrt{C-\chi-\mathrm{W}}+\cosh(\beta d)\sqrt{\mathrm{W}}\,\Lambda\right)^2+\varepsilon\Upsilon^2\right)-\mathrm{W}^2 C}$$

- where $\Upsilon = \sqrt{C-\mathrm{W}}\,\boldsymbol{sin(\alpha h)} + \boldsymbol{cos(\alpha h)}\sqrt{\varepsilon}$, $\Lambda = \sqrt{C-\mathrm{W}}\,\boldsymbol{cos(\alpha h)} - \boldsymbol{sin(\alpha h)}\sqrt{\varepsilon}$, $\alpha = k\sqrt{\mathrm{W}}$, $\beta = k\sqrt{C-\chi-\mathrm{W}}$, $k = \frac{\sqrt{2m}}{\hbar}$

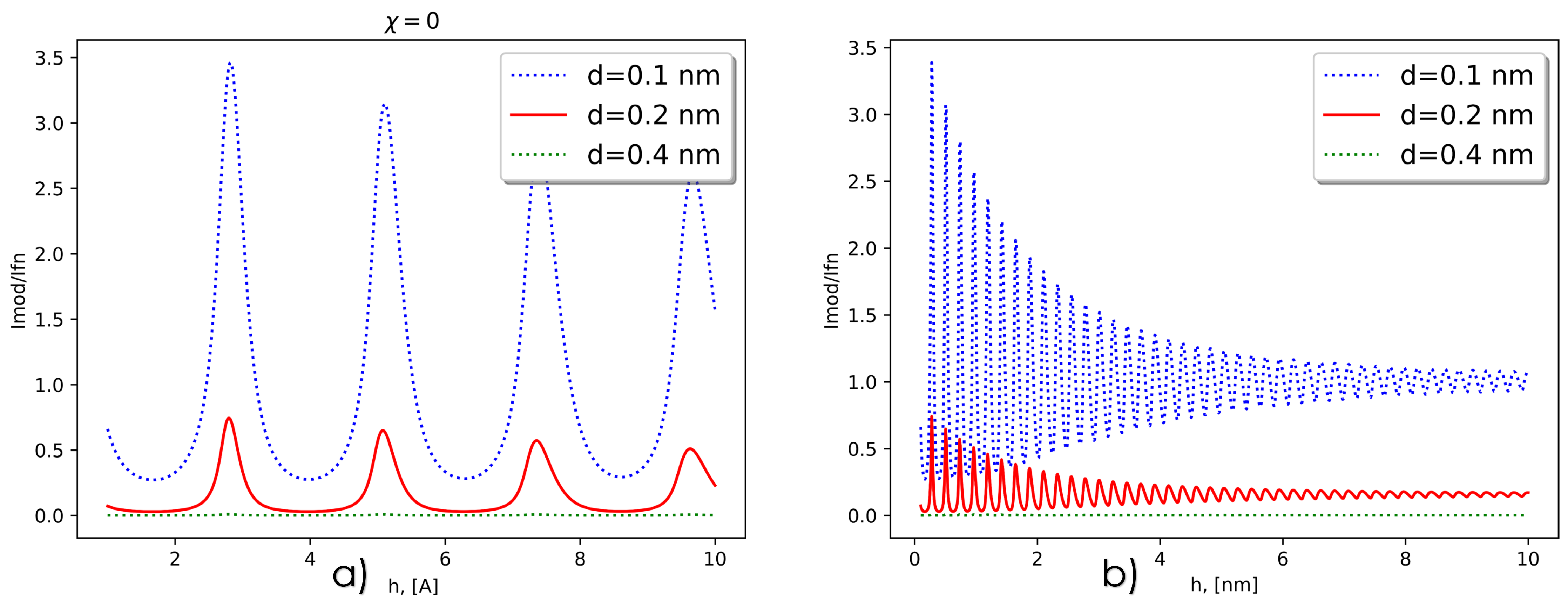
- The condition of maximum: $\boldsymbol{h = \frac{\lambda_B}{4}(2n+1), \lambda_B = \frac{2\pi\hbar}{\sqrt{2mW}}, n = 0, 1, 2, \ldots}$

Agreement with numerical calculations



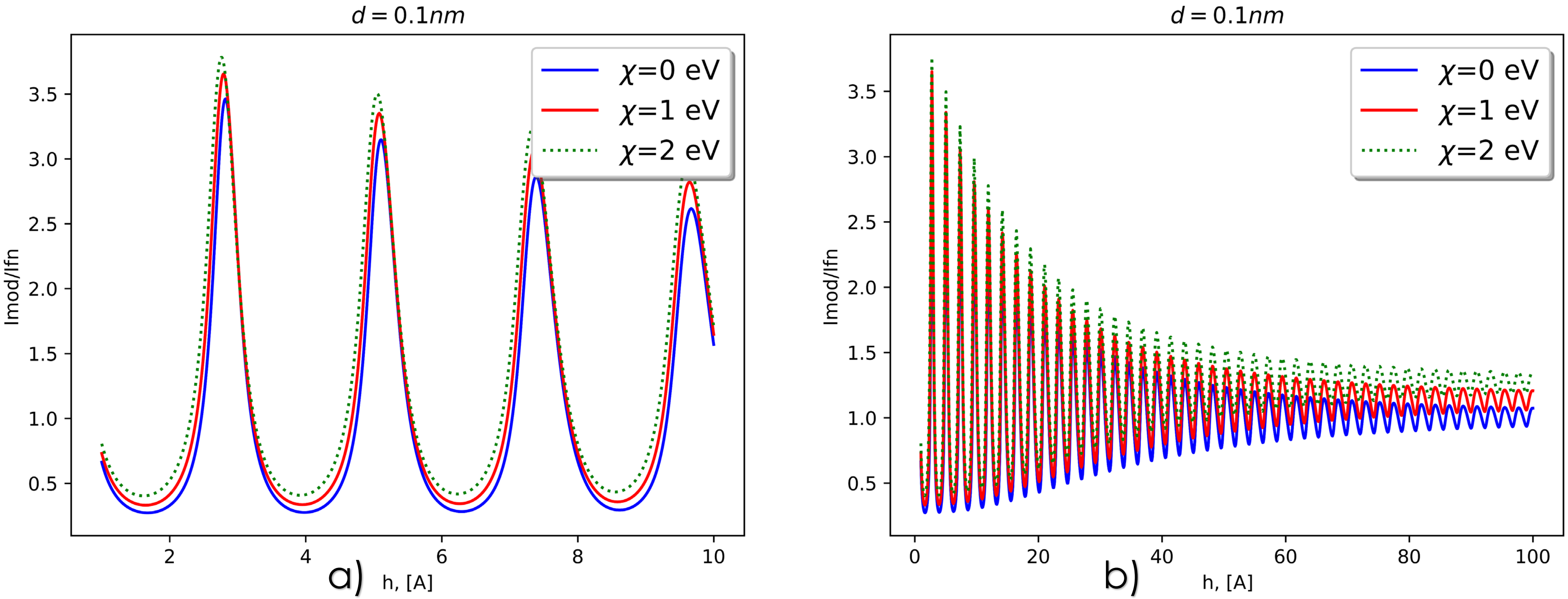
Comparison of the numerical calculations and the analytical formula: a) the dependence of the tunnelling coefficient of the potential barrier on the electron energy b) the field emission current

FEE current VS nanovoid depth and size

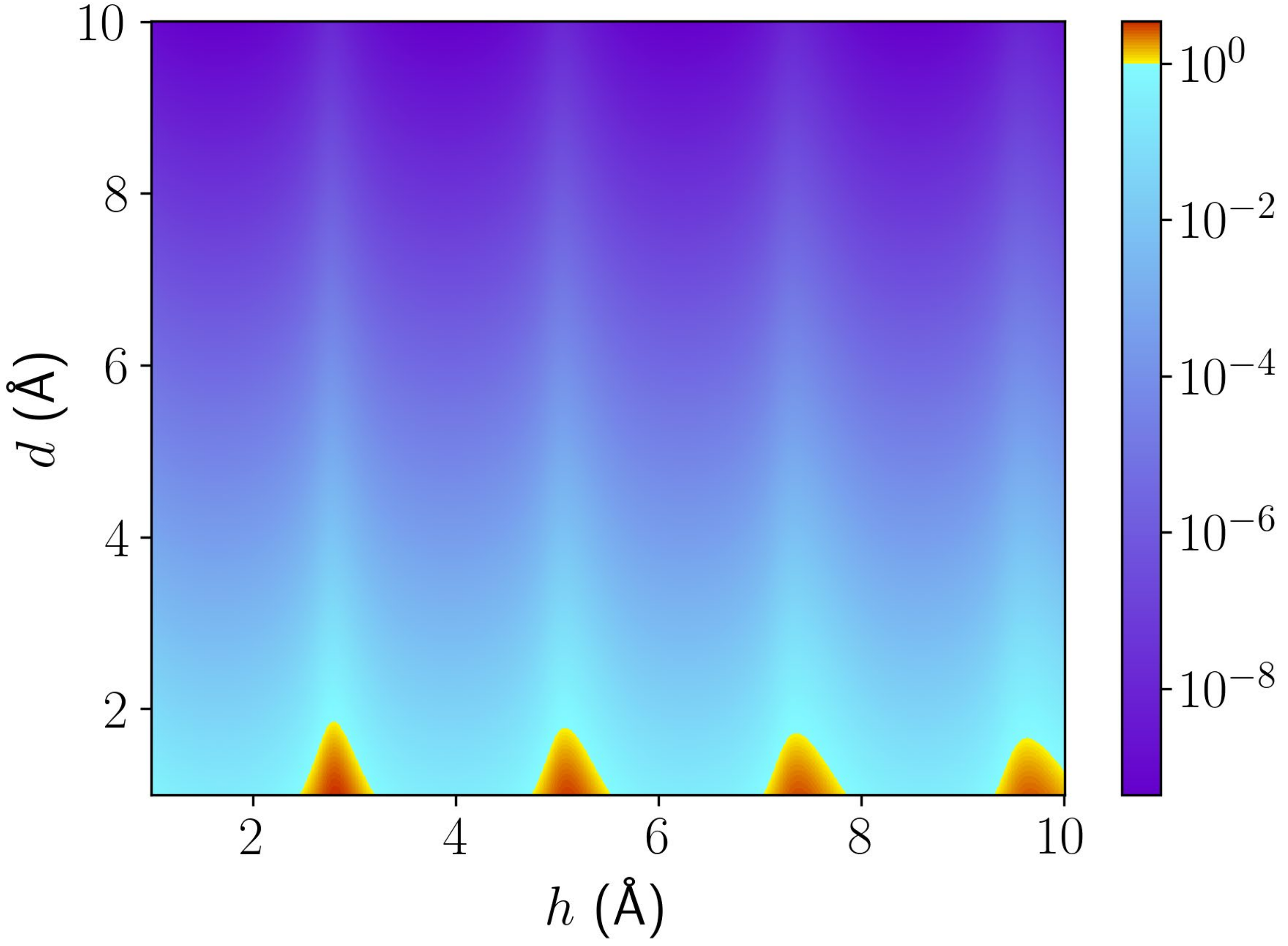


Comparison of the values of the field emission current density j_{mod} *and* j_{F-N} *depending on d and h: a) for h=0÷1 nm; b) for h=0÷10 nm*

FEE current VS nanovoid depth and size

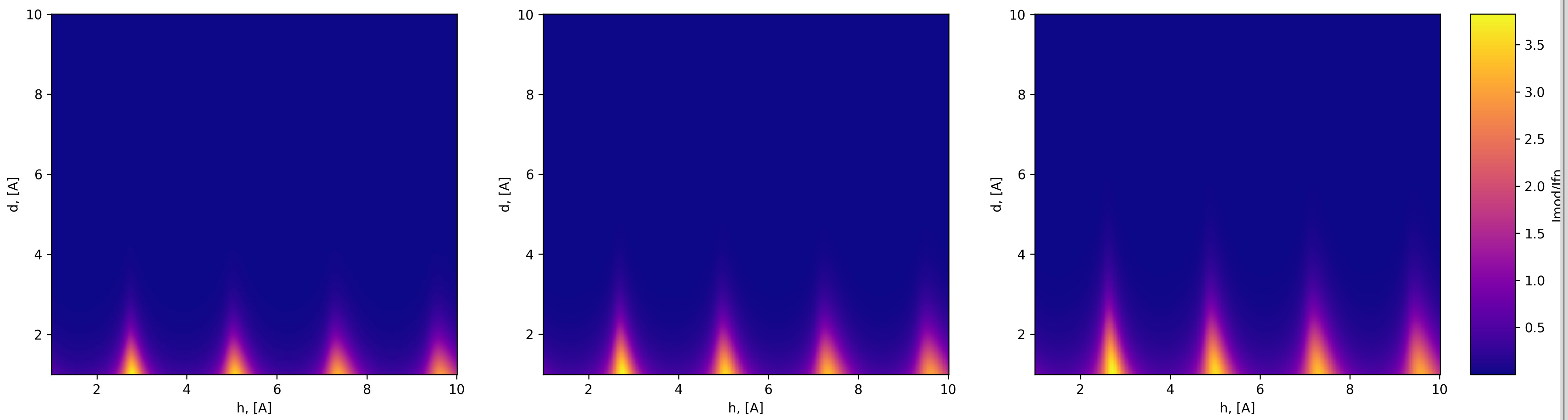


Comparison of the values of the field emission current density j_{mod} *and* j_{F-N} *depending on the electron affinity for the dielectric* χ *with constant d: a) for h=0÷1 nm; b) for h=0÷10 nm*



A color map of the dependence of the current from the modified surface expressed in units of Fowler-Nordheim current as a function of the size of the vacuum gap d and the thickness of the metal layer h at a constant value of the local electric field strength $E_{loc} = 5\ {}^{GV}/_{m}$.

χ=1 eV	χ=2 eV	χ=3 eV



The figures show the result of the numerical calculation of the field emission current density expressed in units of current from an ideal surface in the case when the affinity energy $\boldsymbol{\chi}$=**1**, **2** and **3** eV. The figure shows that the current is indeed resonant. It is also worth noting that in the case when the defect size is $\boldsymbol{d}$>**0.2-0.3** $\boldsymbol{nm}$, a decrease in the field electron emission current will be observed regardless of the depth of their occurrence. At the same time, with the increase of the affinity energy, the resonance region increases.

Conclusions

- It is shown that the field emission current from the metal surface near nanopores has a vibrational resonance feature. The resonance condition is determined by the depth of the nanoscale void from the metal surface, which is a multiple of $h = \frac{\lambda_B}{4}$.
- It was found that when the resonance conditions are met, the density of the field emission current from the copper surface increases by more than 3 times compared to the current from the unmodified surface.
- In the case of non-resonant conditions or an increase in the diameter of the nanopores, the current density decreases to almost zero.
- The surface modification, which leads to the formation of nanopores in the near-surface layer of the material, may indeed be one of the ways to increase the resistance of materials of accelerator structures to breakdowns. The results are in good agreement with the experiment.

Thank you for your attention!