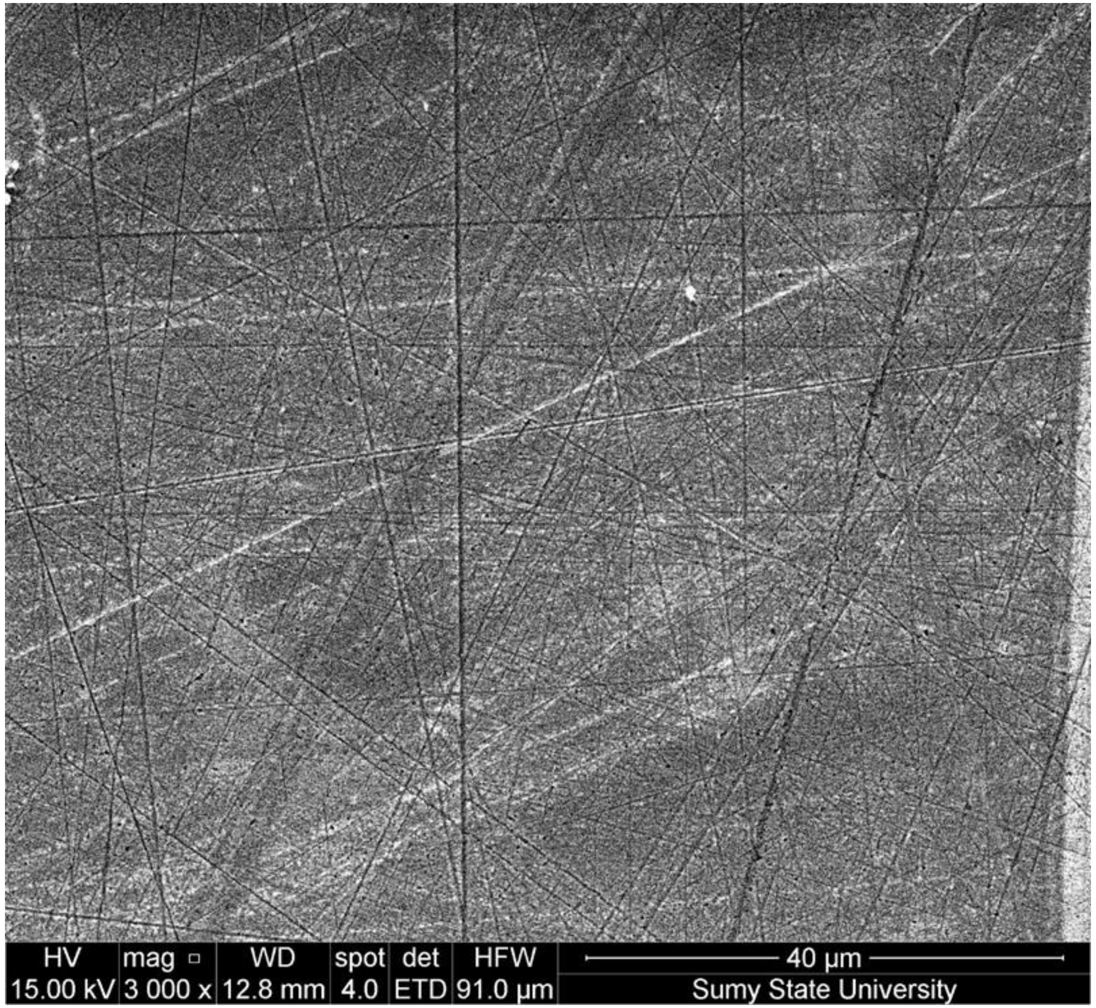
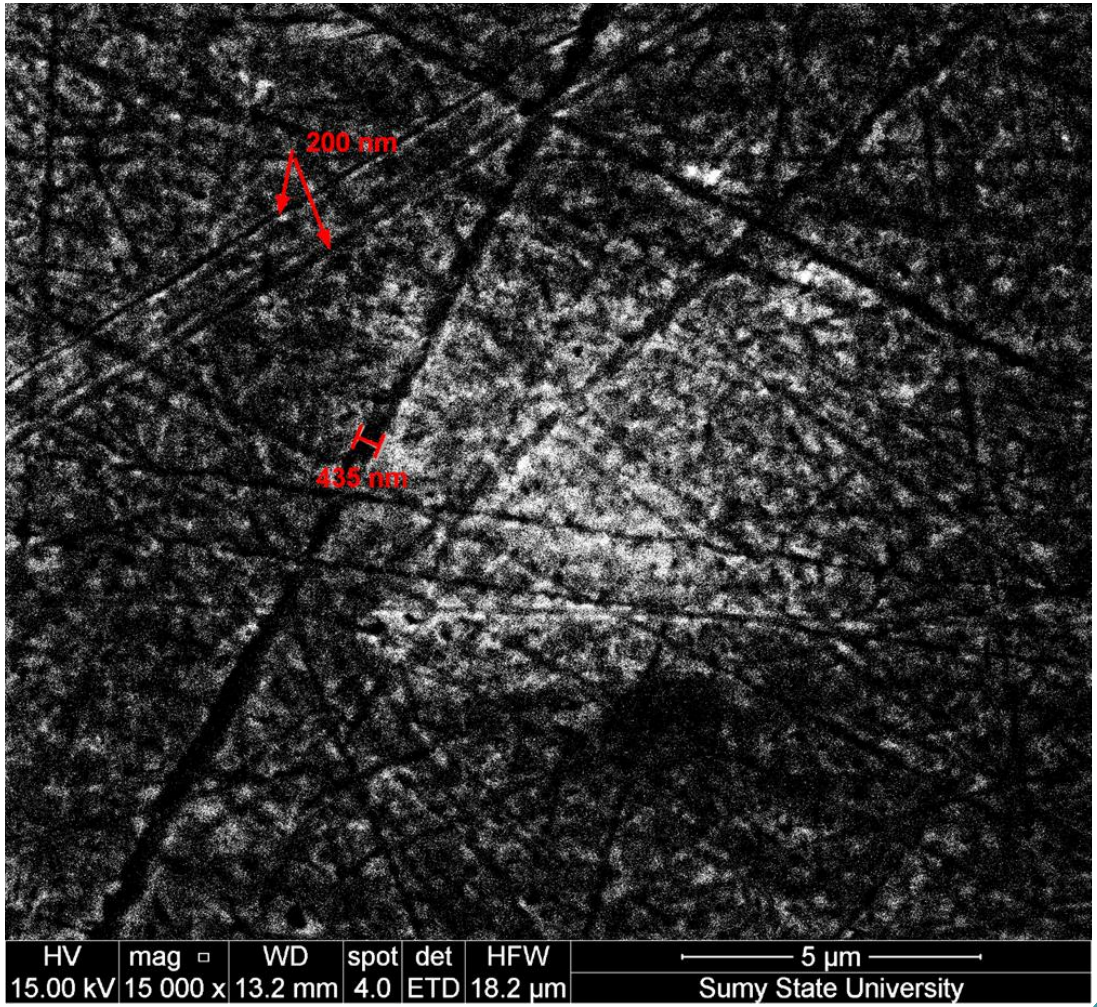
IAP NASU samples

mechanical polishing

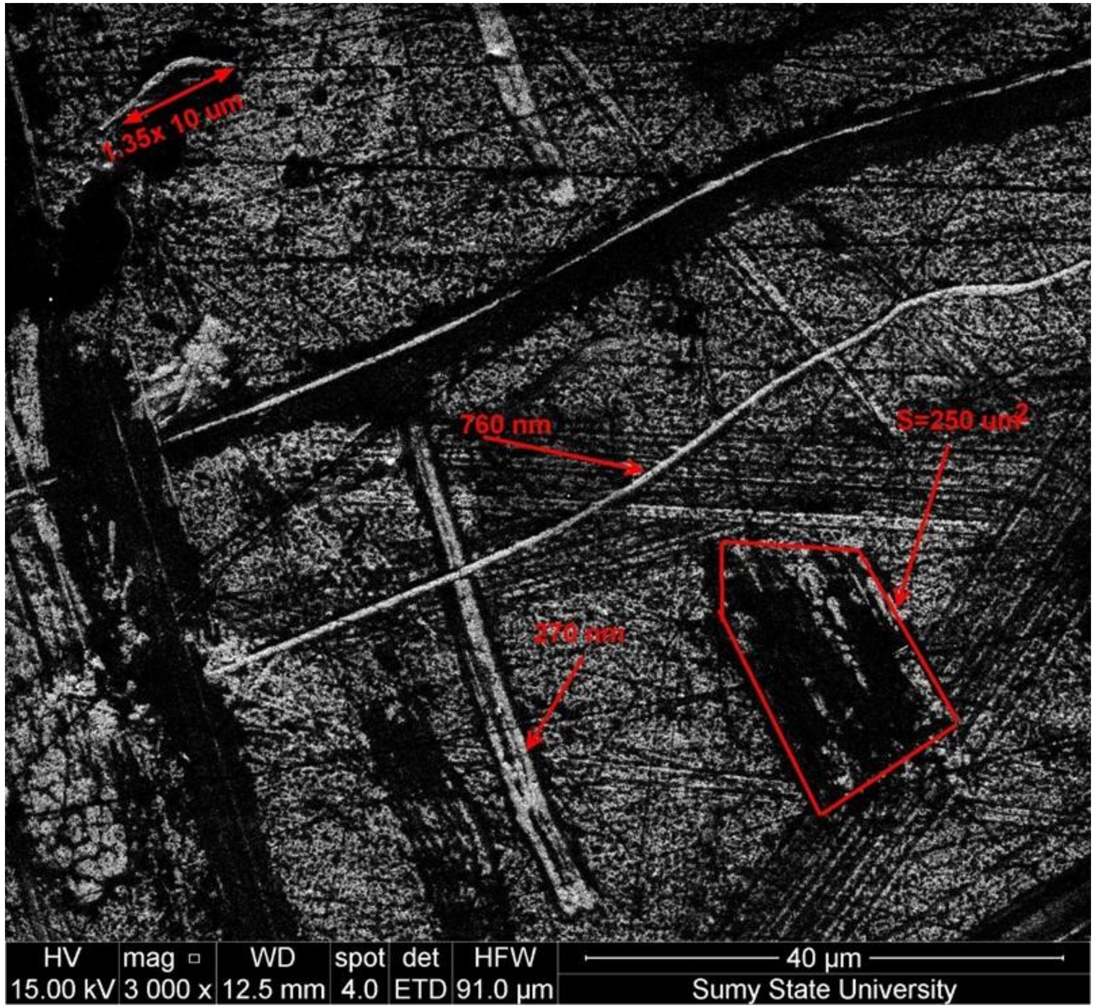
IAP NASU samples

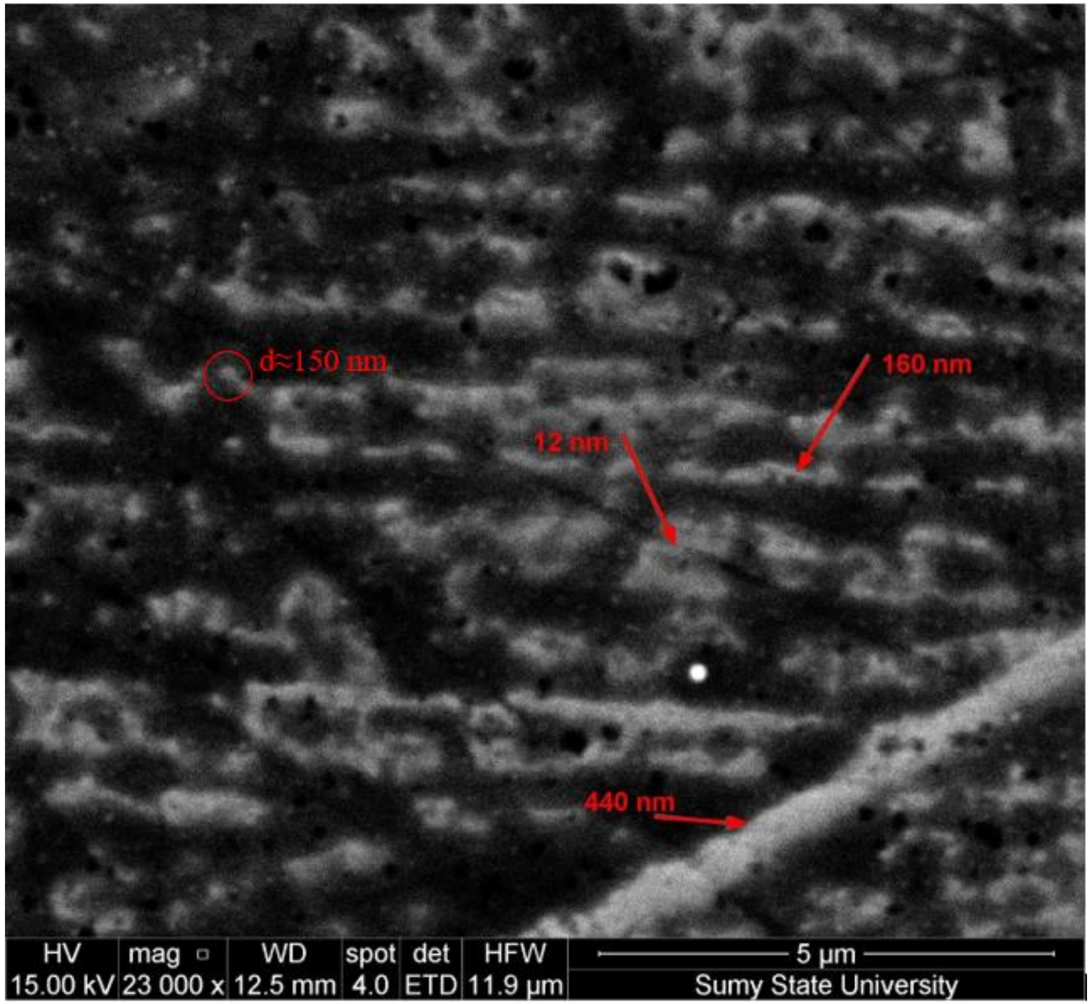




etching in a mixture of acids

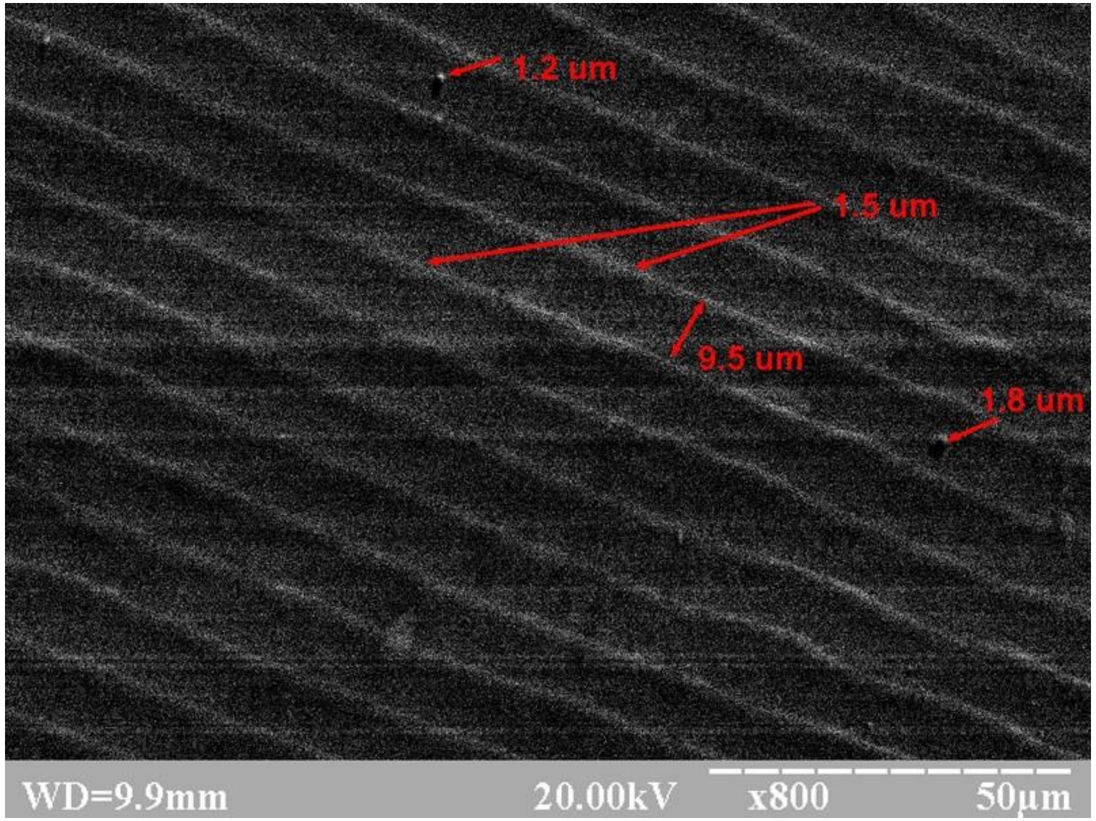
IAP NASU samples

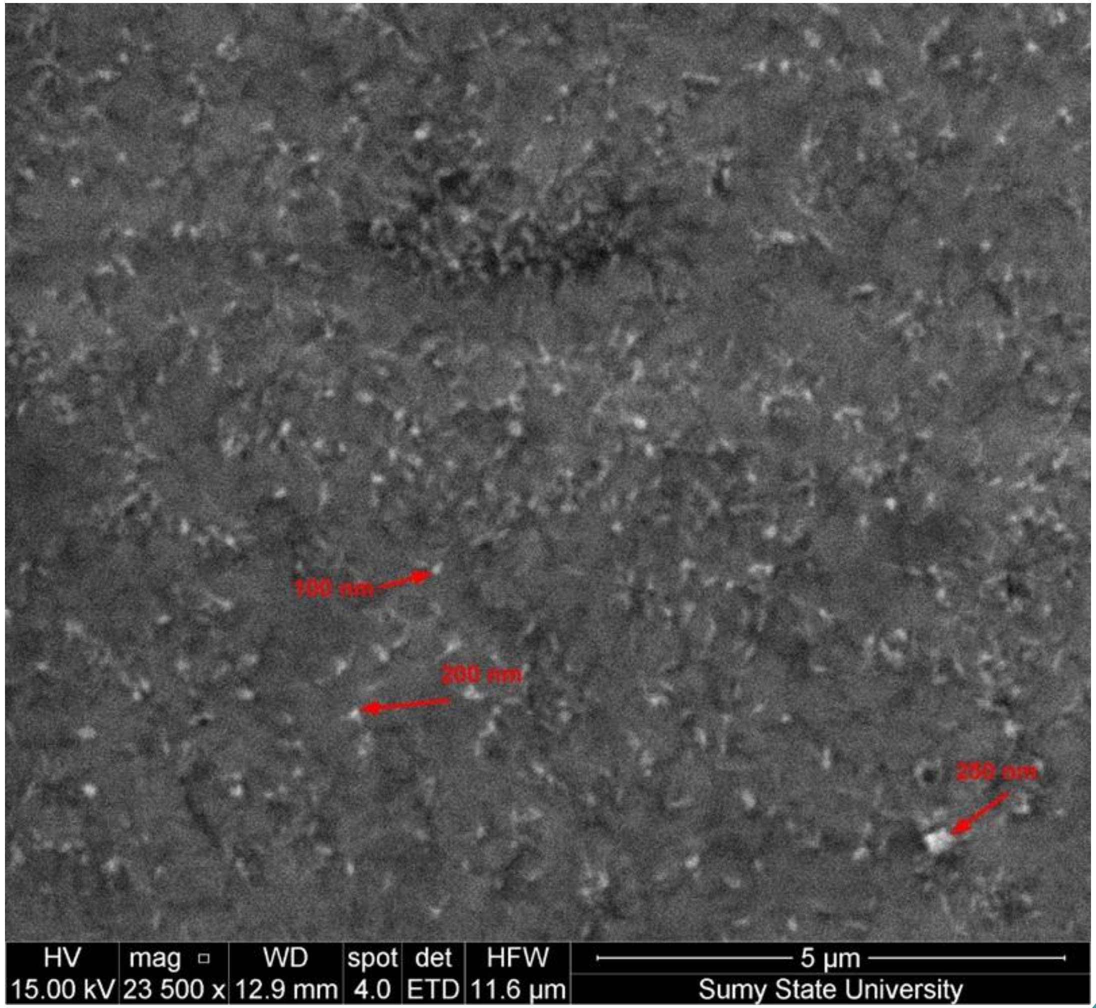




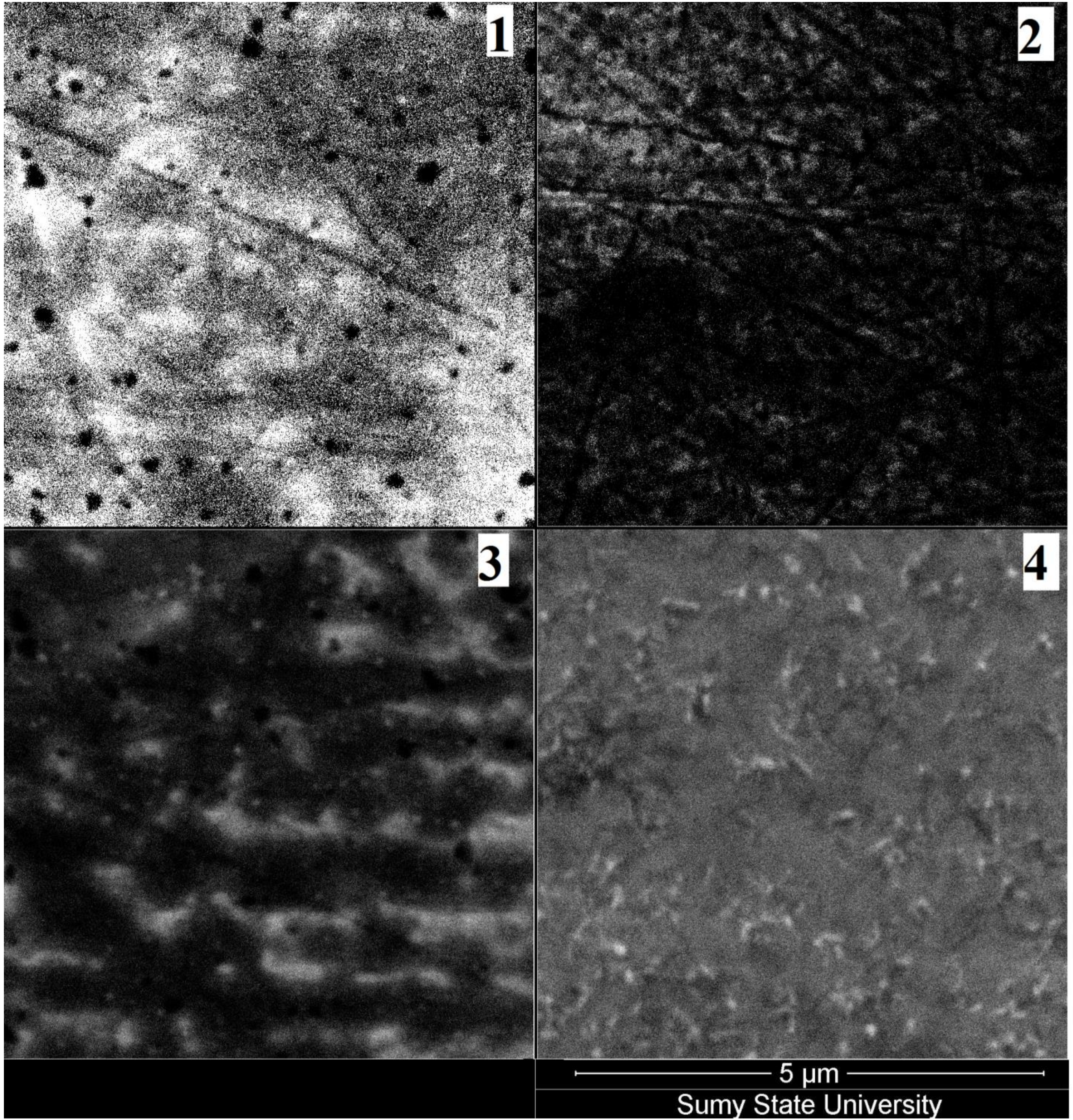
glow discharge cleaning

CERN samples





Standard cleaning procedure CERN

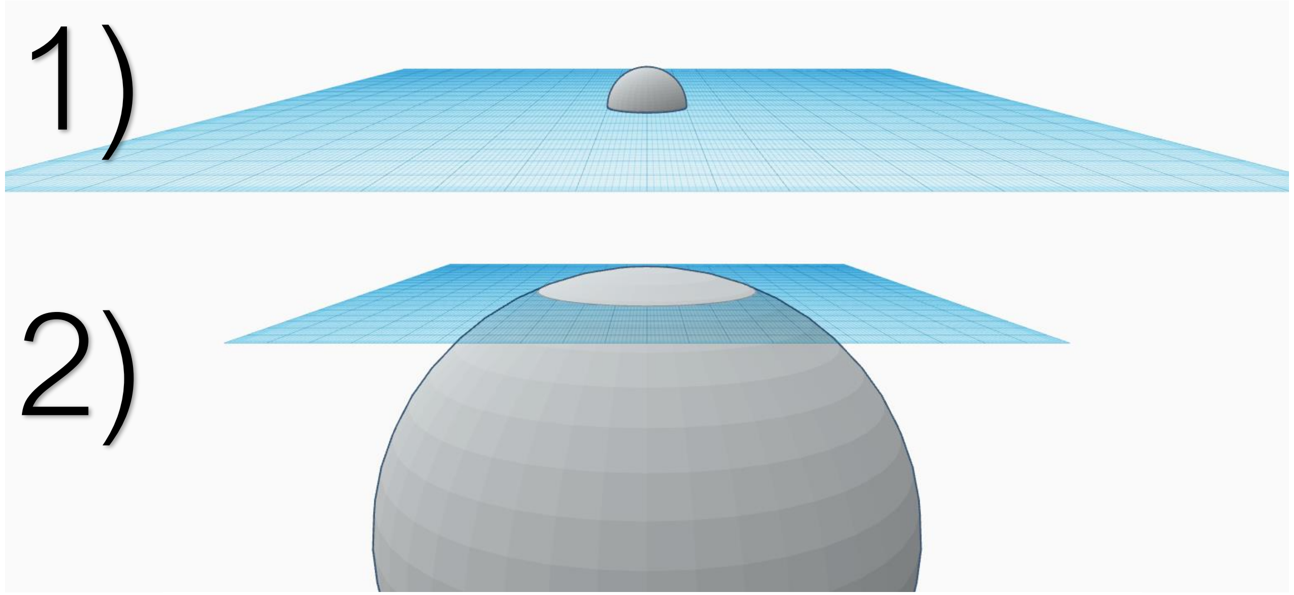


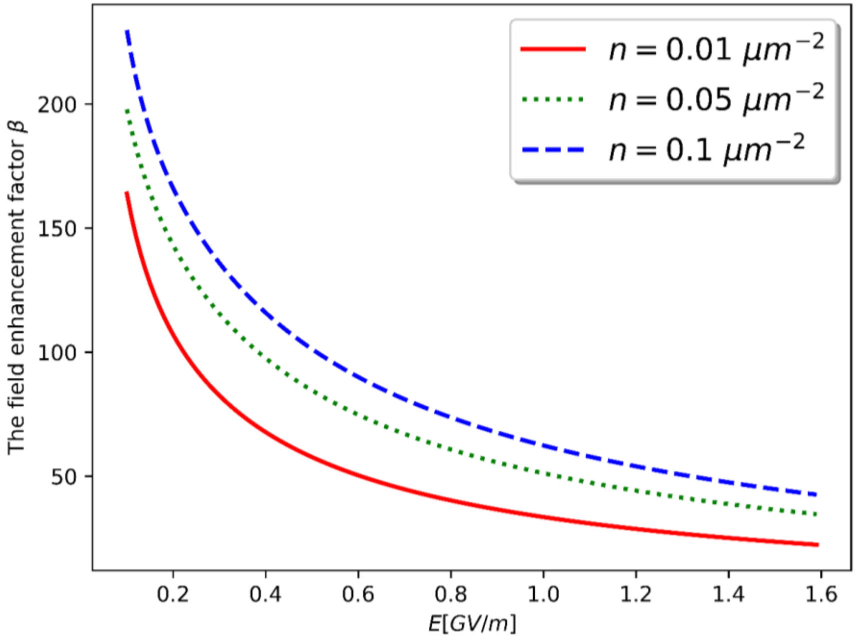
SEM images of the cathode surface

The study of copper cathode samples on a scanning electron microscope showed the presence of micron and submicron irregularities on the surface. We assume that they are the main sources of field electron emission current. Therefore, their consideration is an important step in the modeling of field emission current.

SEM photo of the cathode surface with different stages of preparing: 1 - mechanically polished electrode surface, 2 - etching the electrode in a mixture of acids, 3 - glow discharge surface cleaning, 4 - standard cleaning procedure for Cu at CERN

Modeling tips on the surface





The radius of the points was set randomly using a truncated normal continuous random variable. Two cases were simulated:

1) hemispheres that are located on a perfectly smooth surface *r<100 nm*;

2) surface which is a combination of model hemispheres and a spherical cap of a larger radius *a ~ 1000* nm and similar to nanotips height *h*.

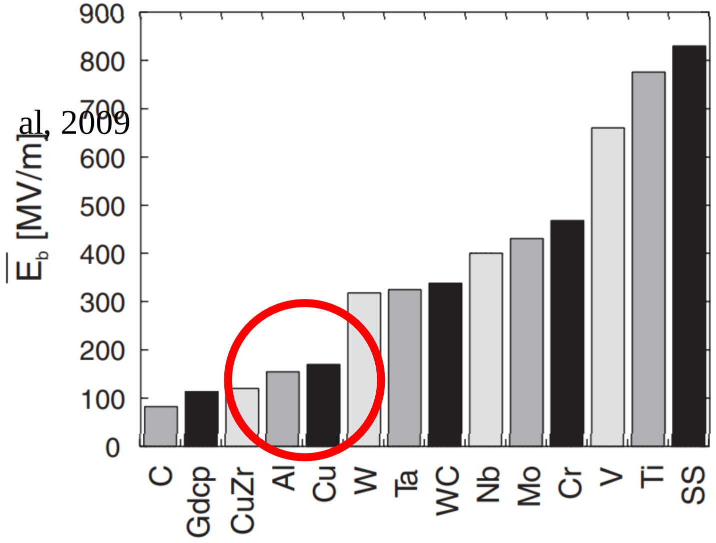
The parameters were selected in such a way as to obtain the electric field enhancement factor in the range ***β = 30 -140***.

It was also taken into account that in the case of distant location of the tips from each other the screening effect can be neglected *(Bocharov, 2005*

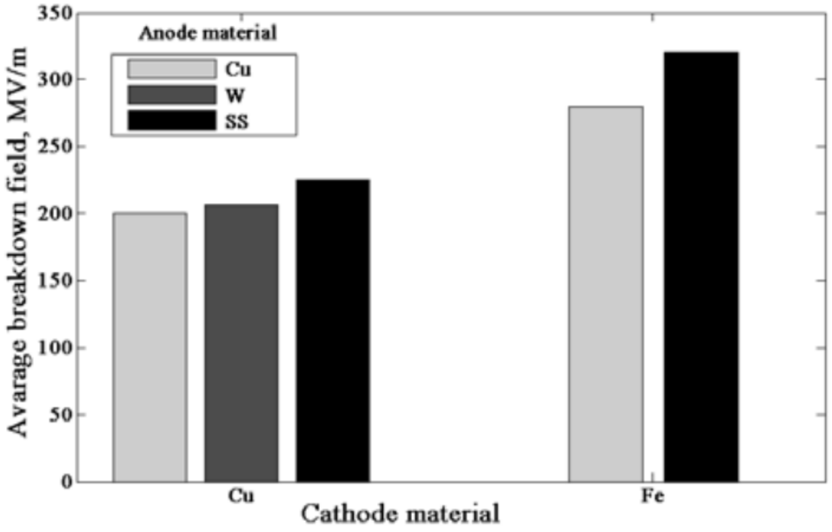
Reducing the impact of the work function

If we take a closer look at the formula for the field emission current density $\left(j = AE^2 exp\left(-\frac{B\varphi^{3/2}}{E}\right)\right)$, we can see that the current strongly depends on two parameters that can be changed: the electric field strength E and the electron work of the metal φ. It is logical to assume that when replacing one metal with another, with a different work of exit, the field emission current, and, accordingly, the probability of breakdown, should change significantly.

For example, if we find the ratio of the current density of field emission of Al and Fe to the current density of copper, we can obtain the following ratios at $E \sim 100 \frac{MV}{m} \Rightarrow \frac{j_{Al}}{j_{Cu}} \approx e^{100}; \frac{j_{Cu}}{j_{Fe}} \approx e^{50}$

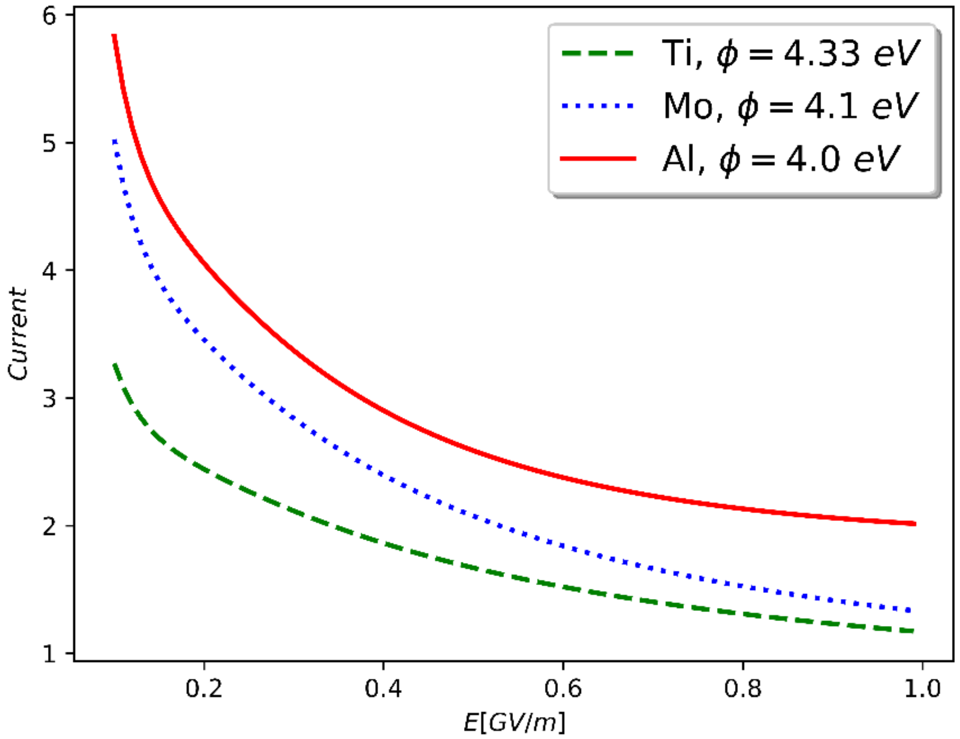


Average breakdown field after conditioning of the main materials tested. (Descoeudres et al, 2009)



The experimental setup for high voltage breakdown studies in the high vacuum (Baturin et al, 2015)

Reducing the impact of the work function

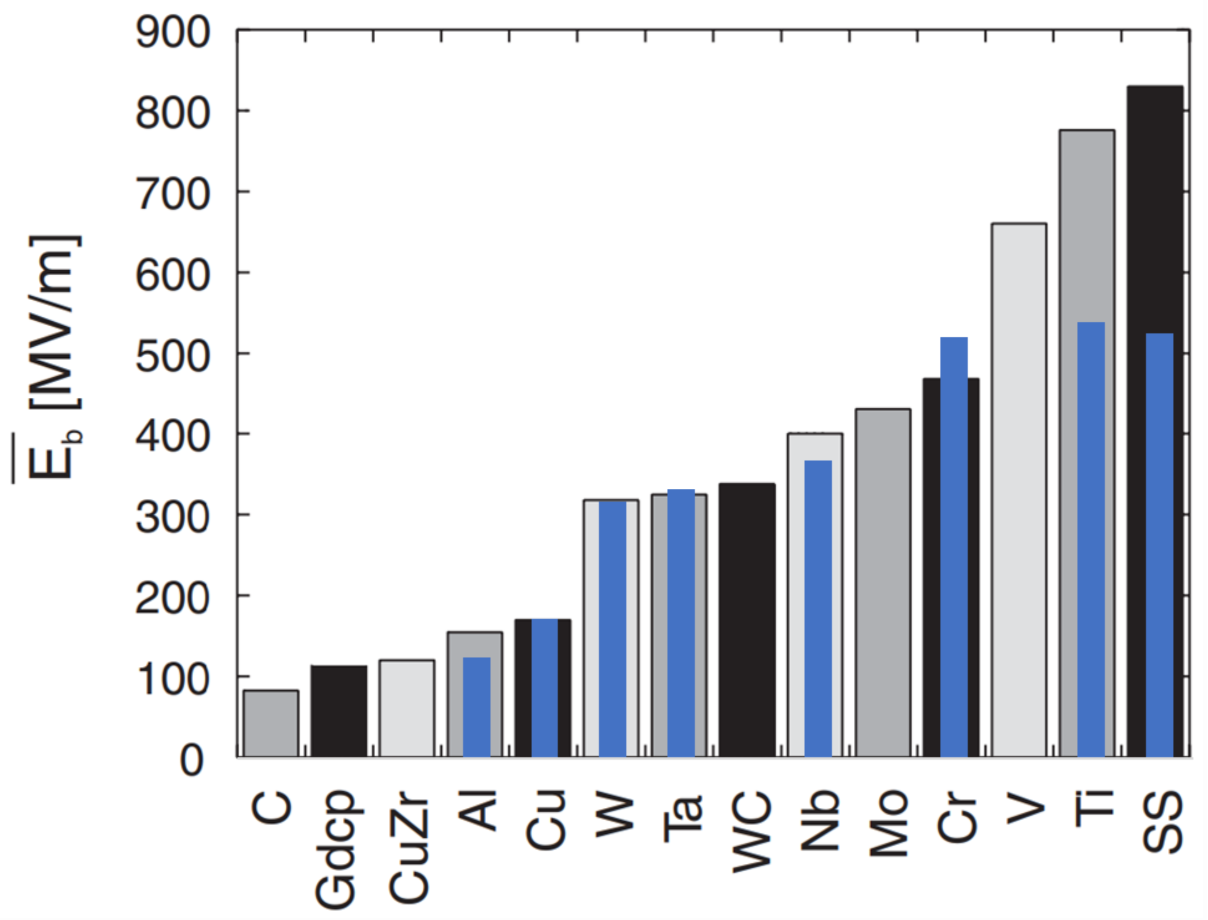


Ratio of field emission currents from the model cathode for materials with different work of output to the current from the model copper cathode at different values of electric field strength.

We used the proposed surface model to calculate the field emission current. The figure shows the ratio of current densities from the model aluminum, titanium and molybdenum surfaces to the current from the copper surface.

The figure shows that the ratio of currents from the model surface is much smaller than predicted for a smooth surface. It can be concluded that taking into account the morphology of the cathode surface is important when finding the field emission current. This allows better modeling of field emission processes and brings theoretical results closer to experimental ones

Average breakdown field modeling



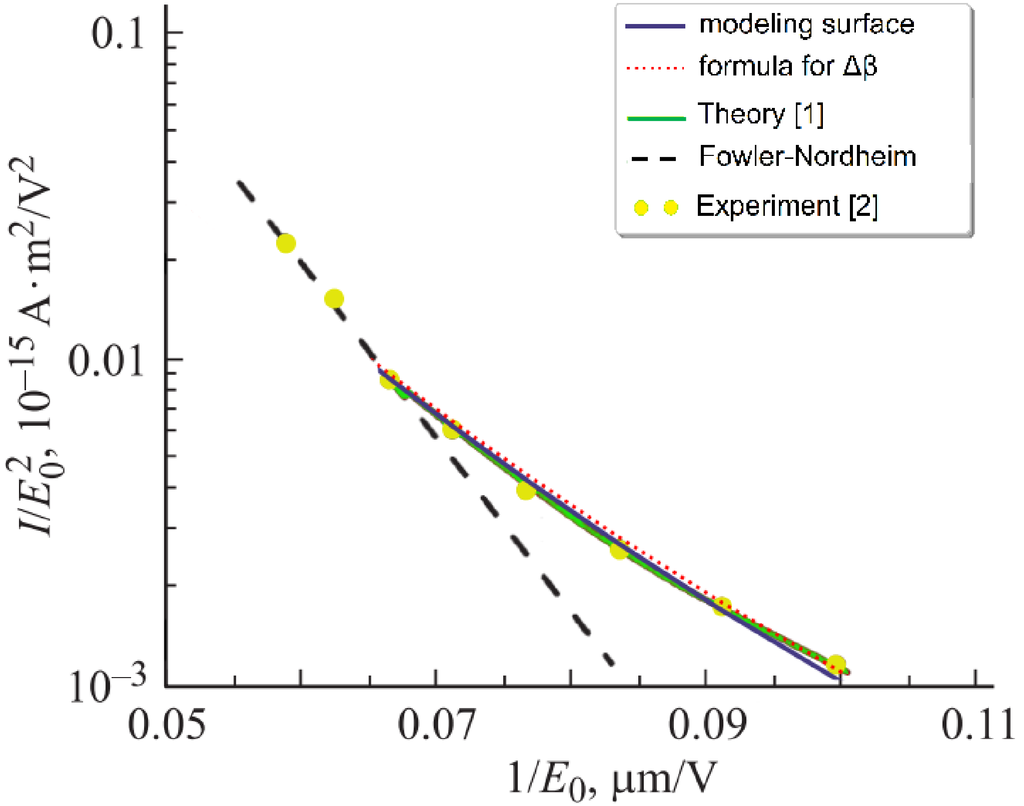
Average breakdown field after conditioning of the main materials tested. (Descoeudres et al, 2009)

For taking into account the presence of submicron and micron irregularities on the cathode surface we have used a theoretical model which combinate hemispheres of low radii and spherical caps of big radii. We calculated the field emission current from the model copper surface at a given electric field strength J_{Cu}. For other materials, the BD current was expressed in units of J_{Cu}, which is depends on the melting point T and electrical resistivity ρ.

$$J_{BD} = J_{Cu}\left(\frac{T}{T_{Cu}}\right)^2 \frac{\rho}{\rho_{Cu}}$$

It can be seen from the Figure that the agreement is quite good for Al, W, Ta, Nb and Cr. The reason for the discrepancy may be the fact that in the model all electrodes had the same surface morphology, and in real studies it could be radically different from each other.

Statistical spread of geometric parameters



I–V characteristics of a CNT-based cathode.

[1] Bocharov et al, Tech. Phys. 55, 289–295 (2010)
[2] Bocharov et al, AIP Conf. Proc 723 528 (2004)

In real metal, the irregularities on the cathode surface have different sizes, although they are in a certain range. Therefore, it is necessary to generalize the formula for the field emission current for the case of different sizes of the edges. Such consideration was made in [1]. The authors assume that the random distribution of tips satisfies the Gaussian distribution.

$$P(\beta) = \frac{1}{\Delta\beta\sqrt{\pi}} \exp\left[-\frac{(\beta-\beta_0)^2}{\Delta\beta^2}\right]$$

where β_0 is an average value of the enhancement factor, $\Delta\beta$ is a variance.

Then field emission current can be written as:

$$J = A(\beta E_0)^2 \exp\left[-\frac{B\varphi^{3/2}}{\beta_0 E_0} + \left(\frac{B\varphi^{3/2}}{\beta_0 E_0}\frac{\Delta\beta}{2\beta_0}\right)^2\right]$$

Conclusions

- The model of the flow of the field emission current considering the morphology of the cathode surface and theoretically investigated the effect of modification of the metal surface on the field emission current in the case of multi-layer metal-metal-vacuum systems was constructed.
- The surface of Cu electrodes prepared by different methods were studied. It is assumed that local irregularities of micron and submicron sizes are the main source of dark current.
- The proposed theoretical model of the cathode surface, considering micron and submicron irregularities, gives a satisfactory agreement of the breakdown field from model cathode with those obtained experimentally.
- It is also shown that the proposed model of the metal surface makes it possible to better simulate the field emission current and to agree the theoretical model with the experimental results.

Thank you for attention!