Anomalies of the field emission process in a magnetic field

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The results of an experimental study of the field emission (FE) of W, Nb, and Mo point microcrystals in a magnetic field are presented. The state of the emitter's material changes when a high-density FE current flows in a magnetic field, which leads to an expansion (or contraction) of the field-emission image, onset of oscillations and a cutoff of the FE current with time. It is assumed that under these conditions a metal-insulator phase transition, stimulated by the deformation of the microcrystal's point, may occur.

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Furseĭ *et al.*[1] established by using tungsten emitters that a magnetic field has a strong effect on the field emission at certain current densities.

In this study we discovered new effects produced in the field emission in a magnetic field using W, Nb, and Mo emitters (Figs. 1–3).[1)]

1. Analysis of the dependence of relative increase of the FE current on the magnetic field intensity H [$j/j_0 = f(H)$, where j, j_0 is the FE current density in a magnetic field and without it, respectively] showed that it has a sharply nonmonotonic nature (Fig. 1). We observed two types of $j/j_0 = f(H)$ curves—curves with a smooth peak obtained by using samples made from polycrystalline W, Nb, and Mo wires that were oriented in the ⟨011⟩ direction and curves with sharp peaks obtained from emitters made directly from a W ⟨001⟩ single crystal (Fig. 1).

2. In the region of sharp peaks (Fig. 1) we observed an excitation of the FE current oscillations with time. The oscillation frequency was 10^3–10^5 Hz (Fig. 2a). In a specific sample the excitation of oscillations is critical for the FE current density and magnetic field intensity. The values of j_0, at which the onset of oscillations occurs, may differ slightly in different emitters and are $j_0 \approx (1\text{–}2) \times 10^5$ A/cm^2, on the average.

A further increase of the initial FE current density to $j = (3\text{–}5) \times 10^5$ A/cm^2 stops the oscillations and cuts off the FE current for the duration of the voltage pulse (Fig. 2b).

We note that the indicated effects have been observed only in fields H corresponding to the regions of sharp peaks (Fig. 1). Experiments involving a large number of samples uniquely show that there are no oscillations and no cutoff of the FE current in all the other parts of the $j/j_0 = f(H)$ curves. The oscillograms of the FE current in a magnetic field in this case have the shape of curves with a saturation.[1]

3. We established that under the influence of a magnetic field the emission pattern changes insignificantly when there is a flow of FE current. The measurements were performed in the "residual" effect mode, i.e., after the magnetic field was shut off but

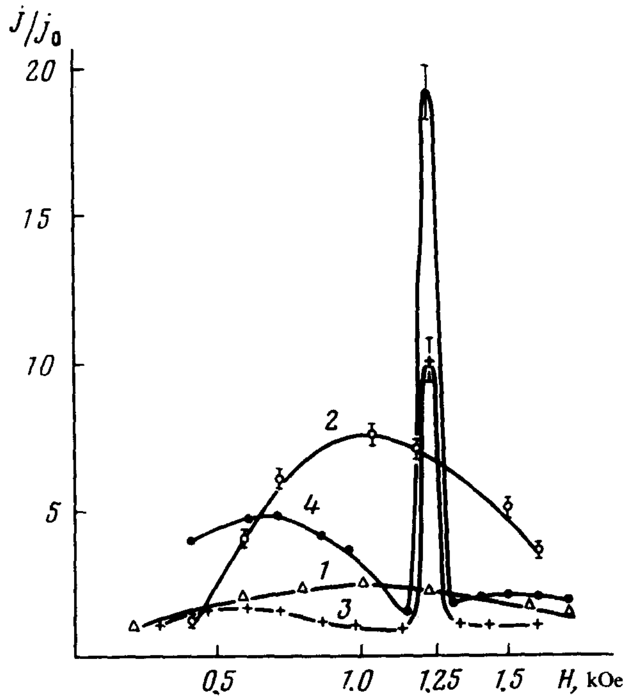

FIG. 1. Dependence of the magnetic effect on the intensity of external magnetic field: 1, W ⟨001⟩, $T=77$ K; 2, Nb ⟨011⟩, $T=300$ K; 3, W ⟨001⟩, $T=300$ K; 4, W ⟨001⟩, $T=77$ K.

before the sample could relax to its initial state. A larger number of samples showed an expansion of the emission pattern.[2)]

A relative increase of distances between the centers of close-packed faces in the emission image reached 10%. Special experimental studies of dimensional variation of the emission pattern only in a strong electric field up to the limiting current densities $j \approx 10^7$ A/cm^2 [$E \approx (6\text{–}7)\times 10^7$ V/cm] showed that the absence of external magnetic field the emission pattern increase much less significantly $\approx(1.0\text{–}1.5)\%$.

4. The aforementioned increase of the emission pattern occurs in all the regions of the $j/j_0 = f(H)$ curves except in the regions of sharp peaks (Fig. 1), but the emission image, which in this case does not change significantly, corresponds to a typical image of an atomically pure emitter surface (Fig. 3a). At the same time, in addition to increasing the distances between the face centers the emission pattern (Fig. 3b) undergoes significant qualitative changes in the region of the sharp peak on the $j/j_0 = f(H)$ curves, indicating a strong disorder in the emitter material. Such change in the surface state is irreversible with respect to time. To restore the initial state of the surface and its "sensitivity" to the magnetic field, the emitter must be heated intensively (to $T \approx 2500$ K).

Note that the "sensitivity" of the emitter to the magnetic field also vanishes as a result of adsorption of residual-gas atoms at the emitter surface.

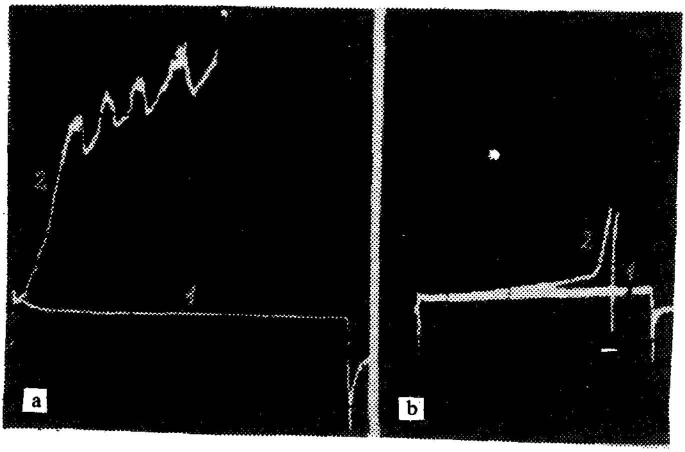

FIG. 2. Time variation of the FE current in a magnetic field, W ⟨001⟩: a, 1 – $H=0$; 2, $H=1.25$ kOe ($j_0=2\times10^5$ A/cm^2); b, 1 – $H=0$; 2, $H=1.25$ kOe ($j_0=3\times10^5$ A/cm^2).

The results of the last experiments show that the scattering of electrons by the emitter surface has a strong effect on the FE process in a magnetic field.

We must state, nonetheless, that it is difficult to propose a final model at this time, principally because many factors in this effect may turn out to be interrelated: specifically, the large densities of the FE current (up to 10^7 A/cm^2) that flows in the external magnetic field, the dimensional factors (the emitter radius is $\approx 10^{-5}$ cm), large negative pressures (up to $\approx 2.5\times10^8$ H/cm^2) per emitter whose temperature is $\approx$ 1000 K, a large surface-to-volume ratio of the sample ($\approx 10^5$ cm^{-1}), and, finally, the pressure of the phase boundary-cutoff of the crystal lattice.

We can say, however, that the sample deformation plays an important role in this effect, as indicated by dimensional variation of the emission pattern and by the dependence of these processes on the perfection of the microcrystal and on the emitter temperature. Note that j/j_0 is much larger than unity at sample temperatures below

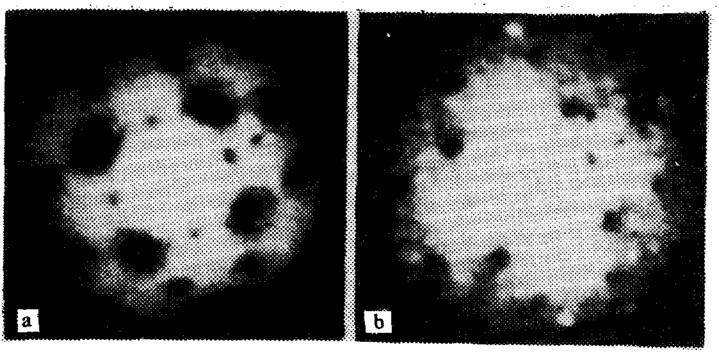

FIG. 3. Variation of the FE image after emission in a magnetic field, W ⟨001⟩; a, initial image, $H=0$; b, $H=1.25$ kOe.

the Debye temperature (Θ) and is almost independent of H at $T > (\Theta)$, in which case $j/j_0 \gtrsim 1$. The deformation in this case can account for the increase in the FE current with time and for the expansion of the emission pattern as a consequence of variation of the shape and size of the emitting vertex of the microcrystal.

Finally, we have reasons to assume that a metal-insulator phase transition,[2] which cuts off the FE current, may occur as a result of deformations (Fig. 2b).

In conclusion, the authors deeply thank A. P. Smirnov, A. I. Shal'nikov, and L. P. Strakhov for a discussion of the results and many valuable remarks.

1)The experiments were performed in a Müller's field emission microscope-projector in a pulsed mode. The pressure of the residual gases was $p \leqslant 5 \times 10^{-10}$ Torr. The duration of the voltage pulse was varied in the range $10^{-4} \leqslant \tau \leqslant 3 \times 10^{-3}$ sec and the magnetic field in the range $0 \leqslant H \leqslant 2.0$ kOe.

2)The inverse effect-contraction of the emission pattern-was observed in the samples made from an imperfect tungsten wire, which had "twinning" dislocations at the vertex. Accordingly, the variation of the FE current in a magnetic field (j/j_0) was also less than unity.

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[1] G. N. Furseĭ, V. É. Ptitsyn, and N. V. Egorov, Pis'ma Zh. Tech. Fiz. 5, 1161 (1979) [Sov. J. Tech. Fiz. Lett. 5, 486 (1979)].

[2] N. F. Mott, Perekhody metall-izolyatov (Metal-Insulator Transitions), Nauka, Moscow, 1979.