TEMPERATURE DEPENDENCE OF FIELD EMISSION OF SINCE CRYSTAL PLANES OF TUNGSTEN

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T–F emission (W. W. Dolan, W. P. Dyke, *Phys. Rev.* **95,** 327 (1954)) of single crystal planes of tungsten as an emitter was investigated in Müller's tube. A comparison of the experimental data with the theory of Murphy and Good is made. A new method of computing the geometrical factor β for any point of the tip is shown.

A field emission tube suitable for measurements of local currents has been constructed ([2]–[5]). The collector current i (T) was measured as a function of temperature T at a fixed anode voltage U. Measurements were made for several values of U. According to Murphy and Good [6] the approximate formula [7] for the *T–F* current is

$$i(T) = i(0)\,(1+K^2T^2/6) \tag{1}$$

where $i(T)$ is field emission current at temperature T, $i(0)$ field emission current at temperature 0° K, and

$$K = 2.77\times10^4\varphi^{1/2}t(y)/F \tag{2}$$

where $t(y) \cong 1$ stands for the slowly-variable Nordheim function, F is electric field determined by $F = \beta U$, where β is a geometrical factor, depending on geometry and shape of the tip and tube. Equation (2) was transformed into the equilibrate shape

$$\frac{\Delta i}{i(T_p)} = \frac{(T/T_p)^2-1}{1+6/K^2T^2} \equiv f(x), \tag{3}$$

where $\Delta i = i(T)-i(T_p)$, $T_p = 295$°K is the temperature at which measurements began. In the coordinate system $\Delta i/i(295) = f[(T/295)^2-1]$, the relationship (3) should be a straight line whose slope is

$$(1+8.99\times10^{-14}\,F^2/\varphi)^{-1}. \tag{4}$$

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Figure 1 shows that in the above-mentioned coordinate system the experimental plots for different crystallographic directions have different runs within the measured teperature range, *i. e.* from 295° to 1150°K; however, within the temperature range from 295° to (450–550)°K (depending on the crystallographic planes) all plots may be approximated by straight lines. It for a definite plane, *e. g.*, (221) in the above-mentioned coordinate system, the family of characteristics is drawn, with U treated as a parameter (Fig. 2), it is evident that the slopes of the plots approximating initial runs of the function $\Delta i/i(295) = f(x)$ are changed for different U [7]. Denoting by ϑ the angle of the slope of the straight line $f(x)$

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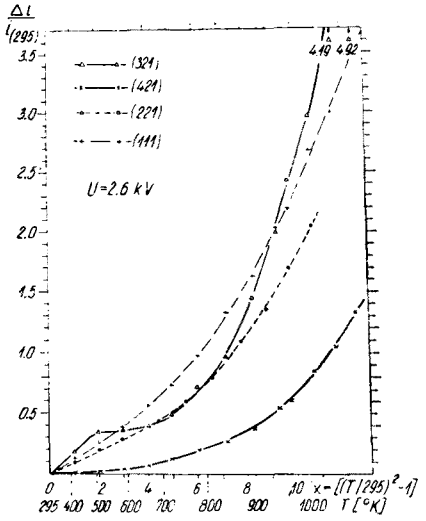

Fig. 1. Relative increase of collector current $\Delta i/i(295)$ as a function of temperature T or variable $x = [(T/295)^2 - 1]$ for different crystallographic planes

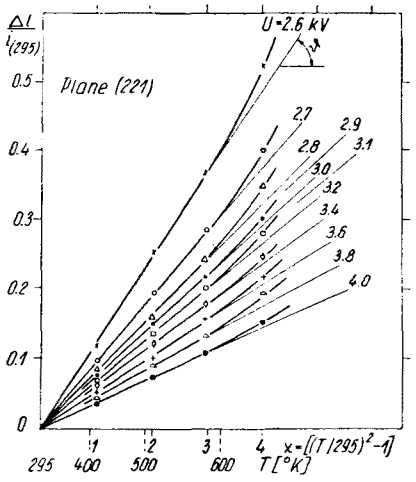

Fig. 2. Relative increase of collector currenst $\Delta i/i(295)$ as a function of temperature T or variable $x = [(T/295)^2 - 1]$ for (221) crystallographic plane, for several values of voltage U

with respect to the x-axis the relation F^2/φ may be determined with the help of Eq. (4) by tg ϑ:

$$F^2/\varphi = 1.11\times10^{14}\,(\mathrm{ctg}\,\vartheta - 1). \tag{5}$$

Now, when we plot the values calculated on the basis of Eq. (5) in the coordinate system $F^2/\varphi = g(U^2)$, we again obtain a straight line (Fig. 3), whose slope is

$$\mathrm{tg}\;\xi = \beta^2/\varphi. \tag{6}$$

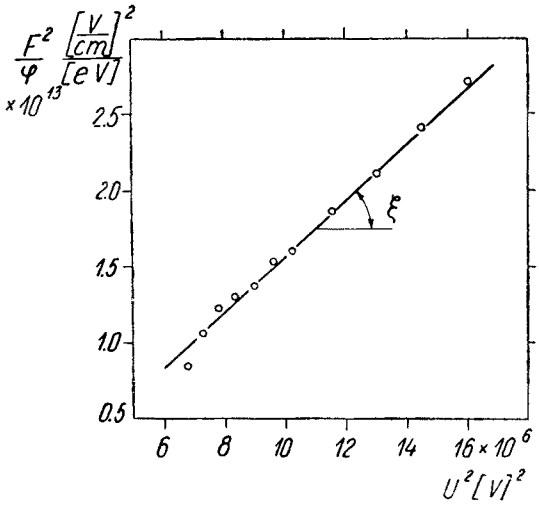

Fig. 3. Values of F^2/φ computed from Eq. (5) as a function of voltage squared

If then we have the F. N.[1] plot for a chosen plane, its slope is

$$m = -B\varphi^{3/2}/\beta, \tag{7}$$

where $B = 6.83\times10^{-7}\,v(y)$ ($v(y)$ is the Nordheim function near unity for the applied fields). Finally, φ and β were calculated from equations (6) and (7). For the (221) plane they have the values $\varphi_{(221)} = 4.4$ eV and $\beta = 9.2\times10^3\,\mathrm{cm}^{-1}$. We see that the value of $\varphi_{(221)}$ calculated in this way is in good agreement with values calculated by others using different methods (Schmidt: $\varphi_{(221)} = 4.37$ eV [4], and Müller: $\varphi_{(221)} = 4.35$ eV [8]). This confirms the correctness of the formula of Murphy and Good for temperatures up to (450–550) °K. This temperature depends on the structure of the crystal faces. The method described here is suitable for computing the distribution of β along a chosen "azimuth" on the tip. The value of β can also be computed by another method[2] based on the suggestion of Ovchinnikov and Carev [9], but taking into account the coefficient of the shape of the tip, α used by Drechsler and Henkel [10].

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[1] Fowler Nordheim.

[2] Publication in preparation.

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REFERENCES

[1] W. W. Dolan, W. P. Dyke, *Phys. Rev.*, **95,** 327 (1954).
[2] R. D. Young, E. W. Müller, *J. Appl. Phys.*, **33,** 91 (1962).
[3] A. G. Van Oostrom, *Validity of the Fowler-Nordheim Model for Electron Emission.* Dissertation.
[4] L. D. Schmidt, *J. Chem. Phys.* **46,** 3830 (1967).
[5] L. W. Swanson, L. C. Crouser, *Phys. Rev.*, **163,** 622 (1967).
[6] E. L. Murphy, R. H. Good, Jr. *Phys. Rev.*, **102,** 1464 (1956).
[7] R. Klein, L. B. Leder, *Phys. Rev.*, **124,** 1046 (1961).
[8] E. W. Müller, *J. Appl. Phys.*, **26,** 732 (1955).
[9] A. P. Ovchinnikov, B. M. Carev, *Fiz. Tverdogo Tela*, **8,** 1493 (1966).
[10] M. Drechsler, E. Henkel, *Z. ang. Phys.*, **6,** 341 (1954).