METHODICS OF CHARACTERISATION FOR THE COLD FIELD-EMISSION SOURCES INTENDED FOR ELECTRON MICROSCOPY

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Abstract: The paper deals with the characterization method of the electron emitter for an electron microscope – Fowler-Nordheim analysis. The method is based on the presence of quantum tunnelling, which occurs during the field emission of electrons. The analysis consists of the computation of the essential characteristics of the emitter. These characteristics determine the overall quality of electron emission, as well as provide information about the actual condition of the emitter.

Keywords: Fowler-Nordheim analysis, electron emission

1. INTRODUCTION

Cold-field emission sources are widely used in electron microscopy for imaging of sub-microscopic structures. The ability of microscopes to operate in such resolutions is given by the focused electron beam with the high value of electron beam brightness. The quality of the primary electron beam is determined by the actual condition of the electron source. Therefore it is essential to describe the basic characteristics of the emitter to assure the imaging capability of the system.

It is desired to establish the quality of the primary beam without the necessity of dismantling the electron jet. For that reason, the emitter characterization method based on the electron emission monitoring is highly desirable. The application of the method for the experimental field-emission cathode [1] described above is the main objective of this paper.

2. FOWLER-NORDHEIM ANALYSIS

In principle, the method is based on the presence of tunnelling phenomenon, which takes place during the cold-field emission of electrons. The Fowler-Nordheim analysis described in this paper is applied on the data obtained from the experimental measurement on the field-emission cathode. The measurement consisted of monitoring the total-emission current on the YAG scintillator at particular extraction voltage. For a given voltage, the corresponding output current was read using a precise Agilent 34410A multimeter. The analysis has two main objectives: (1) to prove that the field emission in the measurement is a consequence of the quantum tunnelling phenomenon and (2) to calculate basic cathode characteristics, which can be correlated with the cathode performance.

2.1. FOWLER-NORDHEIM PLOT

The Fowler-Nordheim plot is used to graphically interpret and analyze the data obtained from the experimental measurement. The purpose of using the Fowler-Nordheim plot is to confirm the assumption that the emission of the electrons from the cathode is caused by the quantum tunnelling. To verify that the electron emission is a consequence of the quantum tunnelling, the V-I relation has to fit the Fowler-Nordheim theoretical model. Otherwise, the cause of the emission current is not the quantum tunnelling, but rather the other phenomenon (thermal excitation, photoelectric effect). The relation of the Fowler-Nordheim theoretical model is as follows:

$$\ln\left(\frac{I}{V^2}\right)=m\left(\frac{1}{V}\right)+n, \tag{1}$$

where V is the extraction voltage, I stands for the emission current monitored during the measurement, m is the slope and n is the y-intercept [2].

To prove that the measured data are consistent with the form of the equation 1, the natural logarithm of the current divided by the square of voltage and the inverse of the voltage need to be computed and graphed afterwards. The yielded figure is linear in case the data fit the Fowler-Nordheim theoretical model. Furthermore, the computation of the least squares line of best fit is carried out. Afterwards, the least squares line of best fit described by the linear form $y=mx+b$ is graphed over the measured data points. Overlapping of the line and the measurement data proves that the data fit the Fowler-Nordheim model, and therefore the emission current is a consequence of the quantum tunnelling phenomenon (see fig. 1).

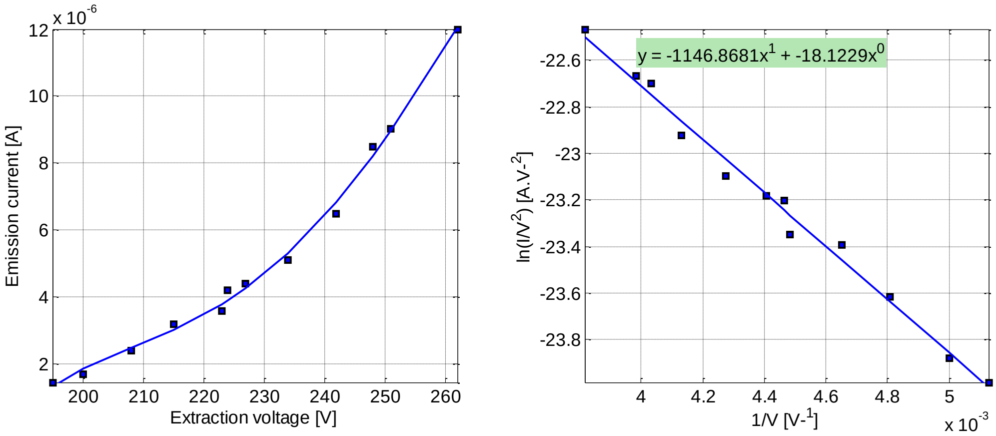

Figure 1: a) Emission current dependency on the extraction voltage b) Linear relation between (1/V) and ln (I/V^2).

2.2. CHARACTERISTICS OF THE EMITTER

Since the presence of quantum tunnelling was proved, Fowler-Nordheim analysis can be used to determine the physical attributes of the emitter. The main quantities determined by the numerical analysis are the active area, the average electric field strength at the tip of the emitter, the emission current density and electron beam brightness.

The electric field strength at the tip of the cathode is given by the following equation:

$$E=\frac{V}{kR}, \tag{2}$$

where kR is the field-voltage proportionality factor and V is the extraction voltage. In order to find the value of the electric field strength, it is necessary to calculate the field-voltage proportionality factor kR at first. The calculation is carried out by the iterative process implemented in Matlab, where the approximation for kR is found. The value of k in the term kR depends on the emitter geometry, however $k \sim 5$ is adequate for most geometries encountered in practice [3].

The second quantity of interest is the active area A which can be calculated from the equation below [2]:

$$A=e^{n}\frac{(E_F+\varphi)(\alpha kR)^2}{k}, \tag{3}$$

$$k=6.2\times10^{-6}\sqrt{\frac{E_F}{\varphi}}, \tag{4}$$

where φ is the work function for tungsten (φ is approximately 4.54 eV for polycrystalline tungsten), E_F is the Fermi energy for tungsten and *α* is the image correction factor. The values of the emission current density (theoretical value in case of the field-emission cathode is 10^{10} A.m^{-2}) and the electron beam brightness (theoretical value is 10^{13} A.m^{-2}.sr^{-1}) are determined according to the following equations respectively:

$$j = \lim_{a \to 0} \frac{I}{A}, \tag{5}$$

$$B = \frac{j}{\pi \alpha^2}, \tag{6}$$

where *I* is the total emission current monitored in the measurement α is the half-angle in which the electrons are emitted [4]. The values yielded in the analysis of the experimental field-emission cathode are to be found summarized in the tab. 1.

Field-voltage proportionality factor, kR [m]	3.19×10^{-8}
Active area on the cathode tip, A [m^2]	6.48×10^{-18}
Electric field at the tip, E_F [V m^{-1}]	7.12×10^{9}
Emission current density at 260 V, j [A m^{-2}]	1.85×10^{12}
Electron beam brightness, B [A m^{-2} sr^{-1}]	3.59×10^{15}

Table 1: Calculated cathode characteristics.

3. CONCLUSIONS

The Fowler-Nordheim analysis has been carried out on the data acquired from the measurement on the experimental field-emission cathode. As it has been already mentioned above, the analysis had two main purposes. At first, it has been proven by means of the Fowler-Nordheim plot that the field emission in the experimental measurement is a consequence of the quantum tunnelling phenomenon. Secondly, the basic cathode characteristics were determined. The characteristics are important for estimation of the quality of the electron emission and also providing information about the current condition of the cathode. The outcome values of the computed quantities are comparable with the theoretical ones. Therefore it is possible to assume that the Fowler-Nordheim analysis is a reliable method to estimate the field-emission cathode characteristics based on the monitoring of the emission. Moreover, the work function of the cathode material can be ascertained from the slope of the Fowler-Nordheim plot, hence it is possible to determine the emitting crystallographic plane on the cathode surface. These assumptions could make the Fowler-Nordheim analysis a powerful tool for interpreting the field emission output data in practice (e.g. for microscope calibration).

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