

CURRENT-STABILITY ANALYSIS OF COLD-EMISSION EPOXY-COATED CATHODES

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Abstract: The noise spectroscopy in the time and frequency domain is one of the non-destructive methods, which can be used to describe events on quantum level, especially the mechanism of charge transport carriers. Our investigations have been performed on epoxy coated cold emission cathodes with sharp tip. Ultra high conditions (where the vacuum level reaches $5 \cdot 10^{-5}$ Pa) decreases the amount of environment interactions with ions and reduces the influence of the electron-induced desorption and adsorption, which poses one of the significant noise sources. For these experiments, cold cathode with epoxy-resin coating was manufactured. A comprehensive investigation was carried out to determine particular noise sources and to compare clean cathodes with the resin-coated one, in order to describe influence of the oxide and dielectric epoxy layer on to the emission current stability. Spectra obtained, for various emission currents at different voltages, are described and explained. The results suggest that the resin-layer changes cathode performance and extends its durability.

Keywords: noise spectroscopy, cold emission cathode, resin coated cathode

1. INTRODUCTION

An analysis of charge carrier transport in polymer insulating layer covered by polymer layer was performed at temperature 300 K. The main goal of our research is to assess the parameters of the band diagram MIS structure [1, 2, 3, and 6].

Insulating films always contain impurities like oxygen vacancies and traps. These impurities form localized states for charge carriers in the forbidden energy gap. When the localized electronic wave functions of the localized states overlap, an electron bound to one impurity state can tunnel to an unoccupied state without involving activation into the conduction band. This tunneling process between impurity sites is referred to as impurity conduction.

The mobility of an electron moving through impurity states is small especially at low temperatures. Then, the conduction mechanism is mainly influenced by electron hopping between neighboring impurity site. This type of the conduction process depends on impurity concentration and the energy depths of the impurity states. The concept of the hopping transport has been used for a long time in connection with ionic conduction; ions move essentially by hopping, whether through interstices or vacancies.

1.1. ELECTRON TUNNELING

The leakage current is at low temperatures and high electric fields mainly influenced by electron tunneling through a potential barrier. Electron tunnelling through thin insulating layer is a quantum effect in which electron is considered as a wave. Wavelength of electron moving with average thermal velocity $v_{th} = 10^5$ m/s is $\lambda = h/m_e v_{th} \sim 1$ nm, where h is Planck constant, $m_e v_{th}$ is electron momentum.

Current can be described as electron traveling wave with an amplitude A_1 in cathode and amplitude A_2 in the conduction band of polymer insulating layer (see Fig. 1). The wave amplitude exponentially decreases with the thickness t of the potential barrier between cathode and insulating layer. The energy of the electron and the electron wave length λ are assumed to be constant during the transport. The barrier high U_0 depends on the work function W_a or W_c of the anode or cathode material and the electron affinity of the insulating layer (Ta_2O_5). Schematic representation of quantum tunneling for a triangular potential barrier is shown in Fig 1, where W is electron total energy and $\Delta e\Phi_B$ is the Schottky barrier lowering. For electric field intensity $E = 1 \text{ mV/cm}$ this value is $\Delta e\Phi_B = 60 \text{ meV}$ for electron tunneling from cathode to insulating layer.

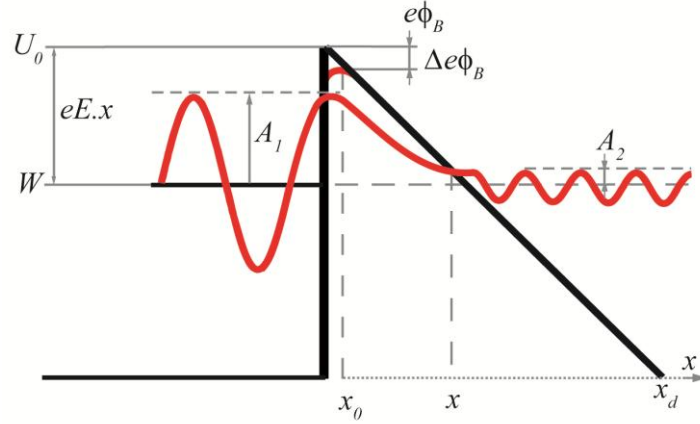


Figure 1. Schematic representation of quantum tunneling through the triangular potential barrier

For the tunneling probability D it holds [2]

$$D = D_0 \exp\left(-\frac{4\pi}{h} \int_0^{x_d} \sqrt{2m^*} \sqrt{U - W} dx\right) \quad (1)$$

where D_0 is constant and in first approximation $D_0 = 1$, x_d is the insulating layer thickness, m^* is effective electron mass, $h = 6.6 \times 10^{-34} \text{ Js}$ is Planck constant and U is the barrier energy and W is electron total energy. After integration we have for tunneling probability

$$D = D_0 \exp\left(-\frac{8\pi\sqrt{2m^*}(e\Phi_B)^{3/2}}{3\hbar E}\right) \quad (2)$$

It is important that tunneling is in first approximation temperature independent and then from experiment in low temperature the barrier high can be estimated for given value of effective electron mass. For the tunneling current density J vs. electric field strength E one can write [1]

$$J = G_T E^2 \exp\left(-\frac{E_T}{E}\right) \quad (3)$$

where G_T and E_T are the tunneling current density constants. The tunneling parameter E_T can be expressed for the energy barrier $e\Phi_0$ as

$$E_T = \frac{8\pi\sqrt{2m^*}}{3\hbar} (e\Phi_0)^{1.5}. \quad (4)$$

The value of tunneling current depends on the electron effective mass and then the potential barrier energy $e\Phi_0$ (in eV) vs. tunneling parameter E_T

2. SAMPLE CATHODE FABRICATION

Basic review, of various etching methods intended for the sharp-tip cathode fabrication, was published in 1991 by Melmed [7]. All of these methods are based on the same principles. Etched metal wire is inserted in to a grounded cylinder which is filled with a liquid electrolyte. The etching procedure is then processed in the cylinder where the etched wire acts like an anode during the process of anodic dissolution. The name of the method (drop-off) is derived from the bottom part of the etched wire which drops-off (down) during the etching procedure. The curvature radius of the tip apex, at the moment of the drop-off, can be expressed as [8]:

$$r = R\sqrt{(\rho_w - \rho_e)L/\sigma} \quad (5)$$

where the R and L are the dropping part radius or length, σ is the ultimate tensile strength and ρ_w and ρ_e are the tungsten and electrolyte densities. This means that the resulting tip sharpness depends on the dropping part dimensions which should be as small as possible. The small mass of the dropping part minimizes some negative effects connected with sudden release of the stored elastic energy when the wire is broken. If the energy release increases to high value, it may cause the tips to recoil, melt or bend causing blunting and tip apex deformation [8].

Usually the initial length of the wire immersed in to the solution is used as the parameter determining the length of the drop-off part. If the wire is not completely immersed, this leads to complete tip dissolution whereas if the wire is immersed too deeply, it leads to the premature neck breaking. In both cases, the sharpness of the fabricated tip becomes blunt. After the electrochemical etching process the tip is unavoidable covered by a residual layer of tungsten oxides and with other contaminants (hydrocarbons and carbides for example).

While the tip apex sharpness dependent on the electrochemical etching, the tips clarity determines its effort. For the cathode fabrication, polycrystalline tungsten wire with the diameter of 0.1mm immersed in the solution of NaOH was used. The NaOH solution was present in two molar concentrations (2M and 0.2M) for the first and second etching phase. The moving part of the etching installation was made of micrometric stepper motor controlled device which allowed us to perform defined reproducible movements. The static part of the etching installation contained the chemically resistant cylinder made of corrosion-proof steel in which the liquid solution was located.

For the ultra-sharp cold-cathode tip fabrication, the tungsten wire immersed in to the NaOH solution, carries an electron flow (less than 10 mA) under the voltage of 6.9V. Both the anode (tungsten wire) and the cathode (steel cylinder) were connected to the precise DC voltage laboratory power source. The current owing through the wire was changing according to the thickness of the tungsten wire. The current value decreases as the wire becomes thinner, (in the range of miliamperes to the approximately 50 microamperes) when the bottom part drops off.

3. MEASUREMENT METHOD

The cathode was tested in two-stage vacuum chamber, under the ultra-high vacuum (UHV) conditions, when the pressure was about $2 \cdot 10^{-5}$ Pa. The accelerating voltage was set to -5kV. The extracting voltage was manually increased to the level where the noise trace became apparent. Immediately, after the electron beam appeared on the faceplate (green spot), the cathode's noise characteristic was recorded. Each of the realization took 8minutes and during this period, 80.000 samples were recorded.

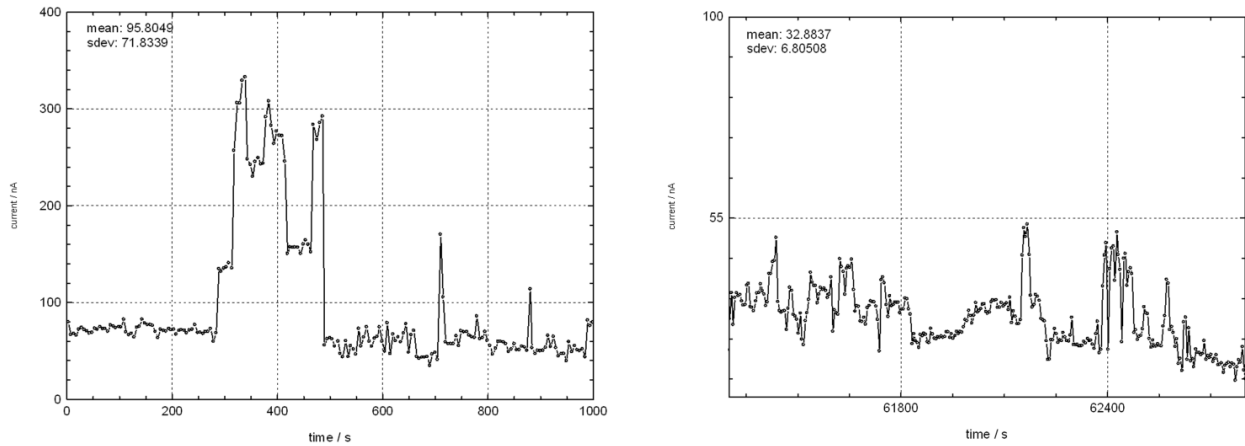


Figure 2. Emission current mean value and standard deviation in time at the beginning of cathode lifetime (a) and on short before its end (b)

Recently, it has been pointed out many times to the presence of the emission current fluctuations, occurring in the investigated structure that causes electrical noise on both thermionic and on cold or Schottky cathodes. Together with the chemical activation, which is connected to work function level change, there is also relation to the noise properties of the particular cathode. For the cold emission cathodes, the prevailing noise component originates from the local changes on the cathode surface, because of surface inhomogenities, that affects work function. Current fluctuations, caused by these changes, have significant amplitude (until 30%) and very low frequency, especially for cathodes working under the room temperature (< 1 Hz). Only limited amount of atoms is taking place in the emission process (about hundreds of atoms) and adsorption of next few electrons causes significant change of the work function.

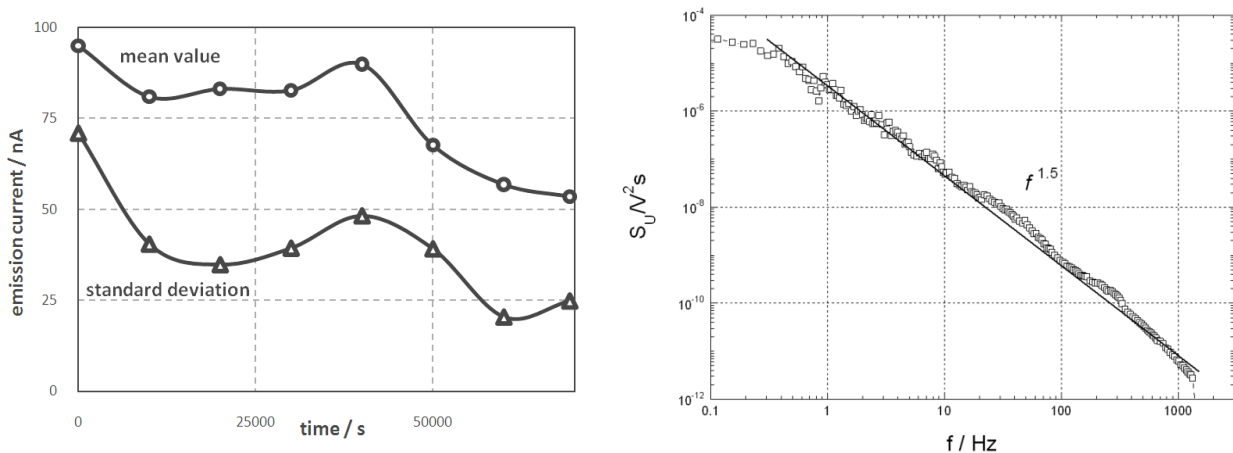


Figure 3. Emission current mean value and standard deviation in time (a) power spectral density of the emission current in lower part of the frequency spectra (b)

Figure 3.a. summarizes long-time noise measurement, which was performed on the cold emission cathode sample for 24 hours. The measurement results suggest presence of diffusion, which is evident from the mean value and standard deviation in time. The emission current is slowly increasing, that is caused by ion movement. Ions are moving inside and causing creation of spatial charge, which has essential influence on the charge transport. During this process, so called the defect band, which is located approximately 0.8eV under the electron affinity level, is created.

Figure 3.b. deals with the spectral analysis of the emission current. On the basis of reached results, it is evident that measured noise has characteristics of so called $1/f$ (flickering) noise. The $1/f$ noise is a process with a frequency spectrum such that the power spectral density is proportional to the

reciprocal of the frequency. The $1/f^n$ noise (where $n > 1$) originates from the superposition of particular $1/f$ and generation-recombination (G-R) processes, which originates from adsorption and desorption of various atoms belonging among residual gas in the vacuum chamber.

4. CONCLUSIONS

Our research shows that the isolation coating-layer has to be as thin as possible, in order to prepare well balanced cold emission cathode with long stability, however too thin layer reduces cathode lifetime as it is bombarded by ions. The tunneling parameter E_T (equation 3) should be lowest as possible in order to reach low effective mass of the electrons which helps them to tunnel through the barrier. From the noise measurements (fig 2.) we can identify the ions, bombarding the cathode surface, which proves itself by sudden burst noise. The bombardment reduces the epoxy layer which leads to its complete destruction after 1 - 10 days. The noise spectral density (where the $1/f$ noise prevails), changes to $1/f^n$, where n is located between 1 and 2. The higher the n is, the more significant G-R is.

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