# COLD EMISSION CATHODES NOISE CHARACTERISTICS

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## ABSTRACT

The paper deals with a method intended for characterizing Schottky and cold-emission cathodes which are intended to be used as electron source for purposes of electron microscopy. The noise spectroscopy in time and frequency domain is based on measuring cathode's voltage noise density in ultra-high vacuum conditions (UHV) in order to avoid environment interaction with ions which are present in the vacuum chamber. The first part of the article describes basic concept of electronic noise together with the description of used cathodes [2, 4]. Second part focuses on the method of measurement and in the last part, reached results are presented together with suitable explanation according to the concept of electronic noise. Main target of this work is to provide a non-destructive characterisation of semiconductor materials and devices.

## 1. INTRODUCTION

Schottky emission is considered to be the predominant electron source technology in actual focused electron beam equipment. Concerning the electron emission, the main idea is based on a fact that cold emission-based source differs from a thermionic one. Cold emission cathode poses point electron source with tip-diameter from $10^0$ to $10^2$ nm, which emits electrons to a relatively wide aperture radius ($10^{-1}$ rad) with high current density ($10^8$ Am$^{-2}$ and higher) [1]. Cold emission cathodes operate at room temperatures. Their main disadvantage is relatively significant electronic noise, where the $1/f$ noise component prevails. Its value can be easily correlated by fluctuations of the emission currents. Next disadvantage, while comparing with thermionic source, is connected with reaching lower current values and also lower immunity against electric bursts.

$$\bar{i}_n^2 = \frac{4\bar{I}^2\tau}{N(1+\omega^2\tau^2)} \tag{1}$$

According to the Slaidiņš [2], the two main sources of electronic noise were awaited. The main types of electronic noises are: *1/f Noise* and *Generation-Recombination* (G-R) noise. The G-R noise originates from emission processes and individual capture of charge carriers which comes to and from the conduction or valence band in a semiconductor [2]. Mathematically, the G-R noise could be described by equation (1) where the $N$ is the average number of carriers, $I$ is the average (DC) current through the device, and $\tau$ is time constant characteristic of the generation-recombination process. We can conclude that the level of G-R noise is proportional to the square of the average (DC) current through the device.

Concerning the 1/*f* noise, we do not know exactly its physical origin, but we can say that it represents a general process encountered in non-equilibrium systems. In electronic devices, flicker noise is always conditioned by the existence of a DC current in a discontinuous medium [2]. Imperfect contacts (such as those between granules of carbon in carbon resistors) can also generate 1/*f* noise. In this case the 1/*f* noise is equivalently called "excess noise," since it adds to the thermal noise of the resistor.

The 1/*f* noise can be modelled using current generator (see equation 2) [3, 4],

$$\bar{i}_n^2 = \frac{KI^\alpha}{f^n}\Delta f \tag{2}$$

where K is a device-dependent constant; $\alpha$ is a constant that range from 0.5 to 2; $n = 1$ for pink noise characterized by constant power per octave, $\Delta f$ represents the bandwidth of the measurement system and I is the DC current passing through the device used samples and method description

The Schottky-cathode sample $WDO_1$ was manufactured from tungsten wire using extended electrochemical etching method. The method's name (drop-off) is derived from the bottom part of the etched wire which drops off (down) during the etching procedure [1].

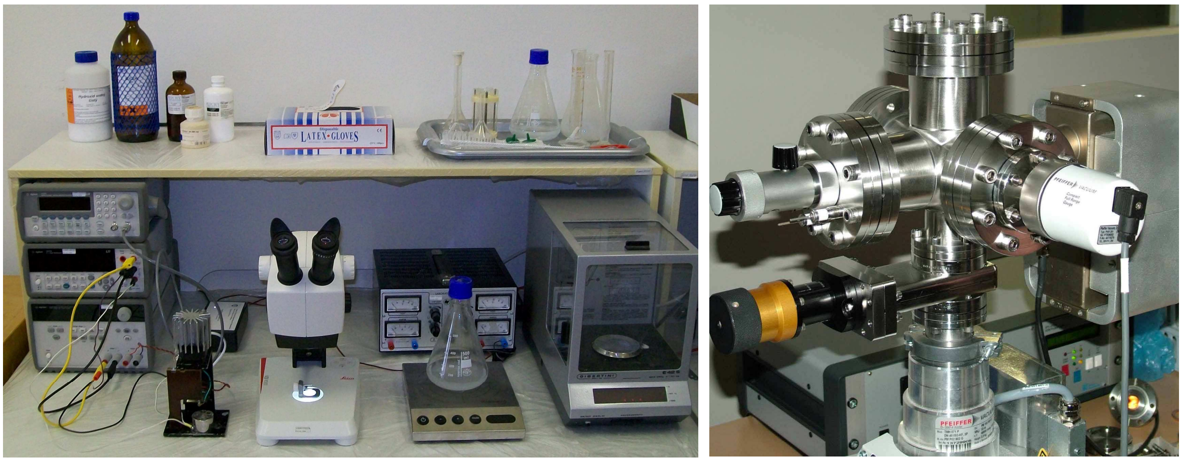

**Fig. 1:** Automated cold cathode etching-installation (left), vacuum testing system (right)

In general, this method is based on the presence of surface tension, which accelerates the etching process near the electrolyte surface and shapes etched wire. The used cathodes were prepared from mechanically cleaned and electrochemically polished tungsten wire which was etched twice using automated etching installation (fig. 1 left). In the first etching phase, the rough shape of the cathode was formed. In the second etching phase, the cathodes' tip was shaped in order to reach ultra sharp profile. After the second etching phase, the cathode was chemically cleaned in order to get rid of the residual oxides and put in the vacuum. Samples $WDO_2$ and $WDO_3$ were moreover covered by Epoxy which protects cathodes' tip before being bombarded by ions present in the chamber [5].

Necessary data, required for performing noise diagnostics, were obtained in vacuum testing system (fig 1. right). Vacuum, which is present in the vacuum chamber, allows setting conditions suitable for electron emitting in order to test the cathode. During cathode testing, the computer with oscilloscope and preamplifier connected, have been used in order to sample voltage in the time domain. Recorded data were then converted to the frequency-domain in order to get voltage noise spectrum, which is essential information for noise diagnostics.

## 2. NOISE CHARACTERISTICS

The result of the noise spectroscopy of sample $WDO_2$ is illustrated in Fig.2. The extracting voltage was manually increased to the level where the noise trace became apparent. Immediately, after the noise had appeared, the cathode's noise characteristic was recorded. For the first sample, the first value of the extracting voltage was 250 V. Its noise characteristic curve by this voltage is illustrated in Fig.2. It is apparent that the cathode-emitted beam of is not stable because of the electron's intensity which was not constant.

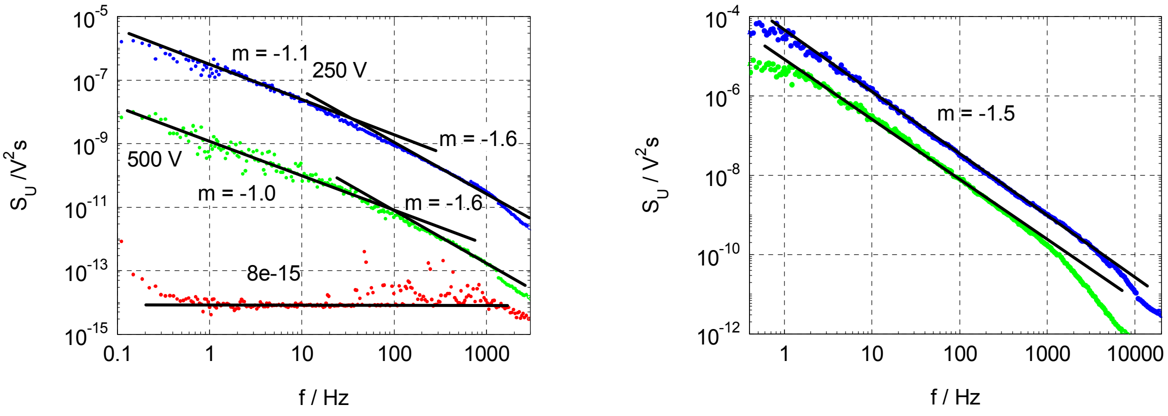

**Fig. 2:** The spectral noise voltage density of sample $WDO_2$ and $WDO_1$

On the basis of reached results the most significant noise component, dominating throughout the spectrum, was the $1/f^n$ noise with relatively high value. In terms of power at a constant bandwidth, $1/f$ noise falls off at 3 dB per octave. The electronic beam has disappeared after approximately 15 minutes and the next measurement of the noise at the same extracting voltage gave us just the background noise (fig. 2, the bottom curve). The electronic beam has appeared again at 500 V of extracting voltage and its noise characteristic is in Fig.2, the middle curve. Noise-characteristics of sample $WDO_1$ are in Fig.2. The electronic beam of this cathode was radiated for several hours and series of measurements at extracting voltages between 370 V and 440 V was carried out. The deviation in values of the dominant $1/f$ noise was insignificant and seemed to be little dependent on the extracting voltage.

The higher value of $1/f$ noise corresponds to the lower value of the extracting voltage. The third sample $WDO_3$ showed wide deviation of noise characteristics, which were measured at the extracting voltage V = 270 V (Fig.3). The noise characteristic of the electronic beam is given by superposition of $1/f^n$ noise with parameter $1.3<n<1.6$ at low frequency and clearly seen generation-recombination noise at frequencies above 200 Hz.

High value of $1/f$ noise and high deviation of noise characteristics of all the cathodes show that the intensity of electronic beam is not stable and the quality of cold emission cathodes should be improved.

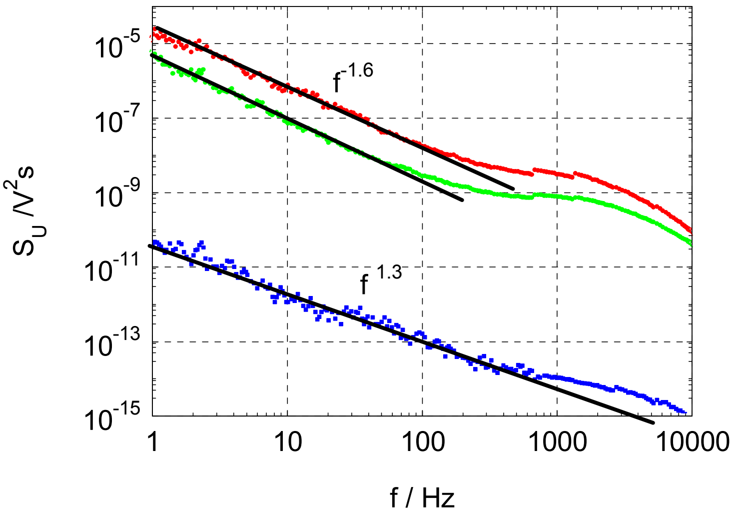

**Fig. 3:** The spectral noise voltage density of sample $WDO_3$

## 3. CONCLUSION

On the basis of reached results, the noise characteristics of microscopic cathodes based on Schottky field emission were presented. Schottky emission is nowadays prevailing on the field of electron source technology and so in actual focused electron beam equipment, because of the lower voltage requirements and overall lower manufacturing prize and easier handling. Its main disadvantage is more significant noise which has to be further observed.

The main sources of noise were: $1/f^{n}$ noise (which generates from particular $1/f$ and G-R processes superposition) and from generation recombination noise with thermal noise. The $1/f^{n}$ noise (where $n > 1$) originates from the superposition of particular $1/f$ and generation-recombination (G-R) processes. The G-R process originates from the positive ions moving in the vacuum chamber. They are accelerated back to the cathode and bombard the emission area. Ion bombardment is mechanically deforming an emitter's surface.

At high enough frequencies the $1/f$ noise is never dominant, on these frequencies the thermal noise is prevailing. The source of $1/f$ noise is not very clear, in other words, there is not a theory, which could explain all of the experiment results [4]. Because Schottky cathodes operate at high temperatures, the surface mobility is high enough to anneal such deformations in a reasonable time. Further noise diagnostics should clarify the relation to charge carriers with its mobility, dependence on temperature, light illumination and electric field intensity in the frequency range.

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