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ARTICLE

Metallic and Composite Micropoint Cathodes: Aging Effect and Electronic and Spatial Characteristics

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Abstract: Composite micro-emitters consisting of a tungsten core coated with different dielectric materials were prepared. Various properties of these emitters were measured, including the current-voltage (IV) characteristics and spatial current distributions. We compared coated and uncoated tips and determined differences between both types. It could be proven that coated emitters are superior to uncoated ones in terms of the current stability and the emission current obtained for the same applied voltages. After these samples have been stored under atmospheric conditions for a period of 10 to 20 years from the first time being characterized, they were tested again. The IV characteristics and spatial current distributions in addition to stability measurements were recorded. Various similarities as well as some differences compared to the initial characterization have been found. It is interesting to note that after one and a half decades these composite emitters are still functioning effectively without being subjected to field desorption processes. The dielectric layers built on the tungsten cores were still in shape and stable. Some theoretical analysis of the tip properties and their change during storage time is included. Particular attention is paid to the deviations from the ideal Fowler-Nordheim (FN) behavior as well as the related slope and intercept correction factors.

Keywords: Field electron emission; Coated tips; Aging effects.

Introduction

As an electron source, the field emitter is particularly attractive due to its favorable emission properties and simple operating principle. In the past decades, there has been sustained interest in field emitters as high brightness electron sources for various technological devices. The most widely used material for such emitters is tungsten [1,2].

Metallic micropoint emitters have faced extra interest by the emergence of microfabrication technology, especially in the form of planar field emitter arrays (e.g. Refs. [3-7]) which were incorporated into devices such as flat-panel cathode luminescent display [8].

To avoid metallic tip degradation from the ion sputtering processes during emission and to obtain an electron source with long lifetime and high beam brightness, a wide range of composite micropoint cathodes has been manufactured. This involved coating the tungsten tips with a variety of dielectric materials [9-11].

A guidance to the interpretation of the measured electron emission characteristics is given by Forbes and Deane [12, 13], along with a detailed analysis of the transmission coefficients for the potential energy barrier.

The aim of this work was to try to analyze long-term stability of such composite microemitters. For this purpose, we considered three insulator coated tungsten tips, which have been manufactured and tested 10 to 20 years ago [2,14,15].

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Thereafter, these tips have been stored under standard atmosphere conditions without any further operation until we now tested them again to study the aging effect on these composite emitters.

Experimental

The preparation procedures, under which the coated W-tips had been manufactured, are described in the original publications [2, 14, 15].

In all cases, we started with tungsten tips, electrochemically etched from a high purity 0.1 mm diameter wire. These tips had afterwards been coated by tetracyanoethylene (TCNE) [2], magnesium oxide (MgO) [14] and zinc oxide (ZnO) [15], respectively.

The analyses were essentially carried out in two evacuated field emission microscopes; one diffusion pumped system with an additional liquid nitrogen (LN_2) trap (vacuum system 1) and one turbo pumped system (vacuum system 2). In both systems, base pressures of less than 1×10^{-8} mbar have been reached after baking the system at a temperature of about 180 °C overnight. The cathode was mounted ~10 mm away from the conductive phosphorus screen (anode), and a current limiting resistor of 20 MΩ was used. The images presented were taken through the vacuum systems' windows by a standard digital camera.

Results

We deal with coated tungsten microemitters, where several coatings have been analyzed; namely TCNE, MgO and ZnO. These samples were coated fifteen years ago, tested, kept in the laboratory under atmospheric conditions and have been re-examined in this work to analyze the impact of aging.

The results presented include the IV characteristics, FN plots and emission images. We compare these results with those previously obtained.

TCNE Coated Microemitter

This type of coating presented one of the most successful metal-insulator composite emitters due to being the electron source that enabled the *in-situ* observation of the transition process from cold to hot emission process during field emission assisted vacuum deposition of polymers on tungsten tips [2]. The emission current obtained (in vacuum system 2) was stable and the emission image showed a bright spot which demonstrated temporal stability after the electron emission switch-on phenomenon. The values previously obtained were 7 µA at 1000 V applied.

The IV characteristics were recorded as shown in Fig. 1 (left) with the FN plot on the right side of the same figure. This result agrees with the results recorded 15 years ago with just a slight decrease in the current obtained. The emission images (shown in Fig. 2) recorded during the voltage increase astonishingly resemble the emission image presented in the original work [2]. Continuing the cycle showed the smooth curve of the IV and FN plots' characteristics for the voltage decrease (see Fig. 3).

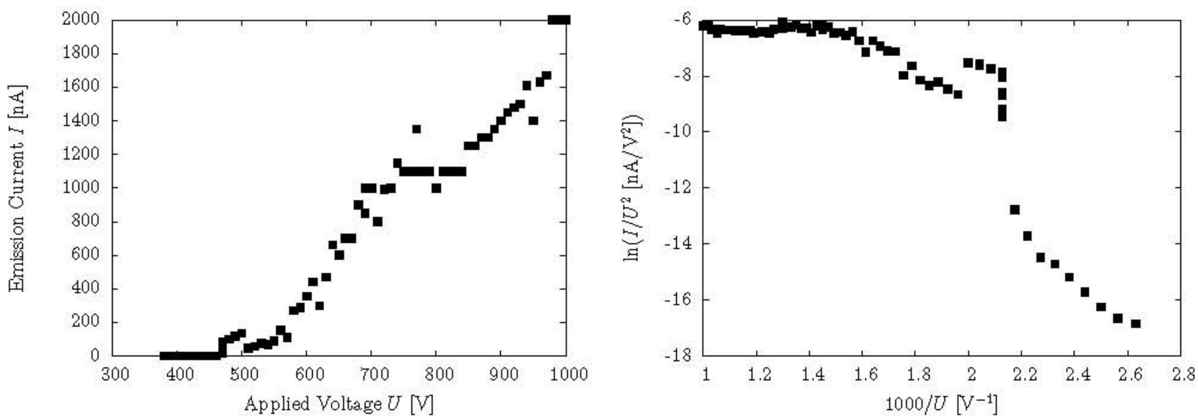

FIG. 1: The IV characteristics (left) and Fowler-Nordheim plot (right) of TCNE-coated tungsten tip during a further voltage increase.

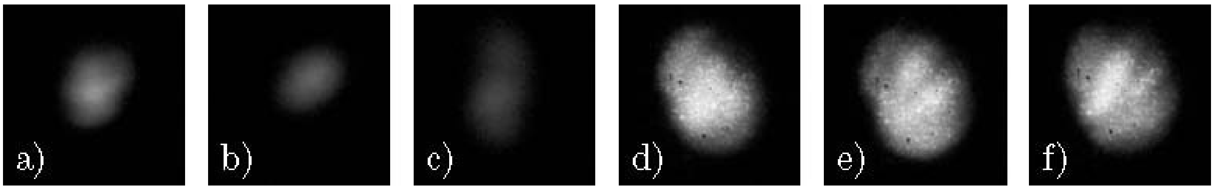

FIG. 2: Field emission images of TCNE-coated tungsten tip taken at 470 V (a,b), 510 V (c) and 980 V (d-f).

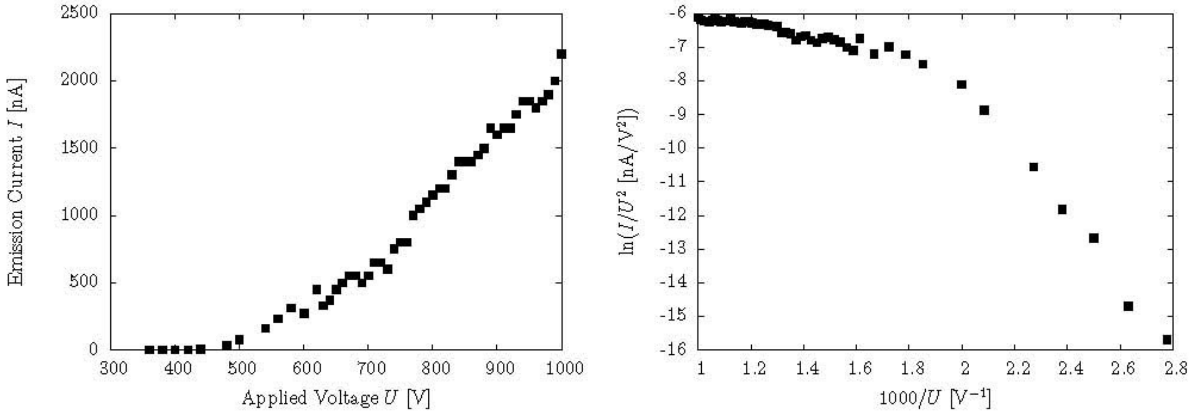

FIG. 3: The IV characteristics (left) and Fowler-Nordheim plot (right) of TCNE-coated tungsten tip during another voltage decrease.

MgO Coated Microemitter

In this section, the MgO coated tungsten emitter, that was examined 12 years ago with its characteristics published in [14] is now being re-examined (in vacuum system 1). The IV characteristics of this composite emitter (see Fig. 4, left) showed a switch on effect at 3340 V to an emission current of 17 µA which then increased gradually to 25 µA with increasing the applied voltage to 4700 V. The related FN plot is presented in the same Fig. 4 (right) with linear behavior obtained for lower fields. The emission images obtained from the MgO coated tungsten tip showed a single spot at low current and 1860 V. Increasing the voltage up to 2000 V showed emission from more than one sub-emission center that increased in number with increasing the voltage up to 2970 V. Increasing the voltage even more to 3340 V leads to the observation of a switch-on effect, thus producing a single spot image. Further increase of the voltage to 3800 V produced a more symmetric and concentrated emission spot, which is similar to that obtained during the original characterization process [14]. After increasing the voltage further to 4700 V, stability measurements were taken revealing limited stability compared to the original characterization. Subsequent decrease of the voltage produced the IV characteristics as shown in Fig. 6 with linear FN plot at the very low applied field region.

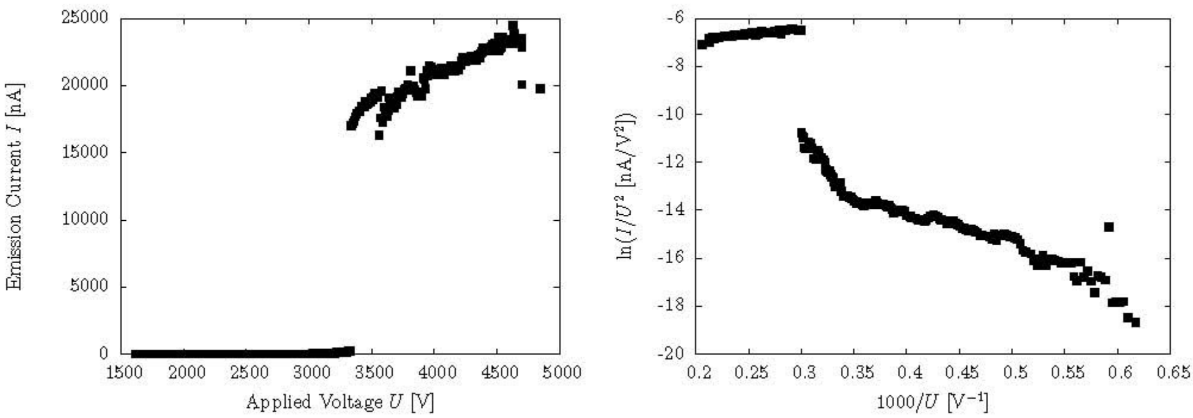

FIG. 4: The IV characteristics (left) and Fowler-Nordheim plot (right) of MgO-coated tungsten tip.

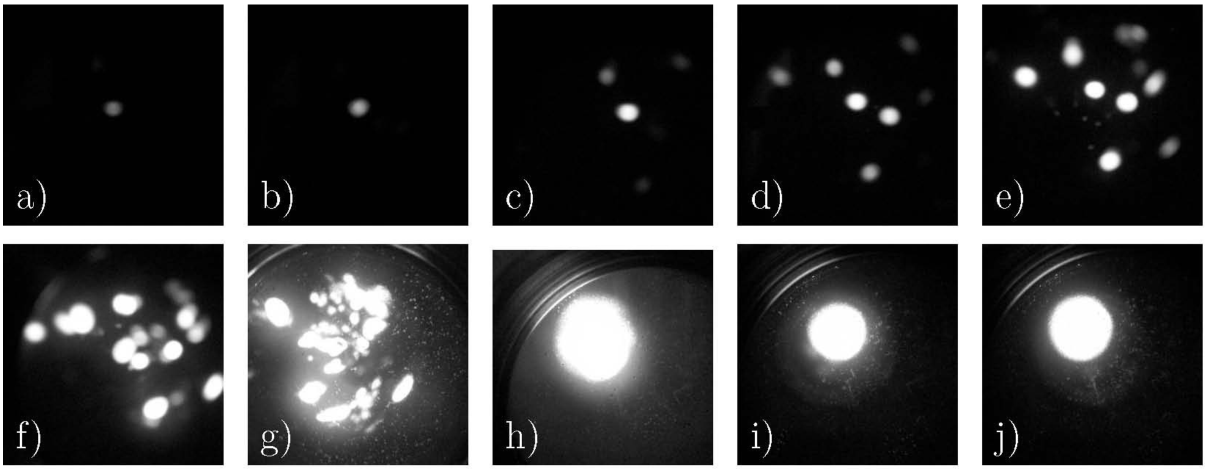

FIG. 5: Field emission images of MgO-coated tungsten tip taken at 1860, 1950, 1970, 2150, 2500, 2970, 3300, 3340, 3560 and 3800 V, respectively (a-j).

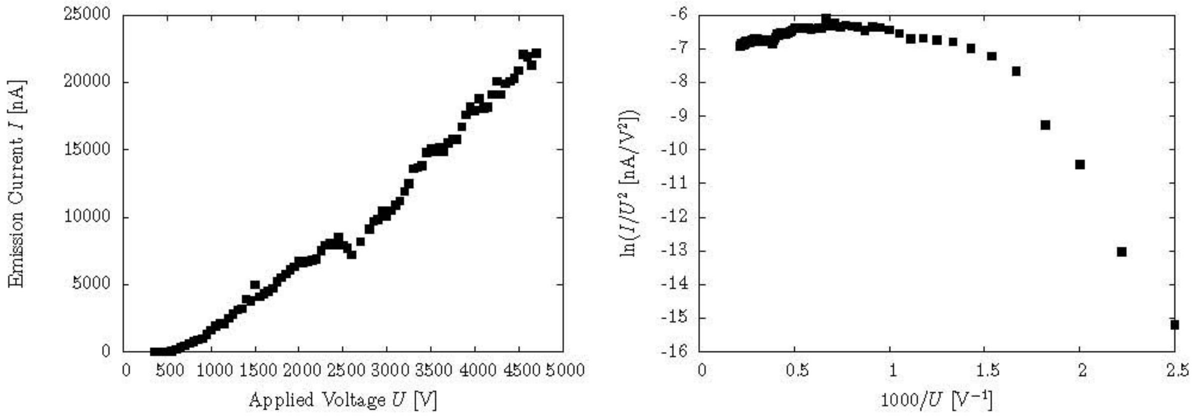

FIG. 6: The IV characteristics (left) and Fowler-Nordheim plot (right) of MgO-coated tungsten tip.

ZnO Coated Microemitter

In this section, the ZnO coated tungsten emitter, that was examined 20 years ago with its characteristics published in [15] is now being re-examined (in vacuum system 2). The IV characteristics obtained from the field emission process at the ZnO coated tungsten microemitter showed a smooth and regular increase of current with voltage (see Fig. 7, left) followed by a switch on from 3 to 6 µA at 3800 V. The emission current values were obtained at higher voltages than they were obtained originally [15], although linearity of the FN plot (see Fig. 7, right) is more obvious for a wider range of voltage. The emission images obtained from this composite emitter showed a striking similarity in the scattered multi-spot appearance compared to the original work at exactly the same voltage. Fig. 8 presents the spatial distributions of emission from ZnO coated tungsten tips showing the stability behavior of this type of electron source. The images demonstrate a limited stability measurement where we notice multiple emission sites randomly switching on and off. Each spot has a different energy distribution spectrum [10]. Subsequently decreasing the voltage showed a very smooth behavior (see Fig. 9).

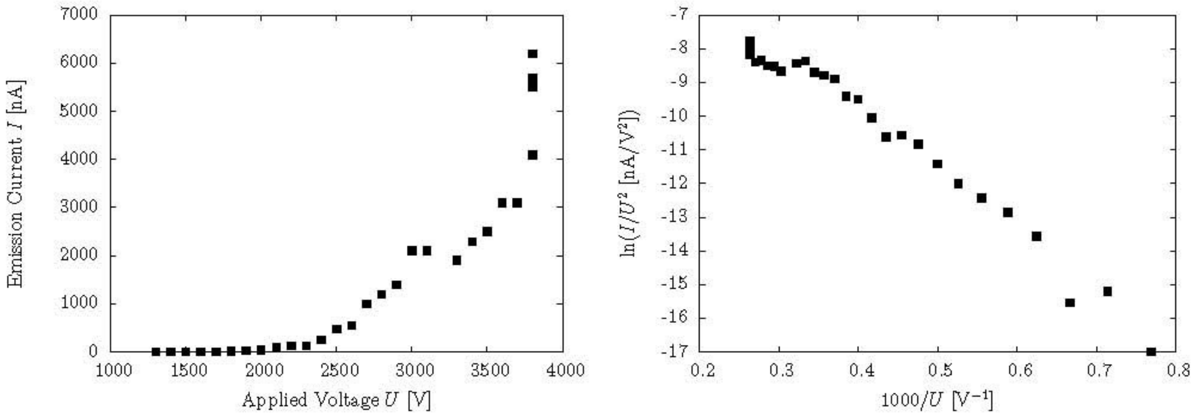

FIG. 7: The IV characteristics (left) and Fowler-Nordheim plot (right) of ZnO-coated tungsten tip.

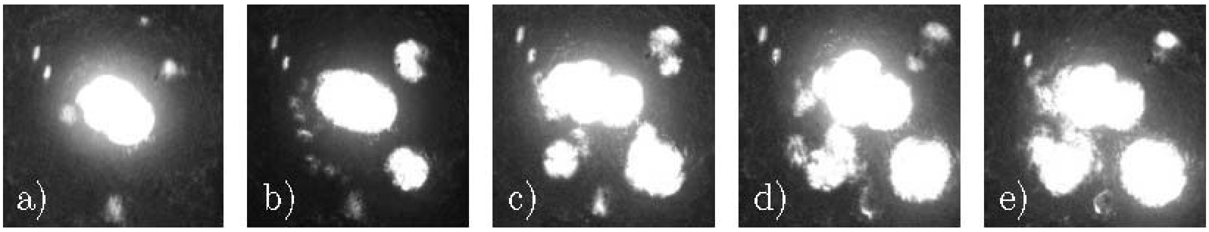

FIG. 8: Field emission images of ZnO-coated tungsten tip during stability measurement at 3800 V. The images were taken every 10 minutes reading an emission current of (a-e) 4.1, 5.7, 5.5, 6.2 and 5.6 µA.

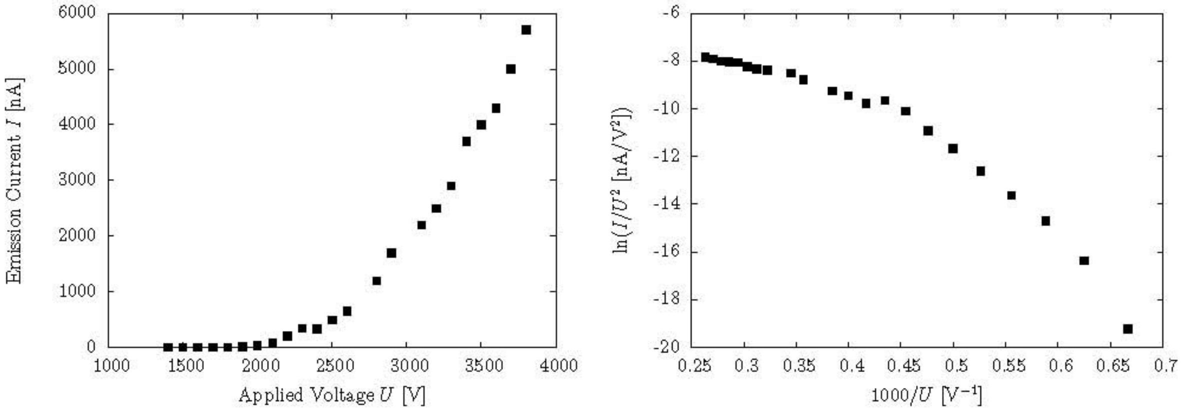

FIG. 9: The IV characteristics (left) and Fowler-Nordheim plot (right) of ZnO-coated tungsten tip.

Conclusions

Composite emitters, consisting of clean tungsten tips with known profile, coated with a variety of insulating materials, such as TCNE, MgO and ZnO were previously prepared and characterized. After about 10 to 20 years of keeping these samples under standard atmosphere conditions, they were tested again to study the strength of coating and the influence of aging. Results obtained by measuring the IV characteristics and emission images showed both striking similarities and marked differences between the characteristics obtained in both ages. One might have expected to find the tips highly degraded due to adsorption of corrosive substances present (at least in traces) within the standard atmosphere. Ultimately, experimental work reported here proves that the dielectric coating used in these experiments formed permanent structures on the tungsten core.

To highlight it once more, the coated tips showed outstanding long time stability by surviving about 15 years under standard atmosphere environment in fully operational condition. Thus, it might be worth systematically testing their capabilities under poor vacuum conditions.

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