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Detailed Characterization of Surface Structure and Influence on Field Emission

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***Abstract*— In most models of vacuum breakdown, there is some initial emission of electrons from the cathodic surface, usually employing some form of Fowler-Nordheim emission. While this may be correct for "textbook" surfaces, it is generally unreliable for real surfaces and fitted parameters are often used. For example, the beta employed is generally unphysical based on usual definitions (e.g., it incorporates more, but unexplained, physics than just a geometry-based field concentration effect). In this work, we describe experimental efforts to better characterize which surface structure parameters influence the vacuum field emission current.**

Keywords—vacuum field emission, electron emission, Fowler-Nordheim

I. Introduction

In this work we try to clarify the role surface characteristics may, or may not, have on field-based emission of electrons from a Pt cathodic surface. The electron emission process depends on the local electronic structure at the surface of the cathode, often capture in the work function *φ*). This is further influenced by the "geometric enhancement factor", *β*. We will interrogate surfaces with a number of diagnostic techniques to better understand the variations and correlations between *φ* and *β*. Local changes in surface emission due to other factors (e.g., from stepped surfaces, crystalline/compositional phase variation, and physi-/chemisorbed layers) are also expected to influence electron emission by modulating the surface potential.

Diagnostic techniques are employed to assess the morphological, crystalline, elemental, and electronic (work function) structure of the surface include scanning-tunneling microscopy (STM), atomic force microscopy (AFM), scanning Kelvin probe force microscopy (SKPM), electron backscatter diffractometry (EBSD) and photoemission electron microscopy (PEEM), although not all are described in detail here. Of particular interest is identifying correlations between morphology (e.g., local geometric field enhancement) and electron emission (via STM-induced surface fields or apparent work function via PEEM).

II. Measurements

We fabricated polycrystalline Pt samples on substrates according to the procedure in [1]. The substrates consisted of a 40 nm ZnO adhesion layer sputtered onto 400 nm of thermal SiO2 on Si (100). ZnO was deposited by RF sputtering (150 W, 3 in ZnO target, 5 mTorr, 1:2 O2:Ar gas ratio) in a Lesker Lab 18 sputter system. 90 nm of Pt was sputtered (300 W, 3 in Pt target, 3 mTorr, Ar) onto ZnO in the same system. Samples were annealed for 1 hr in air at 900 C to create a coarse polycrystalline microstructure. The resulting Pt sample is predominately (111)-oriented. A TEM of the stack is shown in Fig 1. For reference, a reasonable value for the work function of single crystal Pt(111) is 6.1 eV [2].

The most direct measurement of the apparent work function was performed using PEEM. Fig. 2 shows the apparent work function at two essentially limiting cases: freshly prepared, and after a multi-day exposure to air. The distributions of apparent work function are shown in Fig. 3.

Although the distribution width of 0.2 eV in *φ* may at first seem insignificant, because it is in the exponential of the F-N emission it can have a significant effect. Similarly, the 0.6 eV shift in air exposed poly-Pt vs. freshly prepared will greatly increase field-based emission.

The influence of step density [3] is accounted for by measuring the facet tilt via EBSD and AFM, as shown in

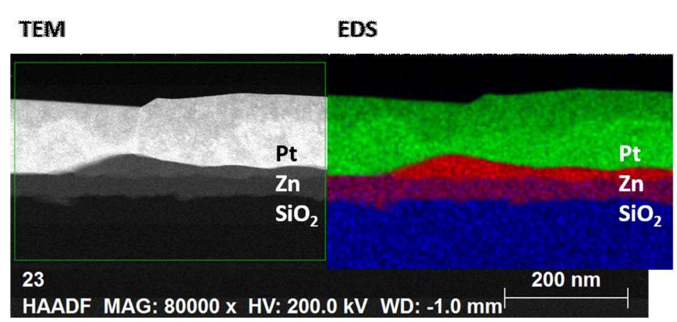

Fig 1. TEM and EDS of electrode stack after preparation.

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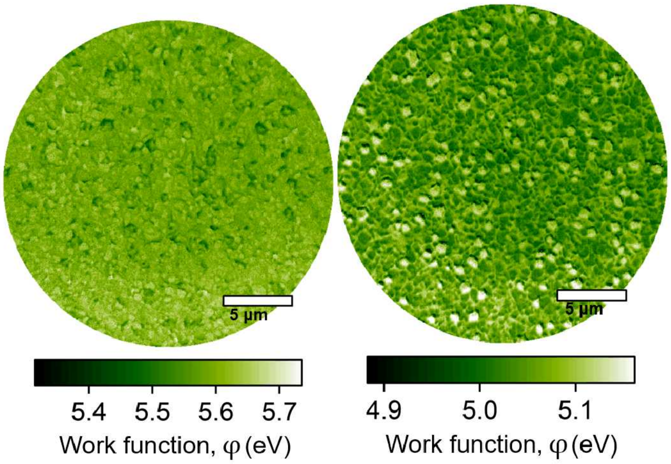

Fig. 2. PEEM measurements of effective work function. Left is freshly prepared (clean), right is after air exposure (dirty).

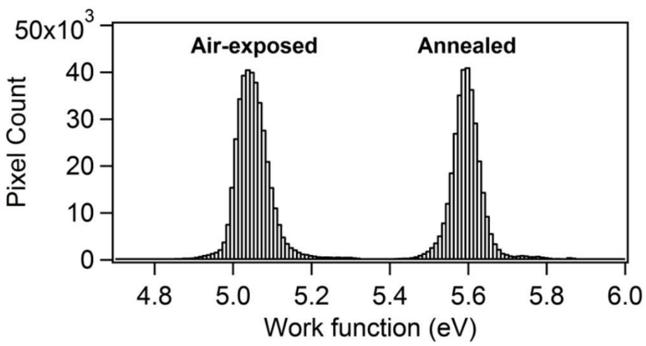

Fig. 3. Shift and slight broadening in apparent work function on Pt due to air exposure

Fig. 4, for the freshly prepared sample. Given this distribution of tilts, we compute a distribution of step densities, and derive an apparent work function correction of -0.21 eV.

Finally, we show the correlation between local topology and increased field emission by SKPM in Fig. 5. In this case we measure the topology and then measure the potential difference between probe tip and sample over the same region. While not strictly a measure of work function, it should indicate the regions of higher electron emission. As can be seen, there are many features that correlate strongly (high tips and high potential), but others that do not.

III. Conclusions

We have demonstrated multiple measurement techniques on the same sample to measure morphology, effective work function, as well as their correlation. These early results show that not all field enhancement regions correspond to increased electron emission (see Fig. 5). We have also incorporated a correction to the work function due to step density. Finally, we have demonstrated the decrease in work function due to air exposure through PEEM measurements. Future work will include co-located field emission and atomic scale topography measurements via the use of fiducials. The overall goal of this work is to provide a better model for the influence of apparent work function φ and removing other factors' influence on β so that it is truly just a geometry enhancement factor.

Acknowledgment

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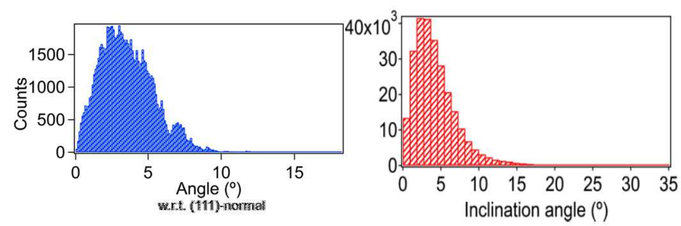

Fig. 4. Two different measurements of distribution of angles. Left is via EBSD, right is via AFM.

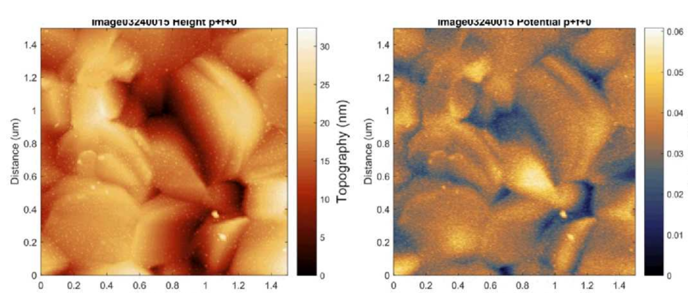

Fig. 5. Comparison of topography (height) information and surface potential, measured by SKPM. Left is height, right is potential. Field enhancements (higher sample-probe potential differences) do not strictly correlate to geometric enhancements, contrary to the typical argument.