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Detailed Characterization of Surface Structure and Influence on Field Emission

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Introduction

The goal of this work is to investigate the roles nanoscale features on, and in, a metallic surface play in field-induced electron emission in vacuum. Through correlating nanoscale features with electron emission we hope to better understand which surface features dominate electron emission, in contrast to assumptions of "textbook" model assumptions that require substantial fitting and calibration (e.g., applying Fowler-Nordheim to a complicated surface). We also investigate the effects of controlled nanoscale layers of film materials or oxides to the metal surface.

Approach

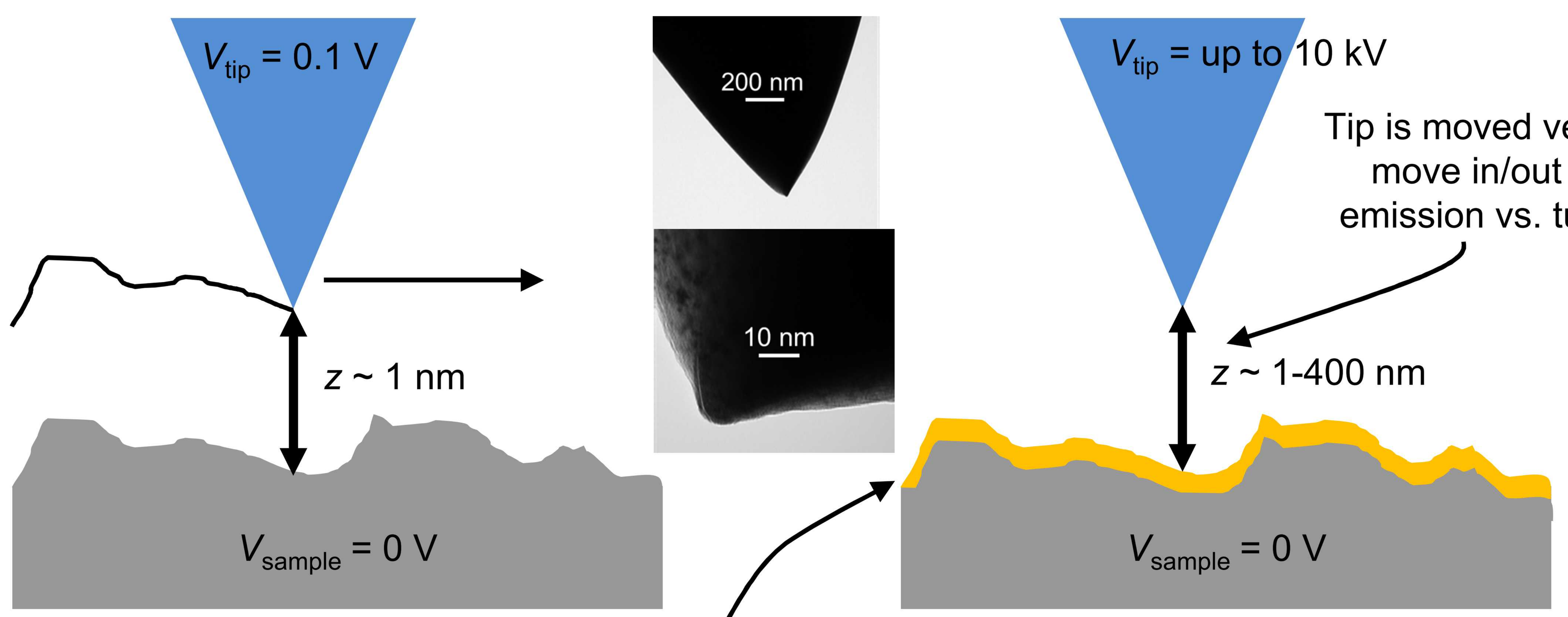
Apply microscopy techniques to characterize the surface at very high resolution (down to nm resolution):

- Surface topography (heights, grain boundaries, crystal orientation) via atomic force microscopy (AFM) and scanning tunneling microscopy (STM)
- Surface potential via scanning Kelvin probe microscopy (SKPM)
- Film depths via energy-dispersive x-ray spectroscopy (EDS)
- Apparent work function via photoemission electron microscopy (PEEM)

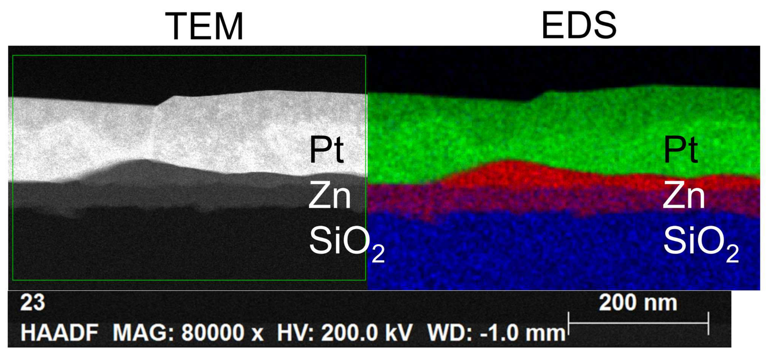
Measure field emission at very short "pin-to-plane" gaps with STM. Atomic layer deposition (ALD) is used to apply thin layers of known materials.

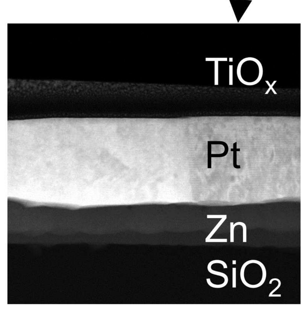
Usual scanning operation. Adjust z to maintain constant current, e.g., 100 pA.

Field emission and discharge operation. Set z and apply "high" voltage.

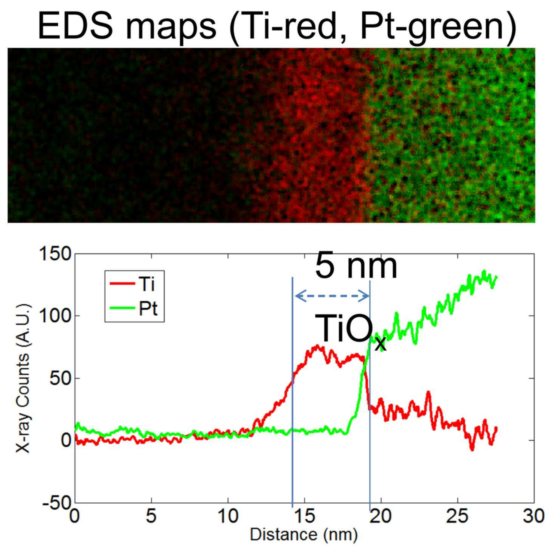


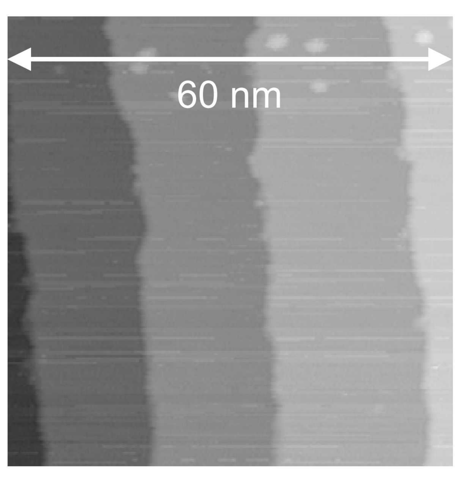
ALD is used to apply 1-10 nm layer of TiO_2



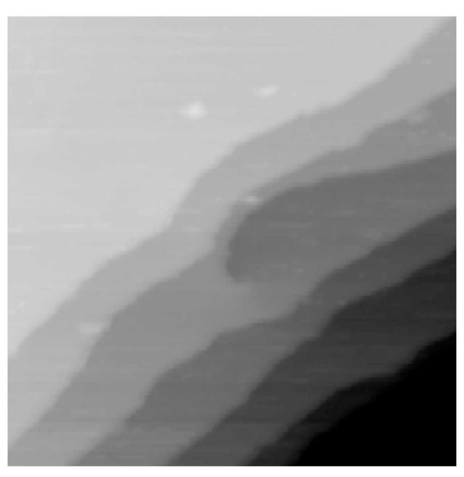


EDS maps (Ti-red, Pt-green)

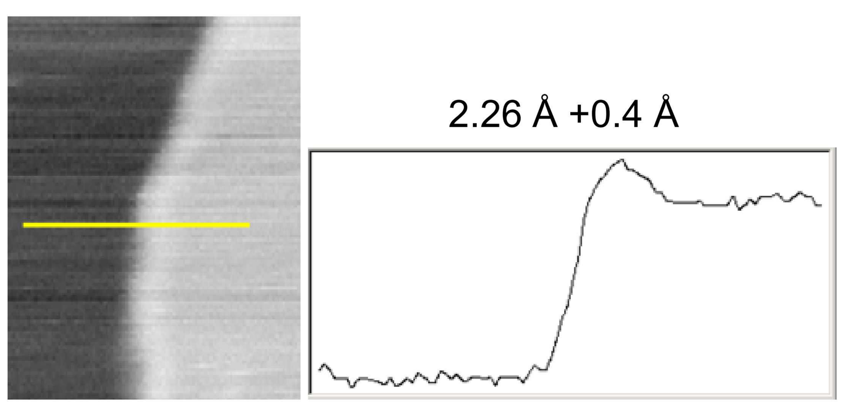




STM scan of Pt surface showing atomic steps

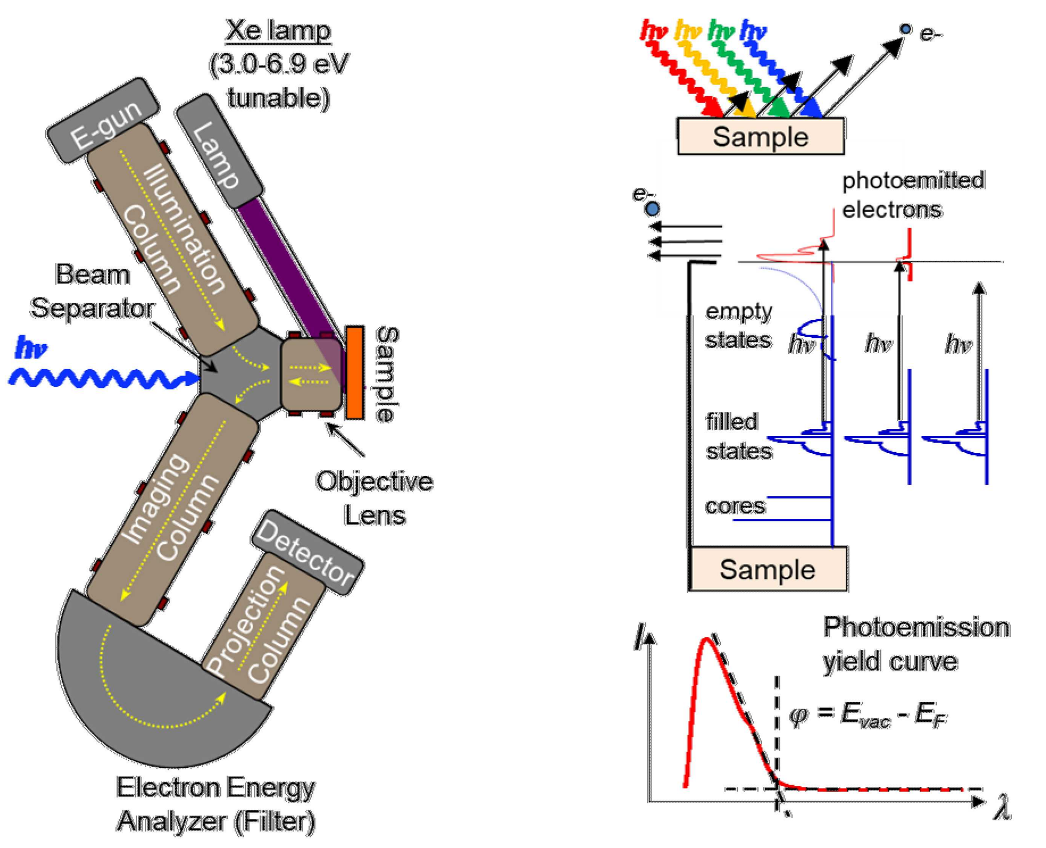


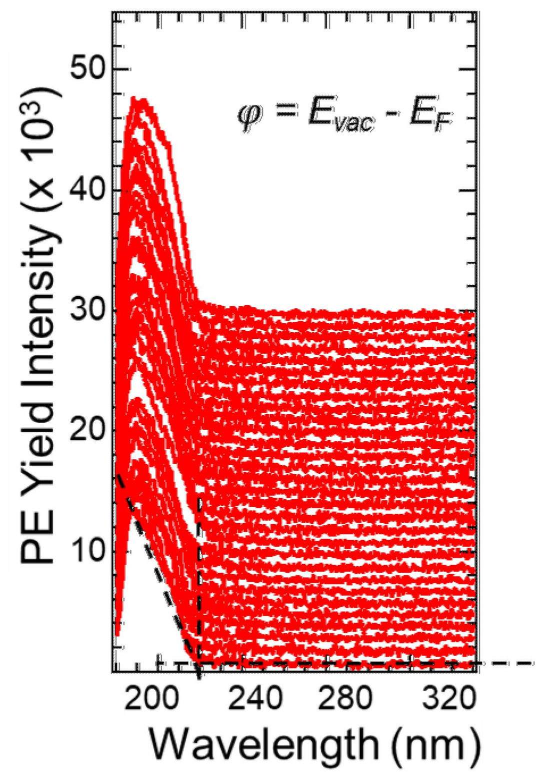
Screw dislocation!



Step edge anomaly "field enhancement"

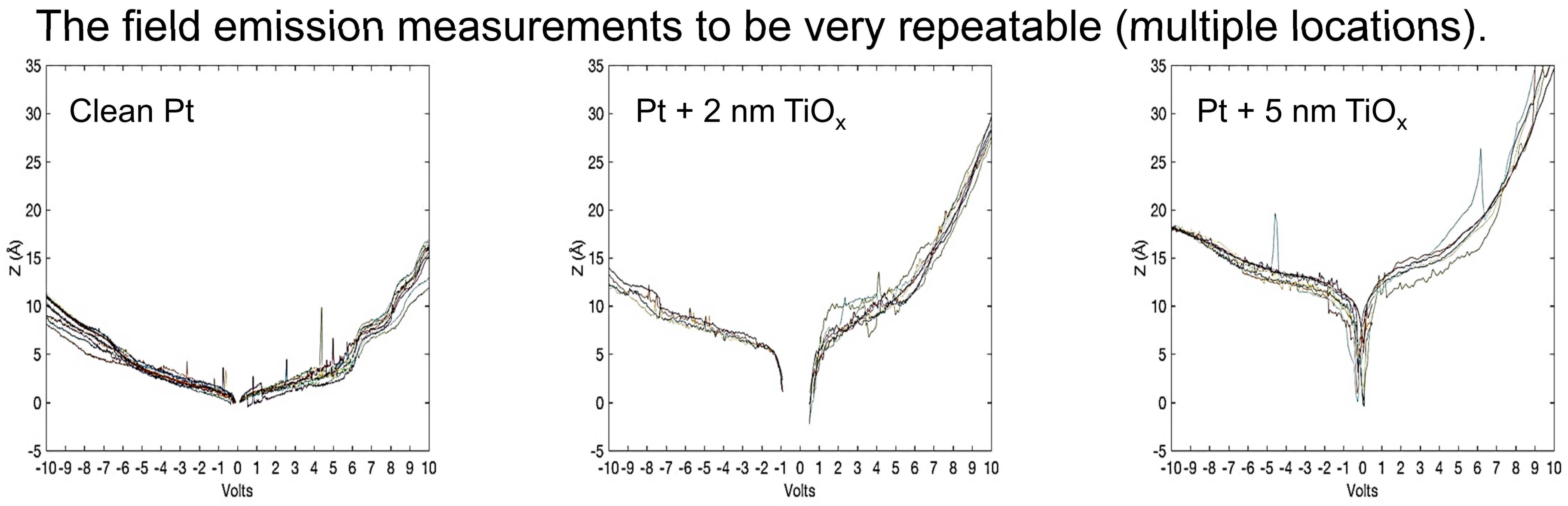
PEEM gives moderate (40 nm) resolution of apparent work function, φ.





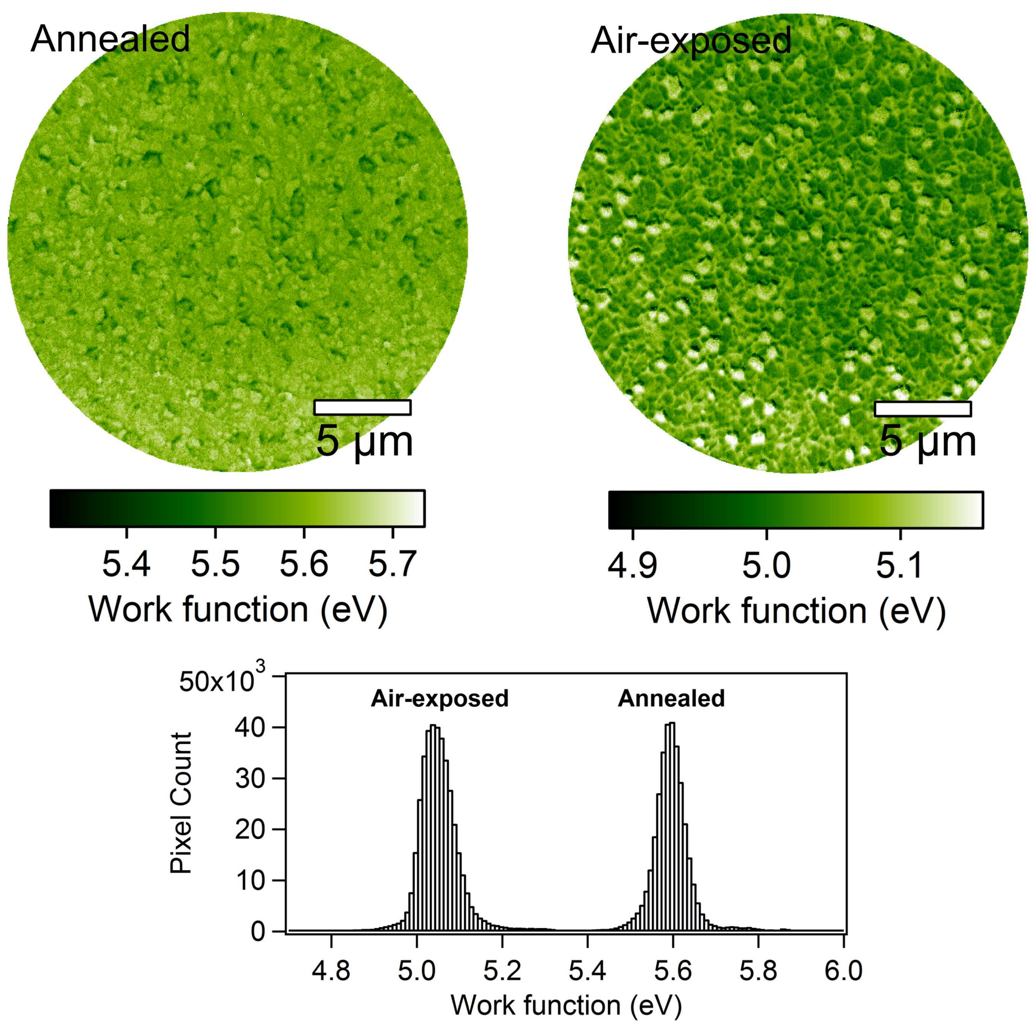
Results

The field emission measurements to be very repeatable (multiple locations).

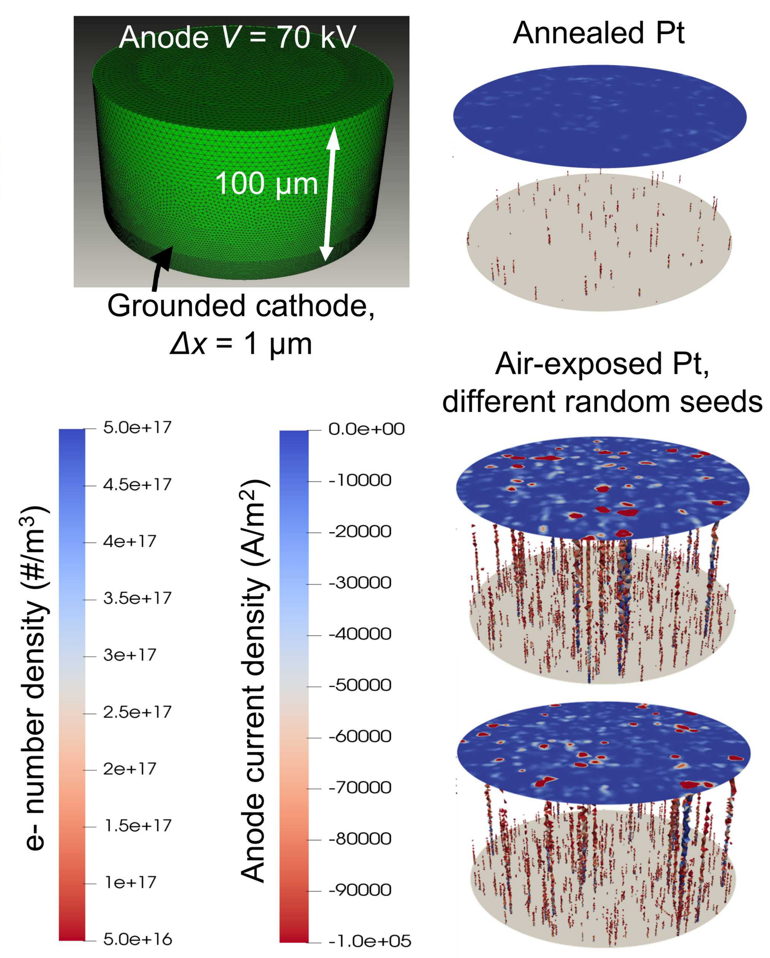


Note that at fixed voltage a larger gap in the 5 nm layer can achieve the same current as a smaller gap for 2 nm layer, and even smaller gap for clean Pt. The oxide layer *increased* field emission!

Using PEEM we measure distributions of φ for "as cleaned" (annealed) Pt surface and after multi-day air exposure. The textbook φ for Pt(111) is 6.1 eV.



PIC-DSMC Modeling



Ongoing and Future Work

- Position registration to match local β with apparent work function.
- First principles physics models for electron emission in measured material.
- Continue deconstruction of β, φ, and other elements of field emission models into experimentally measured material characteristic distributions.

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