

Atom Probe Studies of rf Materials

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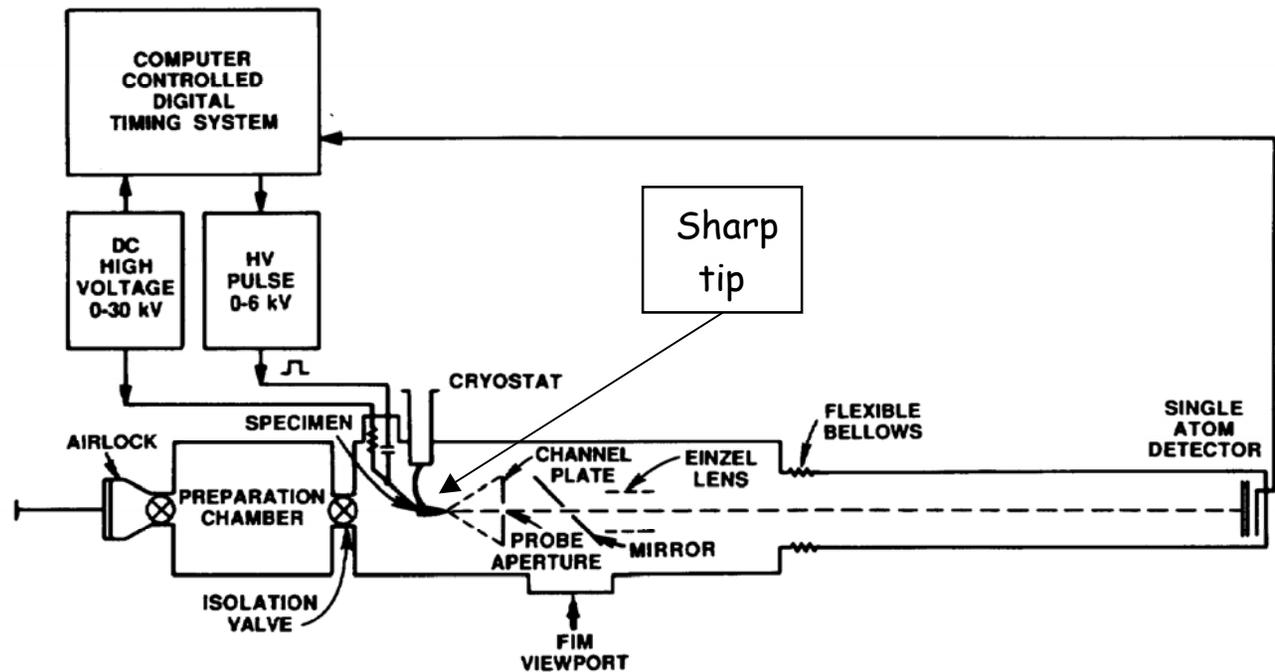
Materials science as it relates to rf materials systems

- We are constructing a facility which combines an atom probe field ion microscope (APFIM) with a multi-element in-situ deposition and surface modification capability
 - Our interest is in structures relevant to normal and superconducting rf systems
 - Atom probe tips serve as models of sharp asperities
- The initial goal will be to understand the properties of evaporated coatings
 - Field emission, bonding, interdiffusion etc., as they relate to breakdown and dark currents in normal cavities
 - We also hope to use this facility to look more generally at interactions of surface structure and high rf fields



Our facility is essentially a modified atom probe field ion microscope (APFIM)

- A sharp tip (end radius ~ 10 nm) is held at cryogenic temperature
- High voltage is applied (in the case of field emission, a negative high voltage) and the resulting image and current are monitored



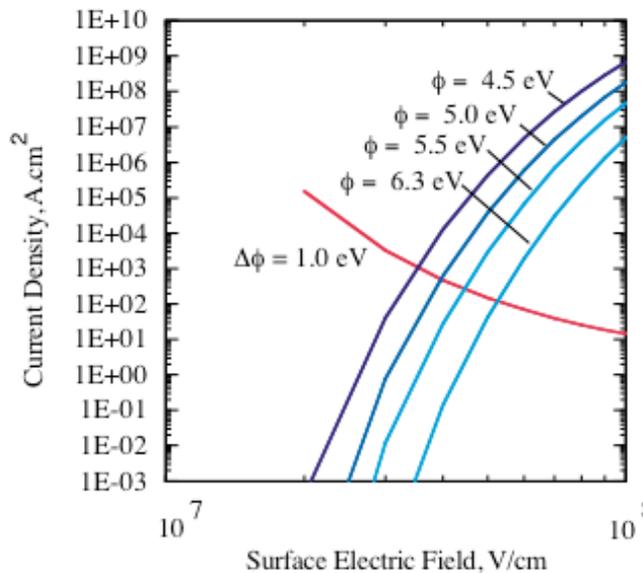
From Miller and Smith, (1989)



Can evaporated coatings significantly reduce the emission from an asperity?

- Fowler-Nordheim theory predicts that field emission has a strong dependence on work function, ϕ
- An increase in work function of 1 eV can reduce field emission current by 10^3 or more
- We will study the effect of evaporated coatings (with high work functions) on the field emission behavior of a well-developed, well-defined asperities (I.e., atom probe tips)

$$i(E_{\text{surf}}) = \frac{A_{\text{FN}}(\beta E_{\text{surf}})^2}{\phi} \exp\left(-\frac{B_{\text{FN}}\phi^{3/2}}{\beta E_{\text{surf}}}\right)$$



Element	Work Function(eV)
Aluminum	4.08
Beryllium	5
Cadmium	4.07
Calcium	4.07
Carbon	4.81
Cesium	2.1
Cobalt	5
Copper	4.7
Gold	5.1
Iridium	5.3
Iron	4.5
Lead	4.14
Magnesium	3.68
Mercury	4.5
Nickel	5.01
Niobium	4.3
Potassium	2.3
Platinum	6.35
Selenium	5.11
Silver	4.73
Sodium	2.28
Uranium	3.6
Zinc	4.3



Field emission (and both field ionization and field evaporation) relies upon the principle of an enhanced electric field at a sharp tip

- $E = V/(k r)$
- Blunting of an atom probe tip during field evaporation is analogous to “conditioning” of an rf cavity
 - The tip has a well-developed profile and radius (~ 10 nm) during controlled field evaporation

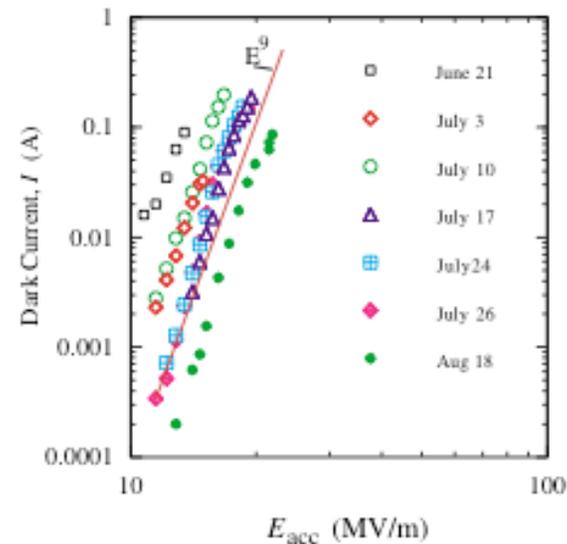
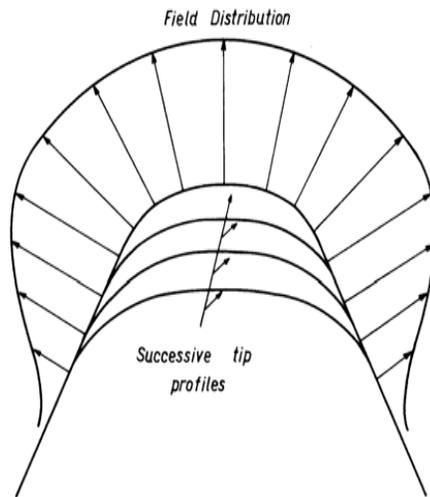
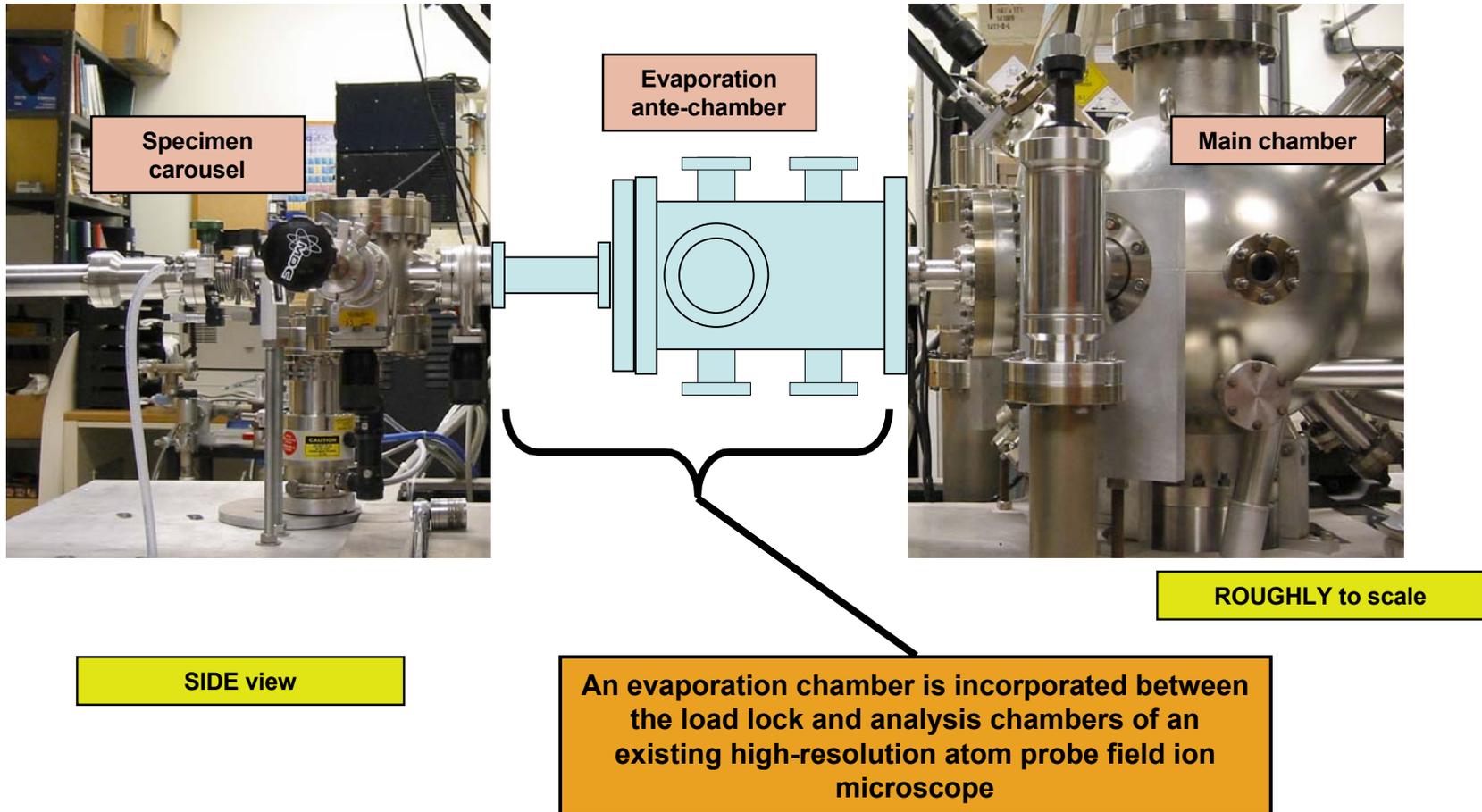


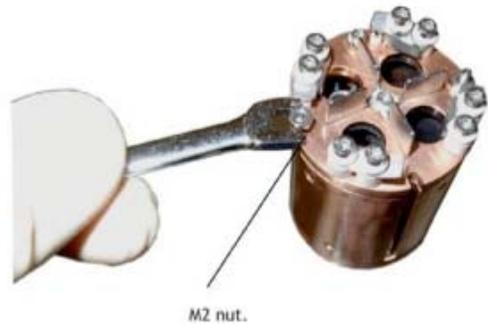
FIG. 5. (Color) High current data during cavity conditioning.

From Norem et al., (2003)

The instrument is created by adding onto an existing atom probe field ion microscope

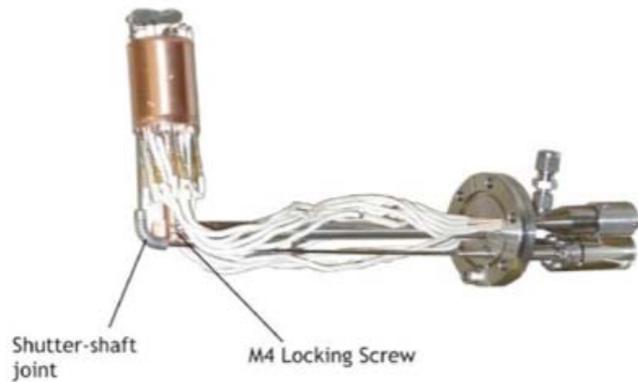


A mini e-beam evaporator unit is built into the evaporation chamber



M2 nut.

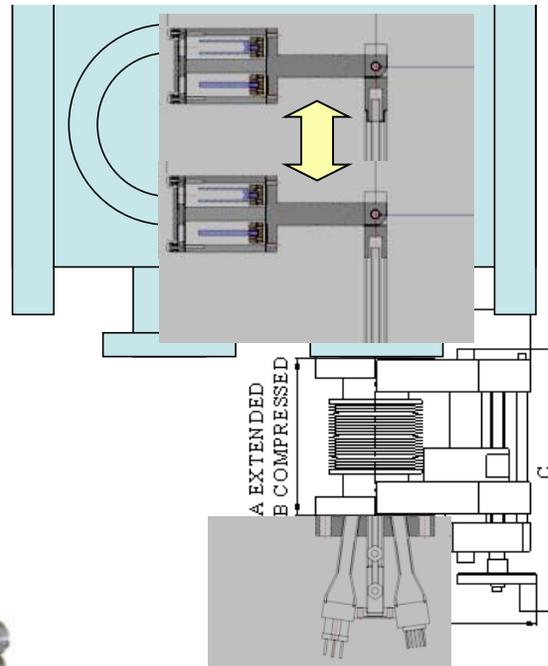
Up to four evaporants



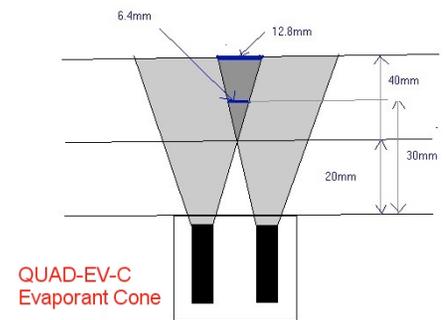
Shutter-shaft joint

M4 Locking Screw

90-degree orientation



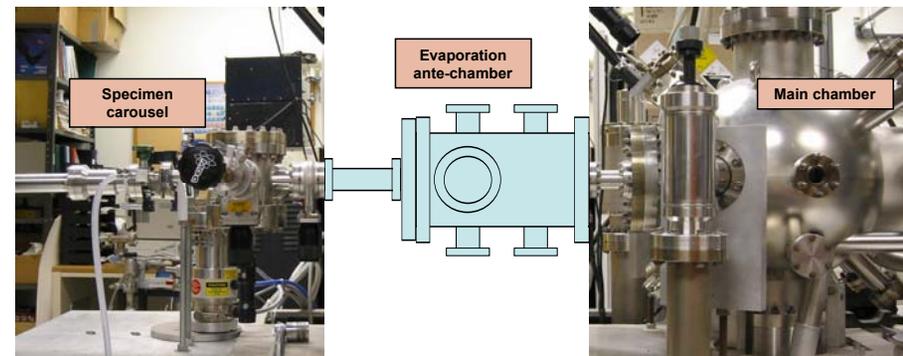
Moves in and out of chamber via UHV bellows



Evaporant profile

Typical experimental sequence (simplified)

1. Move tip into main chamber
2. Develop tip to smooth end-form via field-evaporation
 - Positive high voltage
3. Measure I-E response (field-emission; Fowler-Nordheim plot)
 - Negative high voltage
4. Move tip into evaporation ante-chamber
5. Evaporate onto developed tip surface
 - Other tip treatments
6. Move tip back into main chamber
7. Re-measure I-E response (field-emission; Fowler-Nordheim plot)
 - Negative high voltage
8. Remove coating via field evaporation
 - Positive high voltage
 - Information about coating adhesion, bonding, interdiffusion, etc.



Other work

- Surface chemistry
 - Atom probe analysis of chemistry deposited layers
 - Pulsed voltage- or pulsed laser-controlled evaporation of surface atoms, and of deposited coatings
- Different surface treatment effects on field emission
 - Cleaning treatments
 - Sputtering
- Three-dimensional atom probe analysis of rf materials
 - The recently-acquired local electrode atom probe (LEAP) at Northwestern can allow for data collection rates of up to 72 million ions/hour

