Studies of Electron Field Emission Phenomena in Ultrananocrystalline Diamond (UNCD) and Low Work Function Cu-Li Alloy Thin Films

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SCIENTIFIC ACHIEVEMENT

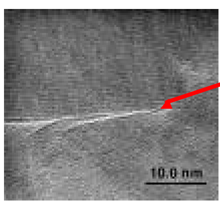
UNCD films exhibit relatively high/stable electron emission currents when exposed to electric fields. Quantum photoyield measurements of the UNCD films revealed that these films have an enhanced density of states within the bulk diamond band gap that is correlated with a reduction in the threshold field for electron emission. In addition, scanning tunneling microscopy studies indicate that the emission sites from UNCD films are related to minima or inflection points in the surface topography, and not to surface asperities. These data in conjunction with tight binding pseudopotential calculations indicate that grain boundaries play a critical role in the electron emission properties of UNCD films, such that these boundaries: (a) provide a conducting path from the substrate to the diamond-vacuum interface, (b) produce a geometric enhancement in the local electric field via internal structures, rather than surface topography, and (c) produce an enhancement in the local density of states within the bulk diamond band gap.

Cu-Li alloy films show a thirteen-fold reduction in the threshold voltage for electron emission, compared with uncoated Si surfaces. The segregated Li monolayer on the surface of the alloy leads to charge transfer between the metal conduction band and the Li adsorbate atom, giving rise to an effective work function even lower than that of the elemental alkali metal that results in relatively high/stable field-induced electron emission.

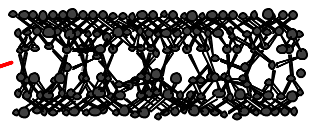
SIGNIFICANCE

The work performed by our group to understand the mechanism responsible for field-induced electron emission from UNCD and Cu-Li alloy films is providing valuable insights into the composition and/or microstructure-property relationships related to this phenomenon in both materials. The fundamental knowledge acquired in this work is providing the basis for applied research directed at developing new multifunctional devices based on the field emission properties of the materials described in this FWP. Both UNCD and Cu-Li alloy films may play critical roles in the development of a whole new generation of devices such as field emission flat panel displays, high frequency travel wave tubes, field emission-based electron microscopes, x-ray tubes, and particle accelerators among many other

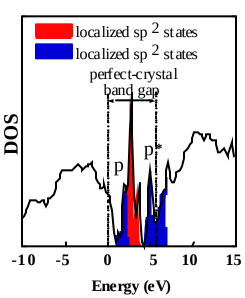
UNCD Film Microstructure and Electronic States



UNCD films are formed by 2-5 nm equiaxed grains and 0.2-0.5 nm grain boundaries

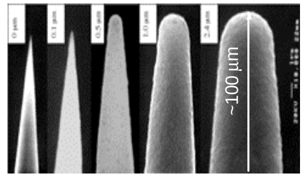


Molecular dynamic simulation predicts UNCD high-energy grain boundaries mostly sp^2 coordinated, which provide the basis for the excellent mechanical properties and electron transport properties of UNCD, the latter when doped with nitrogen

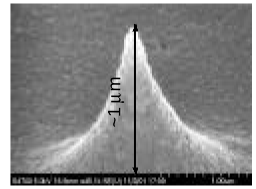


Tight-binding simulations indicate the existence of possible sp^2-bonded gap states in UNCD grain boundaries

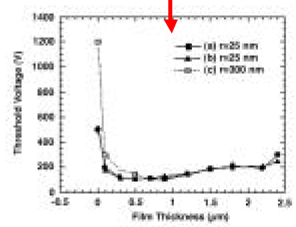
Electron Field Emission from UNCD



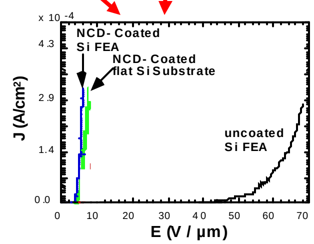
Conformal UNCD coatings on high-aspect ratio Si field emitter tips were used to measure J vs. E and emission threshold voltage vs. film thickness



Conformal UNCD coating on low-aspect ratio Si field emitter tips were used to measure J vs. E from UNCD

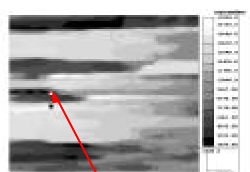


Threshold emission field vs. UNCD film thickness on Si field emitters shown above shows that electron emission from UNCD exhibit very small dependence on film thickness

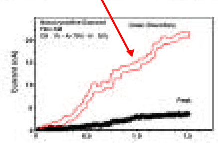


J vs.E curves for uncoated, UNCD-coated Si-field emitters & planar Si surface show extremely low threshold field for UNCD-coated Si

Site Selective Emission from UNCD

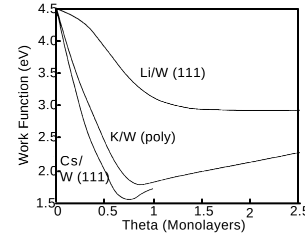


STM topographical image and associated electron emission (red) measured from region close to UNCD grain boundary (dark in STM image)



J vs. E, threshold emission voltage vs. film thickness, STM topographical imaging vs electron emission data, and computer simulation indicate that electron emission from UNCD is largely controlled by grain boundaries

Electron Field Emission from Cu-Li Alloys

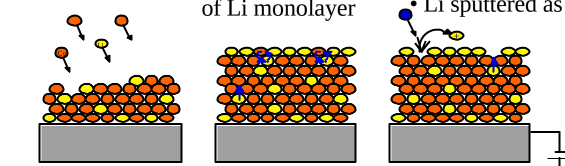


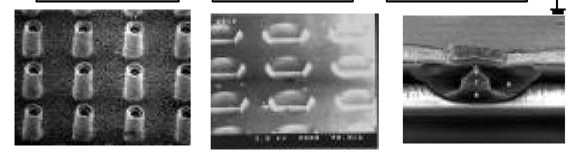
- Charge transfer between segregated surface alkali Li layer and Cu-Li alloy substrate:
  - ☑ Reduces work function
  - ☑ Modeled by formation of surface dipoles

Magnetron Deposition

Gibbsian segreg. induces formation of Li monolayer

Self-sustaining
- low Li sputter yield
- Li sputtered as Li^+

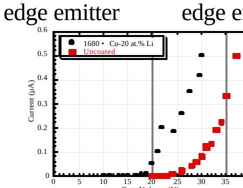


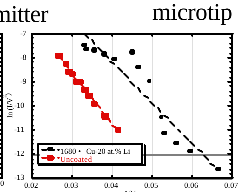


Vertical Cu-Li edge emitter

Horizontal Cu-Li edge emitter

Gated Cu-Li microtip





I vs V for gated Cu-Li tip

Fowler-Nordheim curve

CONCLUSIONS

Work on both UNCD and low-work function Cu-Li alloy films demonstrated that both materials exhibit extremely low field emission threshold voltage and relatively high / stable electron emission. Electron emission from UNCD appears to be largely controlled by grain boundaries, while emission from Cu-Li alloy films is controlled by Li segregated layer on the surface. Both materials can be applied to many field emission-based devices

FUTURE WORK

- **Studies of electron field emission from UNCD using *in situ* TEM holography and STM techniques to elucidate emission mechanism**
- **Studies of field emission from both undoped and nitrogen-doped UNCD under vacuum and background gases**
- **Use of field emitter arrays to investigate biological processes via UNCD-coated microtips-biomolecule interactions**

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