Photocathodes for High Repetition Rate Light Sources

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Alkali Antimonide and Diamond Amplifier

Materials science-based approach to cathode growth

- Cathode chemistry with XPS and XRF/EDX
- Cathode structure with XRD and SEM
- Diamond defect mapping; understanding the mechanism of emission
- Performance with QE mapping, ARPES and momentum measurement
- Diagnostics integrated into growth chambers
- Universal load-lock to enable growth chamber->gun->analysis

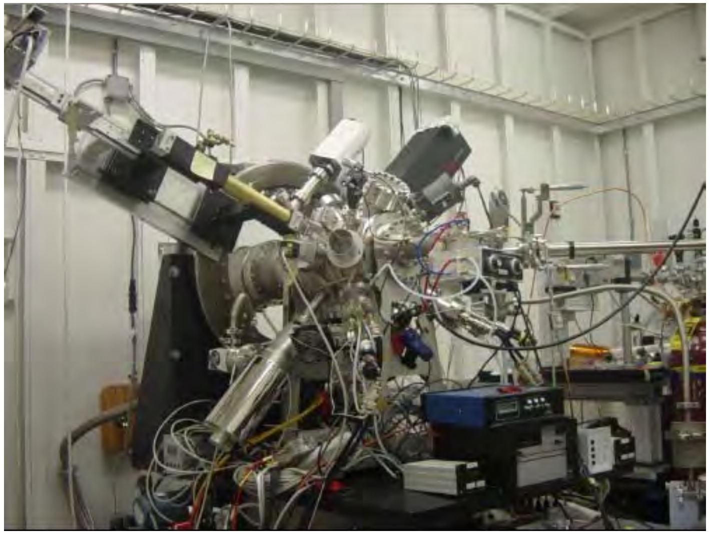
Utilization of user facilities **greatly** expands capabilities

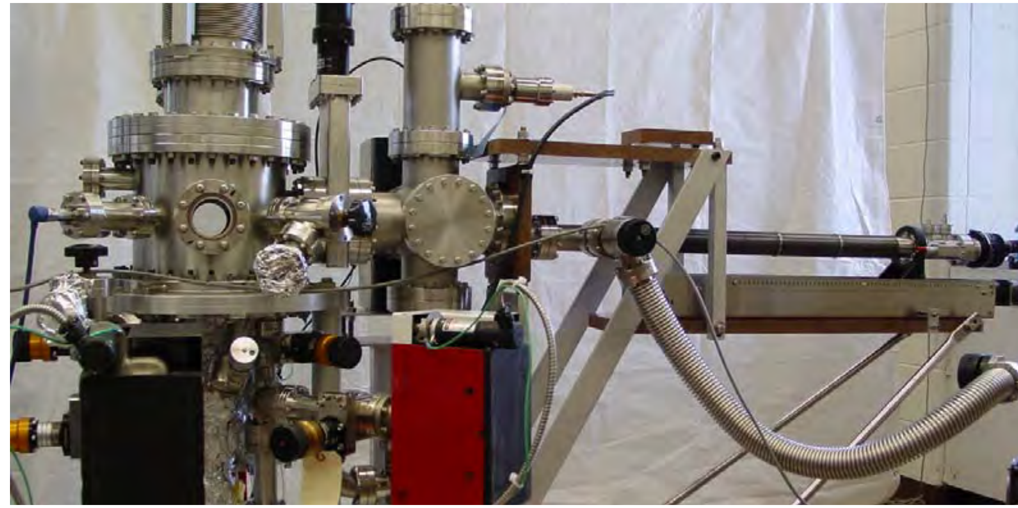
Gun, lifetime and exposure tests

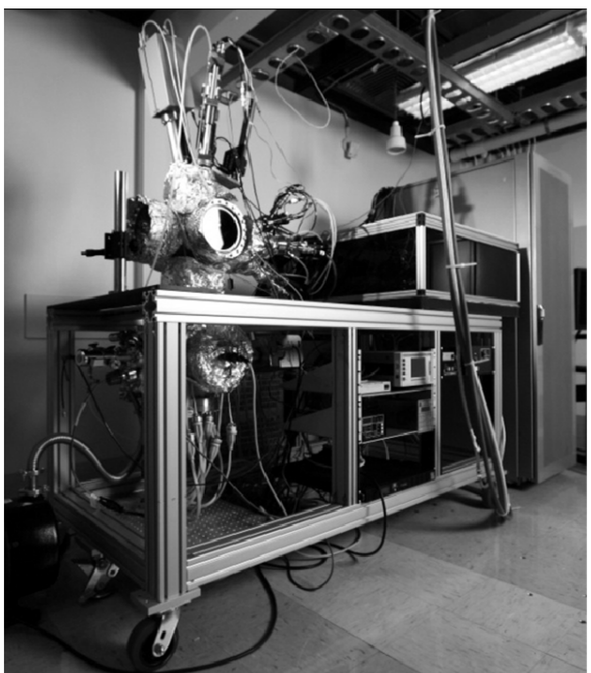
- Test cathodes in “real-world” environments
- Subsequent analysis will identify defects and failure modes

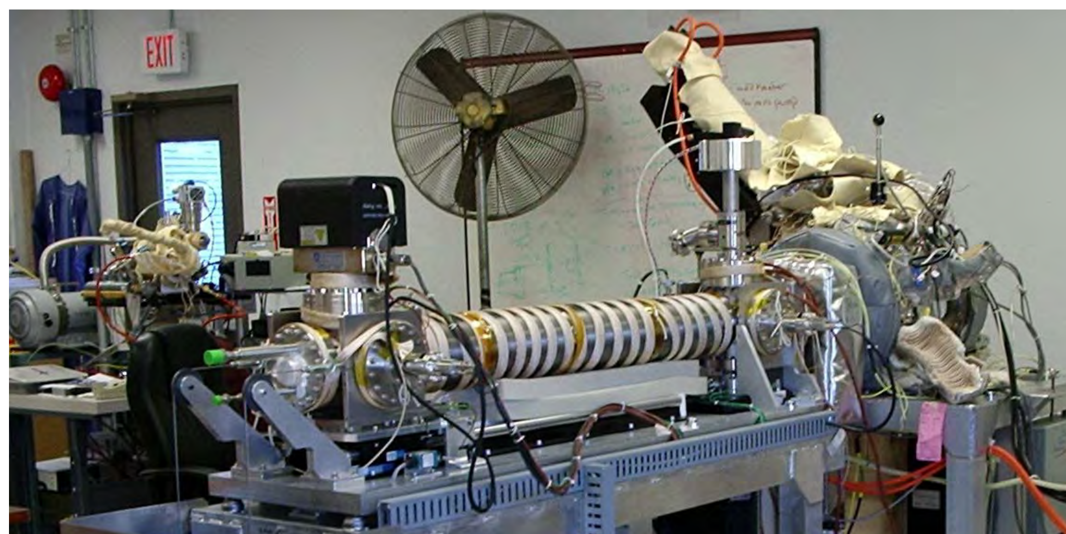
Take the cooking out of making cathodes

Alkali Antominide Growth









K_2CsSb: A cathode with excellent characteristics for accelerator applications


APPLIED PHYSICS LETTERS 99, 034103 (2011)

A low emittance and high efficiency visible light photocathode for high brightness accelerator-based X-ray light sources

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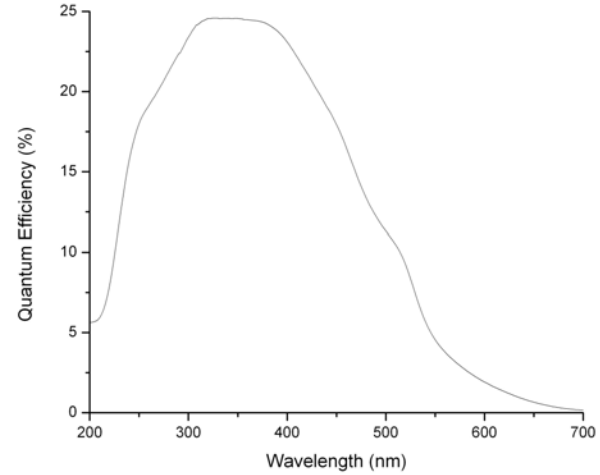
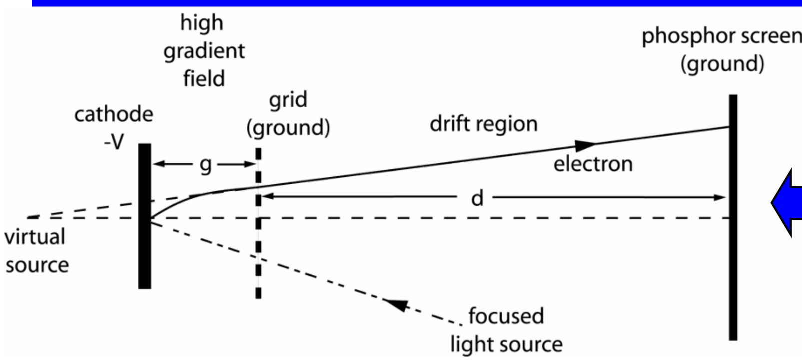
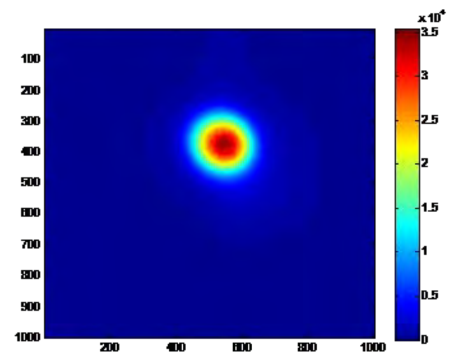
Free-electron lasers and energy recovery linacs represent a new generation of ultra-high brightness electron accelerator based x-ray sources. Photocathodes are a critical performance-limiting component of these systems. Here, we describe the development of photocathodes based on potassium-cesium-antimonide that satisfy many of the key requirements of future light sources, such as robustness, high quantum efficiency when excited with visible light, and low transverse emittance. © 2011 American Institute of Physics. [doi:10.1063/1.3612916]



Fast (msec), high field (4 MV/m; can be > 10 MV/m) measurement of transverse momentum

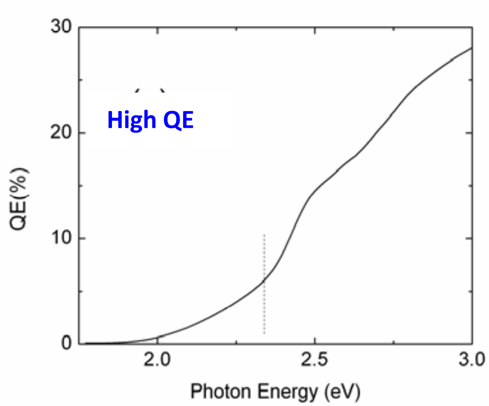


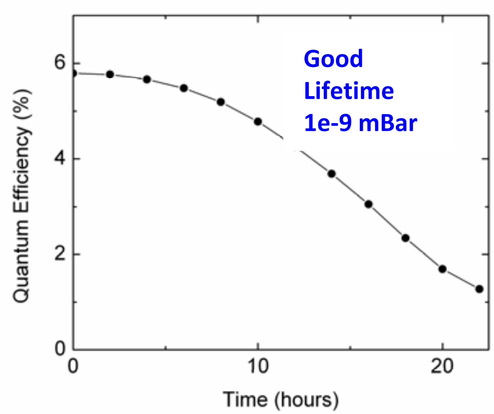


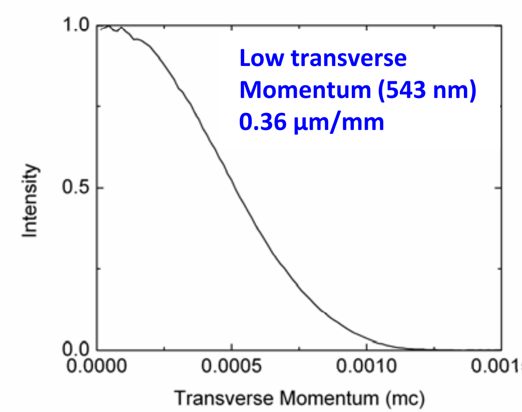
$$r = \sqrt{\frac{mc^2}{2eV}}(2g + d)\left[\frac{p_x}{mc}\right]$$

r = radial coord on detector
g – cathode to grid distance
d = drift distance

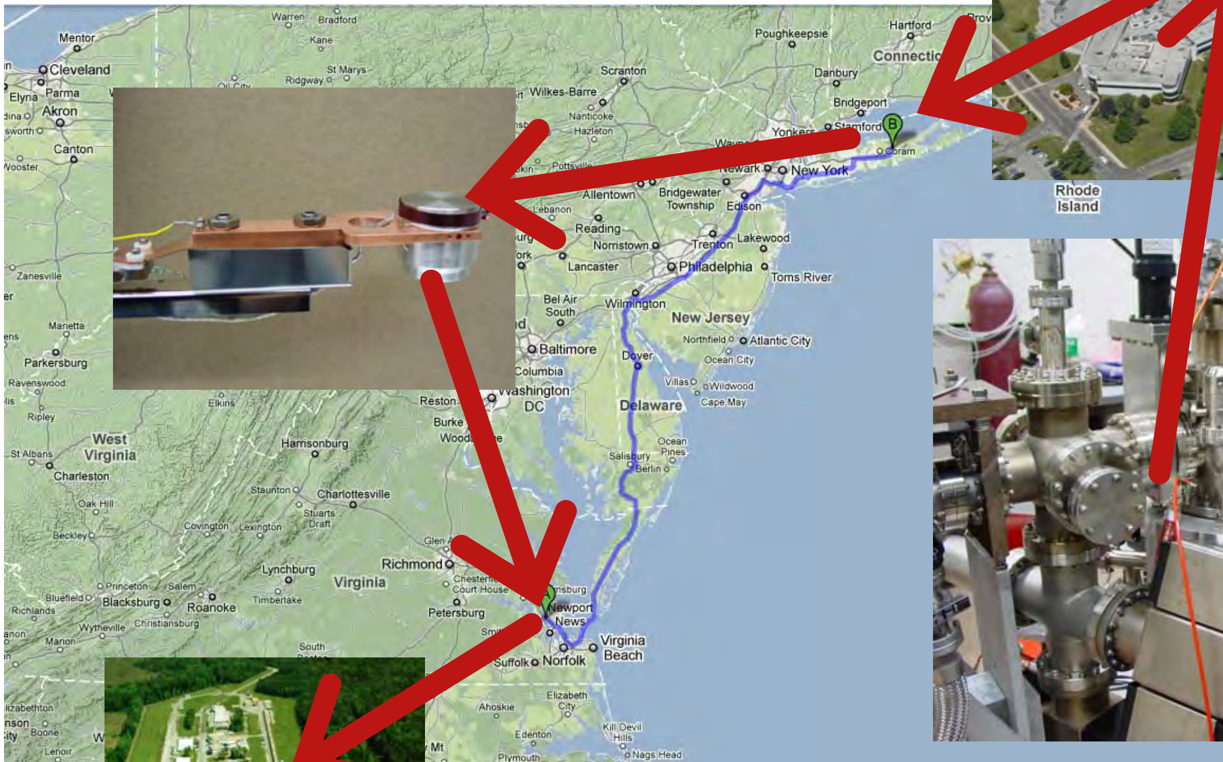
Instrumental resolution less than for kT

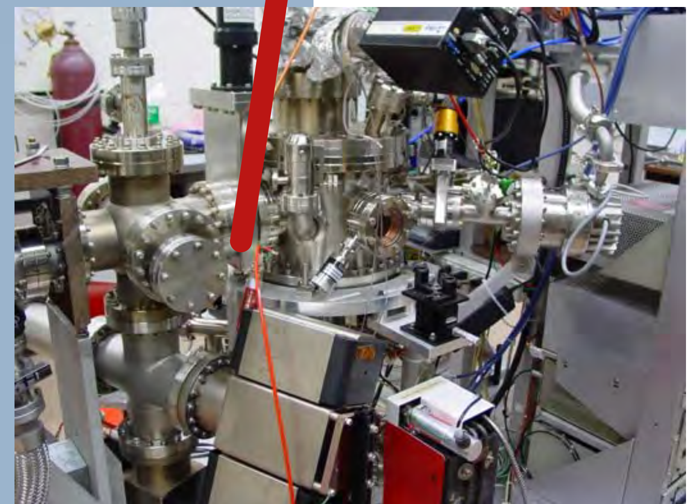






Photocathode was made at BNL...



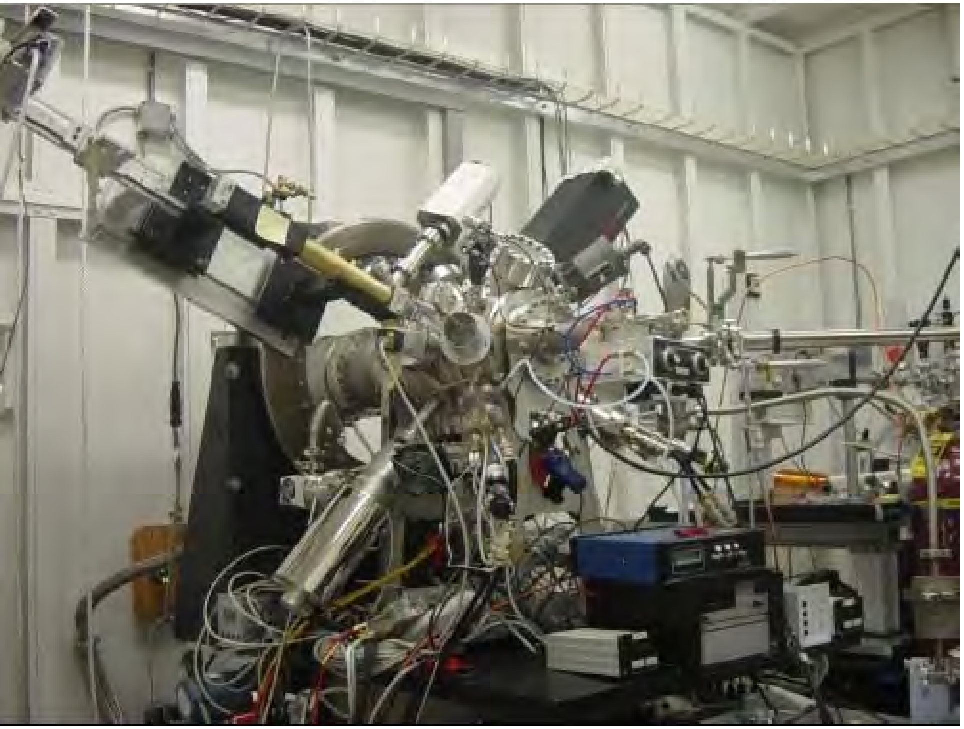


...and brought to JLab for testing.

Long Dark Lifetime!

For Details, see Triveni's Poster

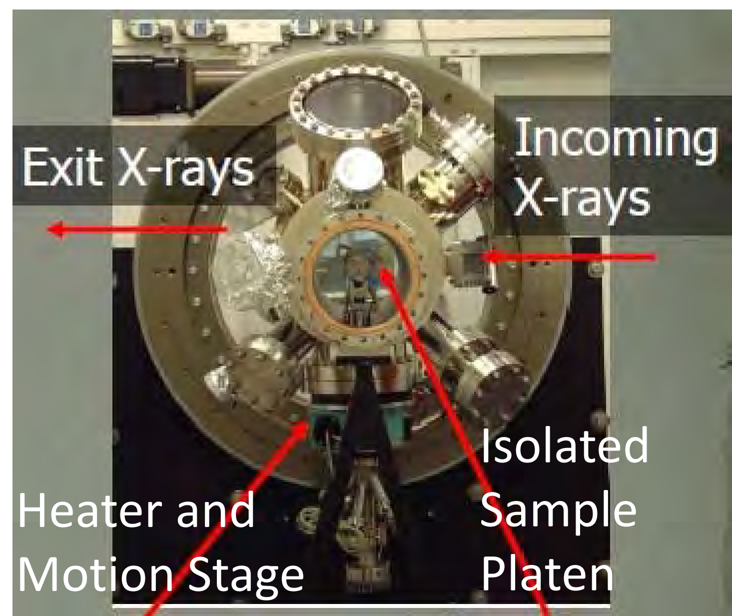
Deposition with *In Situ* Analysis

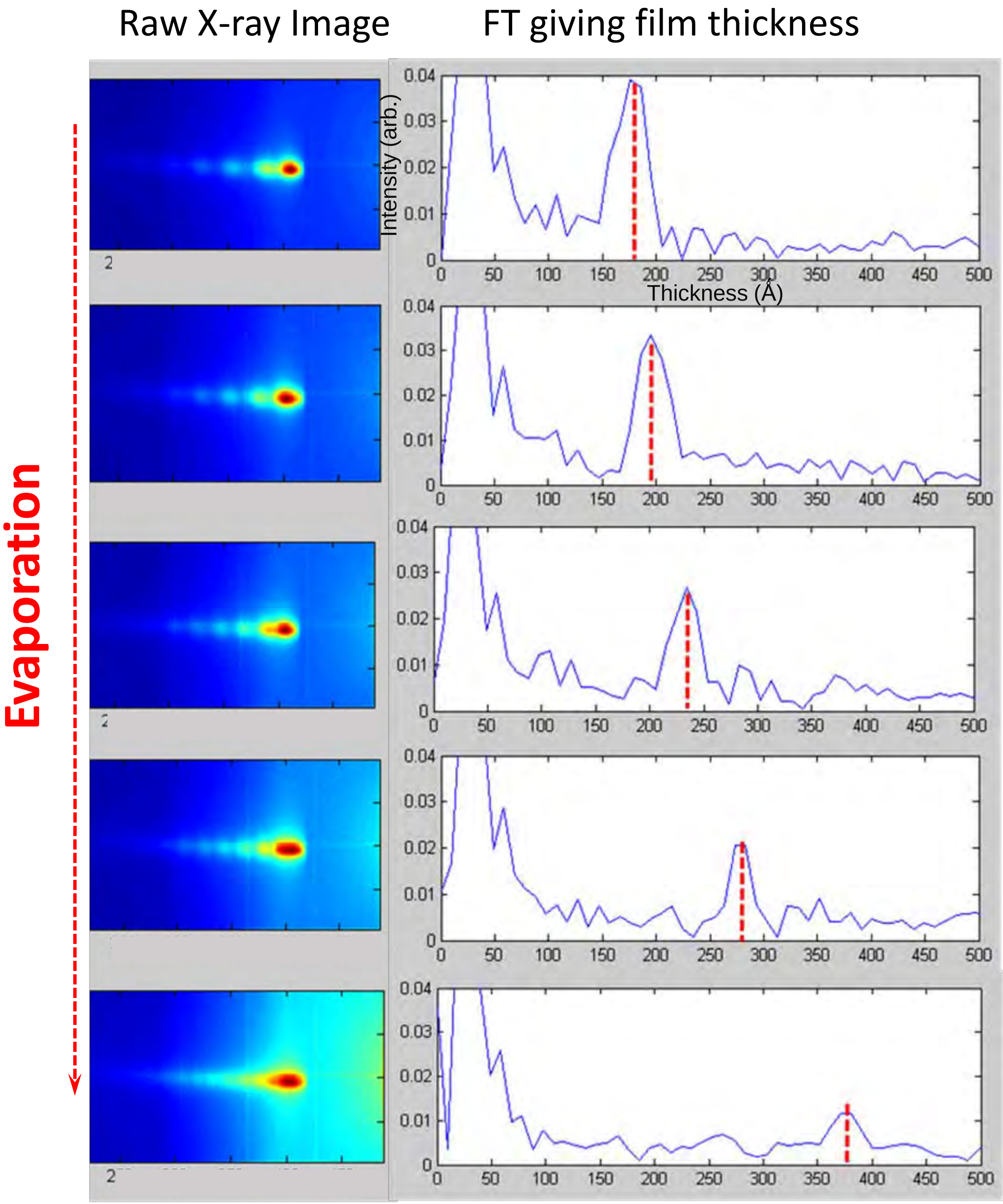


UHV system w/ Load Lock
Sb Line Source (evaporation)
Sb Sputtering
K and Cs Alvasources
SAES Getter Sources
Heat Cathode to 800C
Gas cooling
QE Measurement with 532 nm
Residual Gas Analyzer, Quartz FTM

In-Situ Diagnostics (during growth):

- Pilatus 100k X-ray camera
- XRD for grain size and orientation in plane and reflection geometry
- X-ray fluorescence for stoichiometry and contamination
- XRR for film thickness



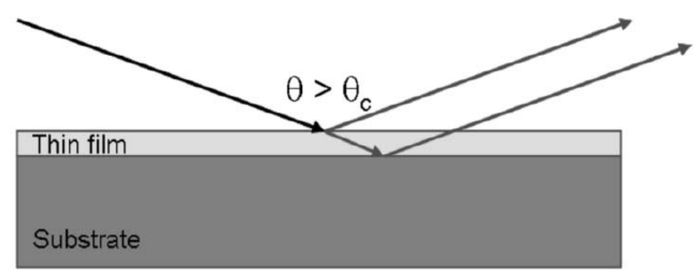


Pilatus 100k detector
4 degrees from normal
Grazing incidence X-rays

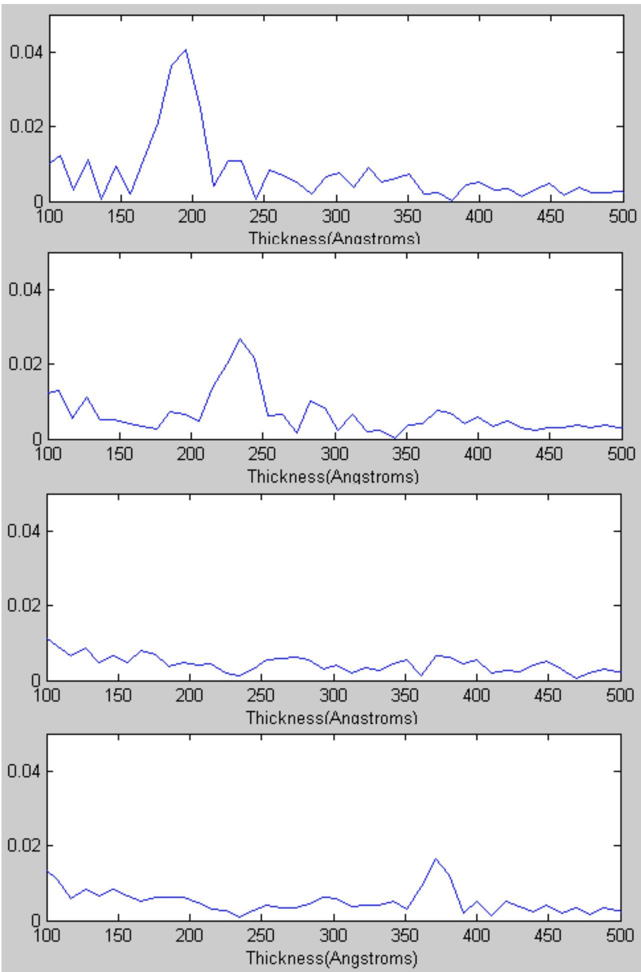
Interference between the top surface and bottom surface reflection

Fourier transform provides film thickness during deposition

SEM measurements gave a final film thickness of 39 nm (compared to 37 nm from XRR)



K-growth on Sb: One Example



Sb-film (18nm)

K-evaporation started

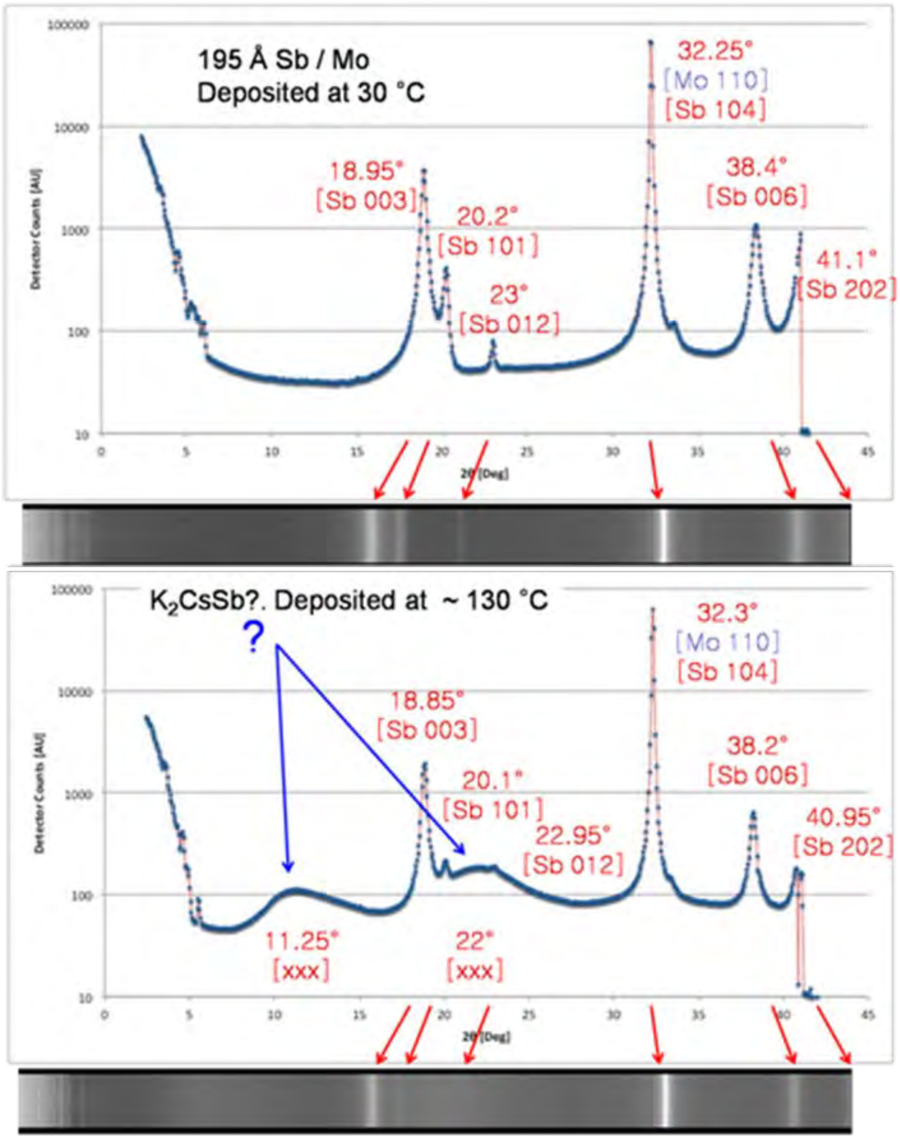
K-evaporation goes on

Final film

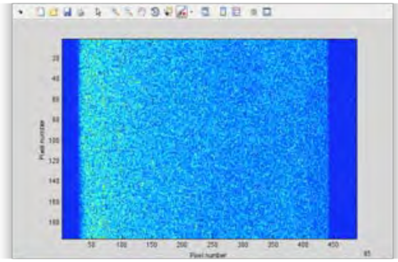
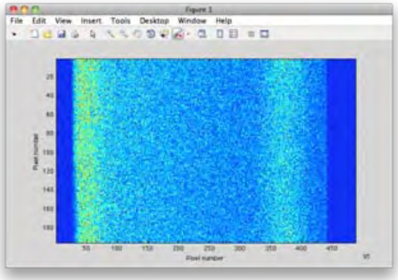
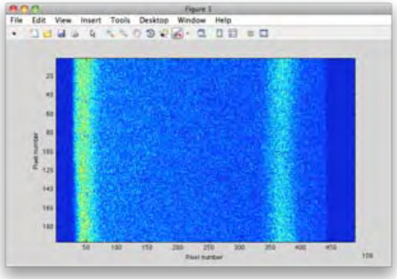
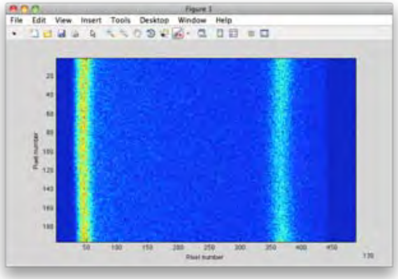
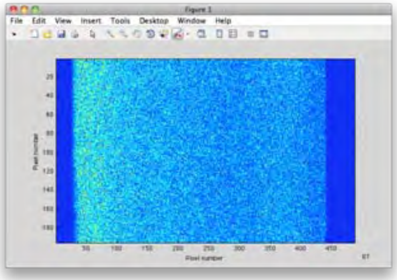
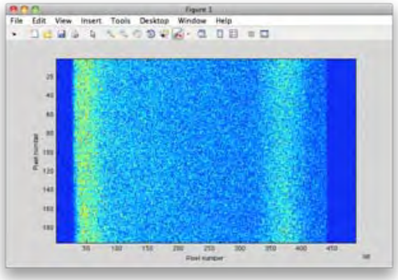
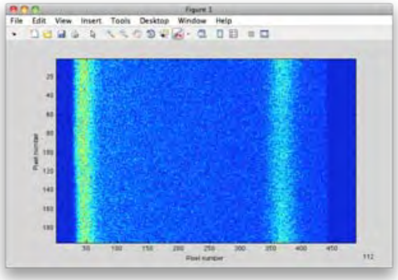
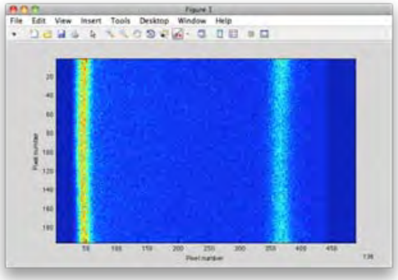
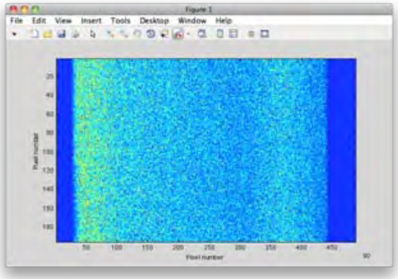
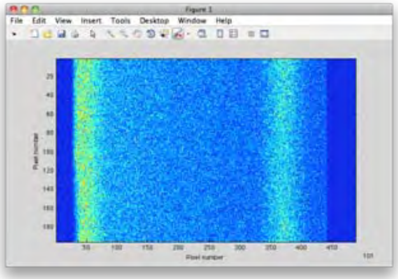
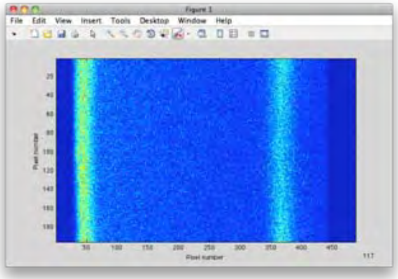
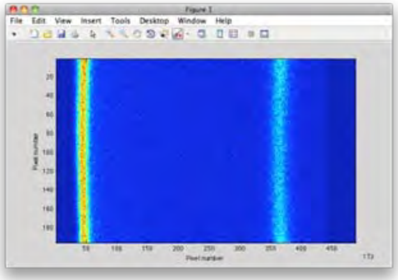
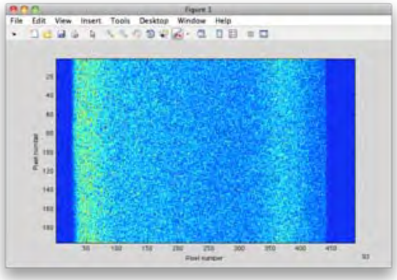
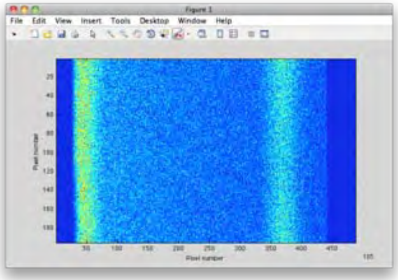
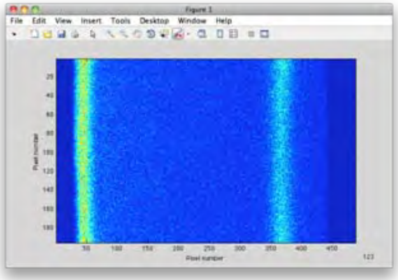
- *In-situ* sputtered Sb film (18 nm) – begin to observe fringes around 3 nm
- K-evaporation starts:
  - Roughness is increasing
  - Single peak shows that K instantaneously (1s) reacts and intermixes
- Ongoing evaporation of K:
  - Film shows large roughness (no peak)
- Final Film:
  - At 37 nm, roughness has decreased and peak reappears
  - Crystalline phase transition?

Currently in progress: More quantitative analysis and systematic recipe variations

In Situ X-ray Diffraction (XRD)

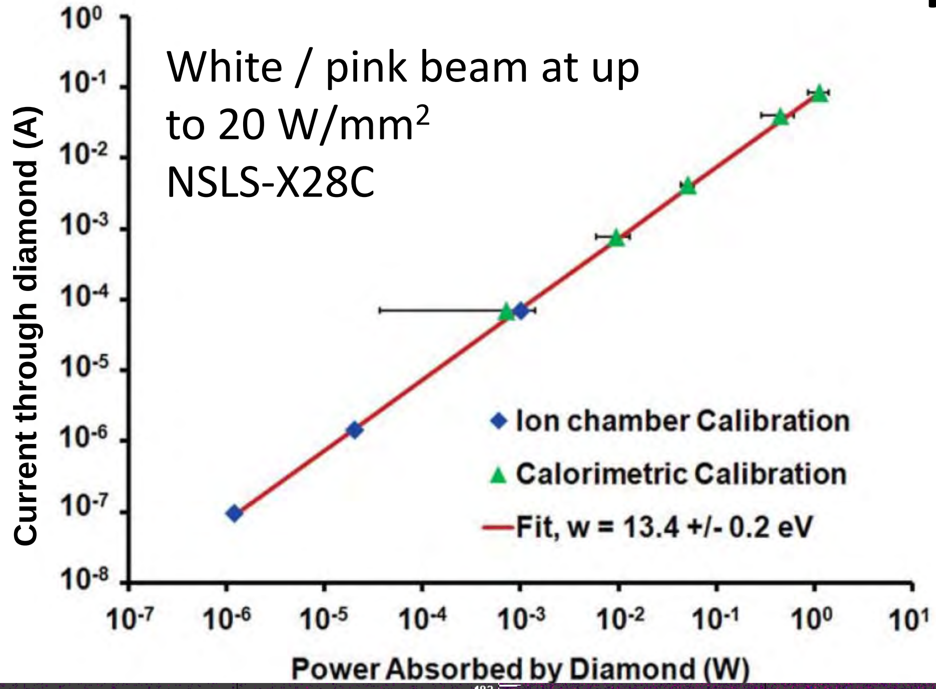


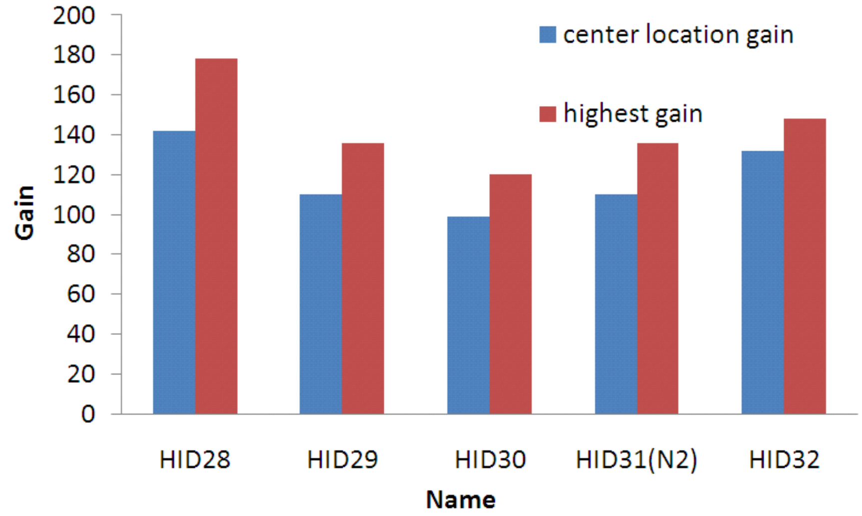
- High indexed peaks disappear:
  - Indication that crystallite gets smaller or very strained
- Sb peaks show reduced intensity
  - Smaller crystals but still Sb-phase present
- Strong background observable:
  - Not clear which $Cs_xK_ySb_n$-phases are produced
  - Is active cathode material in amorphous phase?
- Combined with XPS results, may suggest this cathode had insufficient K to react all of the Sb

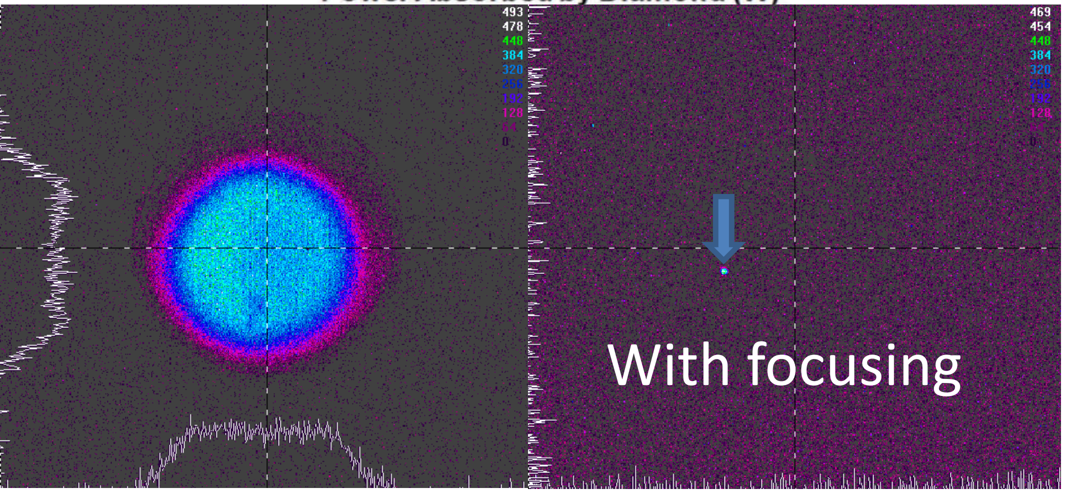
















42 nm final film thickness
Onset of crystalline structure ~8nm

Diamond Amplifier Results







Demonstrated emission and gain of >100 for 7 keV primaries

Emitting ~60% of secondaries

X-ray photons have been used to generate current densities in excess of 20A/cm^2 with no deviation from response linearity

X. Chang et al., Phys. Rev. Lett. **105**, 164801 (2010)
J. Bohon, E. Muller and J. Smedley, J. Synchrotron Rad. **17**, 711-718 (2010)

Currently Underway

Diamond

Effect of B doping on emission
Schottky barrier in diamond-metal interface (XPS)
Amplifier in SRF & NCRF guns

Alkali Antimonide

Determine the effect of micro-roughness on emittance
Substrate influence
Evaporation vs Sputtering
Optimize the crystal growth
  Larger grains -> higher QE?
Improve stoichiometry control
  XPS and XRF
New cathode for Jlab DC Gun tests

Next Steps

Cathode tests in the VHF gun and the SRF guns
Lifetime at high current
  Failure modes
O_2 and water chemistry
  XPS for surface oxidation?

Come to my poster for:

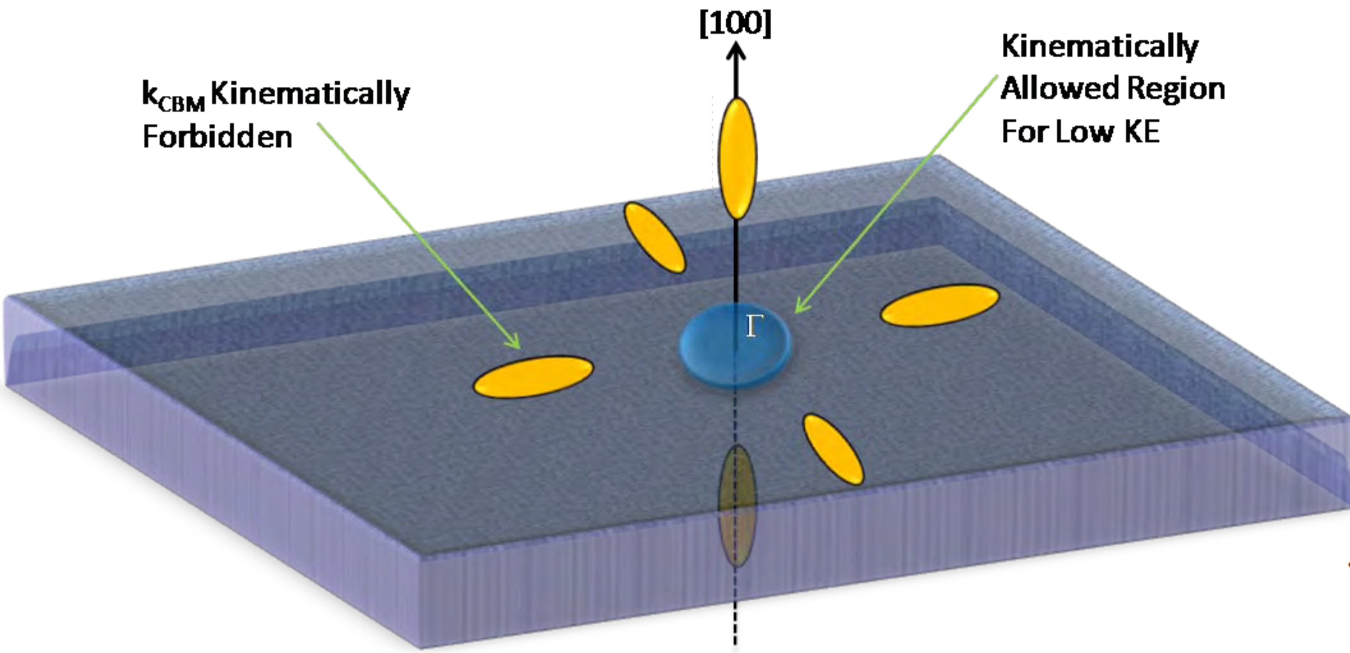
In-situ growth chemistry (XPS)
Why does diamond emit?

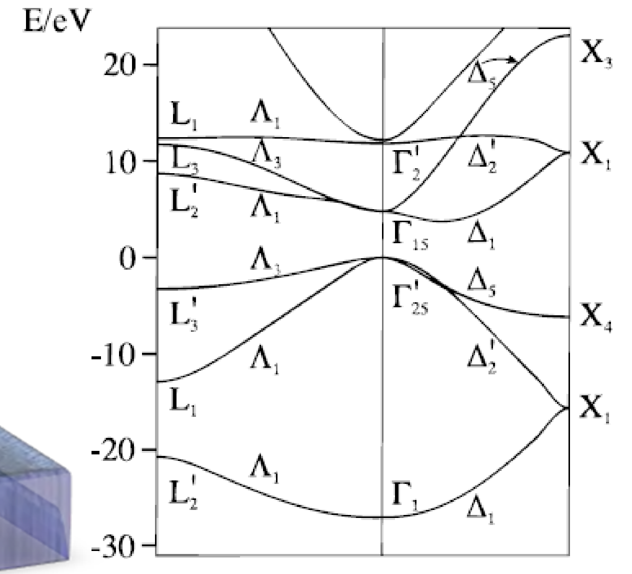
Publications

E. Wang, et al; Phys. Rev. ST Accel. Beams **14**, 061302 (2011)
D. A. Dimitrov, et al. ; Modeling and Simulations of Electron Emission from Diamond-Amplified Cathodes, PAC 2011
T. Vecchione et al; Appl. Phys. Lett. **99**, 034103 (2011)

Why Does Diamond Emit?

Projection of k-space onto [100] Surface





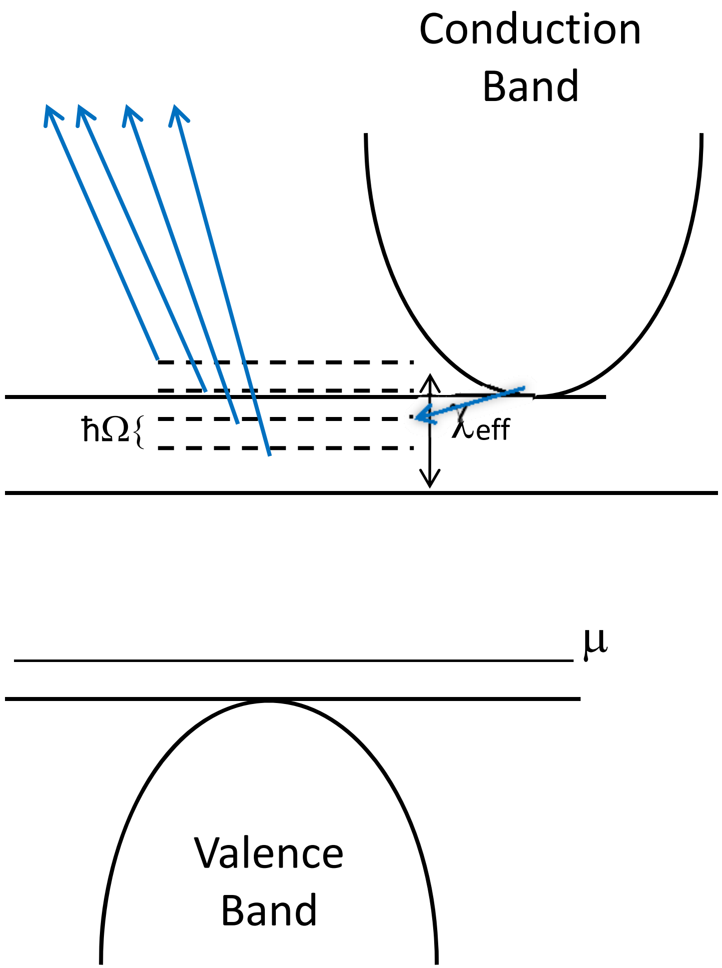
J. Phys. Chem., Vol. 100, No. 26, 1996

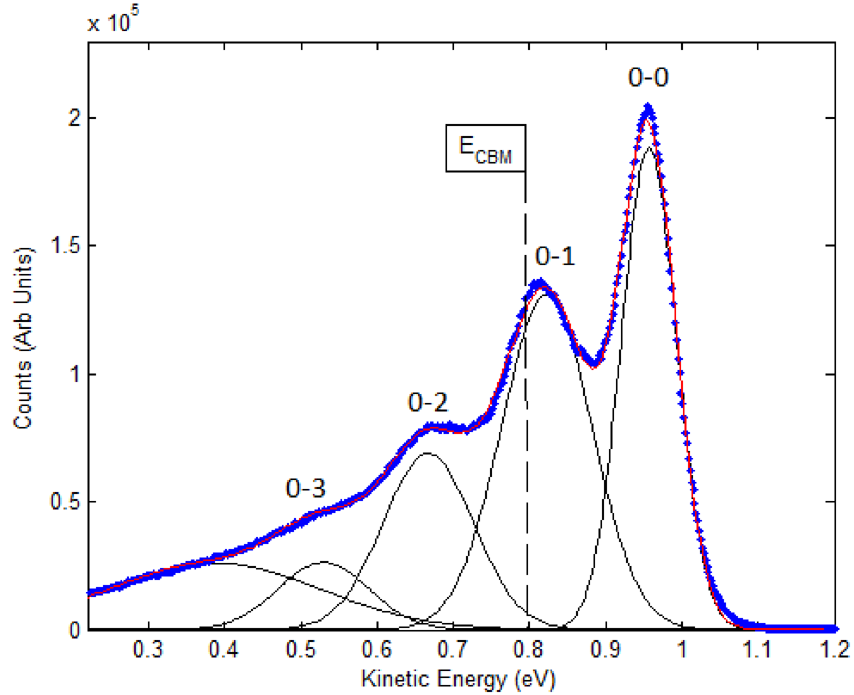
Hydrogen termination causes diamond to have a work function ~1 eV lower than its band gap **but** the band gap is indirect

Thus even electrons with energy 1 eV above the conduction band minimum are not in a momentum state capable of emission

This is the crux of the problem for Negative Electron Affinity Diamond

6 eV Laser ARPES





- E_F located at 1.662 eV according to Au reference!
- KE scale referenced to E_{vac} for NEA material; NEA = -0.955 eV
- Peak spacing 142±5 meV, consistent with the 145 meV energy of optical phonon which connects Γ to Δ

J. D. Rameau, et al., Phys. Rev. Lett. **106**, 137602 (2011)