Alkali Antimonide Cathodes

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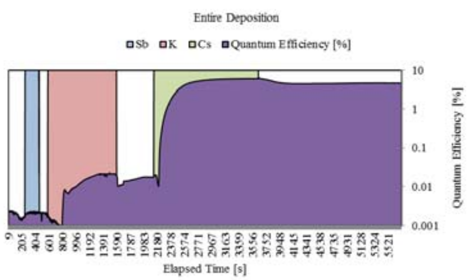
ABSTRACT

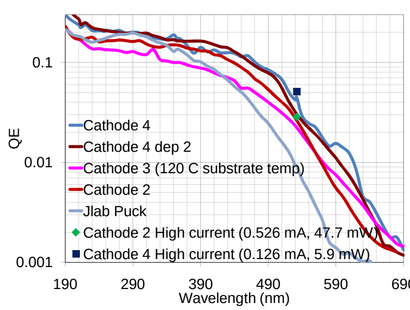
The alkali antimonides are capable of providing a high quantum efficiency (QE) under illumination by green light. These cathodes are attractive for high-average-current photoinjector applications, but have historically been plagued by extreme vacuum sensitivity, non-reproducibility and poor lifetime. We report on an ongoing effort to improve the performance of alkali antimonides (principally K_2CsSb) based on characterization of cathode formation during growth. Cathodes have been fabricated which have a QE of 6% at 532 nm. The films are much more resistant to oxygen / water than previously thought, with a 50% yield lifetime of 20 hrs at 2 pBar partial pressure of water. In-situ x-ray diffraction to has been used to compare grain size and texture in antimony layers, and energy dispersive x-ray spectroscopy has been used to characterize the formation of Sb layers on various substrates.

RECIPE DEVELOPMENT

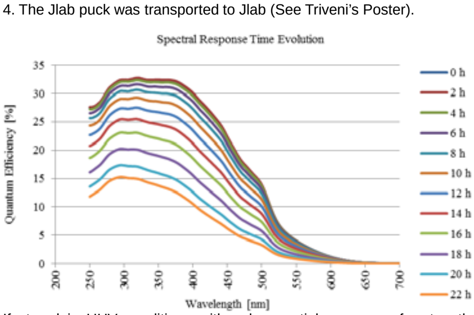


An example of a relatively simple recipe that produced a bi-alkali antimonide photocathode with 4.5% QE at 532 nm.
Mo Substrate heat cleaned @ 600C for 30 min
200 Å layer of Sb was deposited with Mo at 190 °C
K was evaporated at 140 °C to maximize yield
Cs was evaporated at 120 °C to maximize yield
Max QE was 6% at 532 nm, dropped to 4.5% during cooling

SPECTRAL RESPONSE

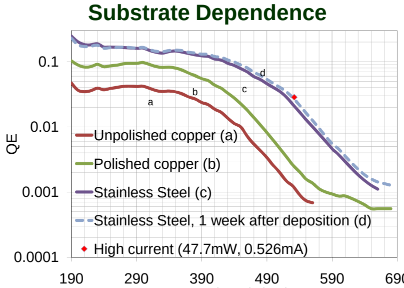


Cathodes grown with BNL system, using a similar recipe. 0.5 mA was extracted from cathode 2, and 1.3 mA/mm² was extracted from cathode 4. The Jlab puck was transported to Jlab (See Triveni's Poster).



If stored in UHV conditions with a low partial pressure of water, the response did not degrade with time, even over many months. In addition, when illuminated with a laser focused to a spot diameter of 100 mm, a current density of 1 mA/mm² could be maintained indefinitely. Large partial pressures of water (2e-9 mBar) cause a 50% drop in QE after 22 hours.

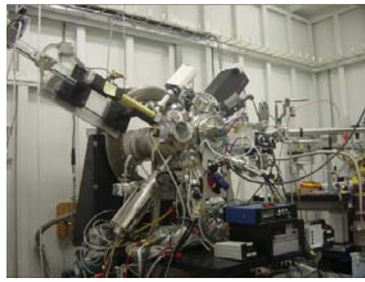
Substrate Dependence



Copper makes an especially poor cathode substrate, as it alloys with antimony at 150C. Stainless steel and molybdenum both yield good cathodes, though initial antimony adhesion can be difficult.

GROWTH SYSTEMS

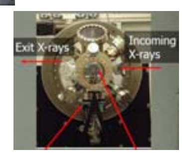
NSLS Beamline X21 – In-Situ X-ray Analysis



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

In-Situ Diagnostic capabilities (during growth):
- X-ray diffraction for grain size and orientation
- Diffraction can be performed in plane and in reflection geometry
- X-ray fluorescence for stoichiometry and contamination
- Reflection high energy electron diffraction

Other Capabilities:
- Pulsed Laser Deposition, Atomic Layer Deposition
- Ion Cleaning, Knudsen MBE cells



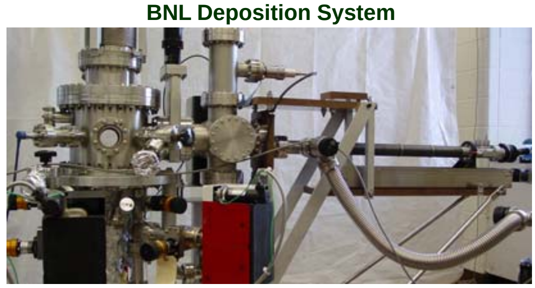
Heater and Motion Stage
Isolated Sample Platen

LBNL Programmable Deposition

UHV system
Horizontal deposition
Sb Pellet Source (Knudsen MBE cell)
K and Cs Alvasources
Heat Cathode to 600C
Gas cooling
UV-VIS light source (Energetiq)
Monochromator
- Can monitor QE during growth at any wavelength

Residual Gas Analyzer
Quartz Film Thickness Monitor (FTM)
Load Lock
Electron analyzer to measure transverse momentum
Entire system is computer controlled, allowing rapid recipe development

BNL Deposition System

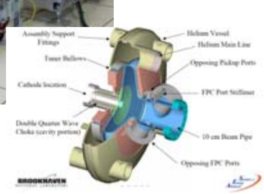


UHV system – typically 0.02 nTorr
Sb Pellet Source – Vertical Deposition
K and Cs Alvasources or Saes Getter Sources
Heat Cathode to 150C, Gas or LN cooling
UV-VIS light source (Ocean Optics) & Monochromator
Can monitor QE during growth with 532 nm laser
Reflection and transmission QE measurements
High power (50 mW) laser test chamber w/ anode
Residual Gas Analyzer & Quartz FTM
Load Lock with handoff - recently transported a cathode to Jlab

SRF Gun Tests

UHV system
Horizontal Deposition
Sb Pellet Source
K and Cs Alvasources
Saes Getter Sources
Heat Cathode to 150C
Residual Gas Analyzer
Quartz FTM

Transport Cart to introduce cathode into 700 MHz SRF Gun

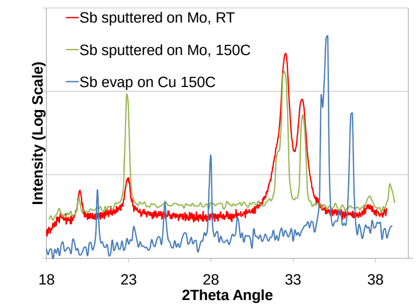


Eventual goal is to test cathode in SRF cavity, and use X21 diagnostic capabilities to determine failure modes

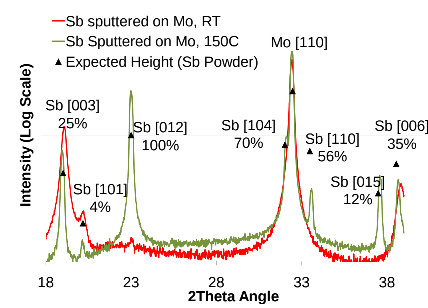
SUBSTRATE DEPENDENCE

Antimony Diffraction

Preliminary diffraction data has been obtained using two NSLS beamline (X20C & X21) of antimony films, both sputtered and evaporated.

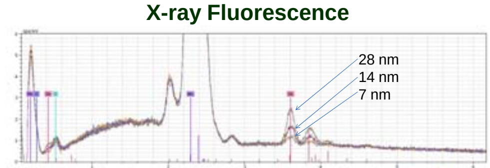


Sb in plane diffraction for Sb sputtered onto polished Mo substrates at room temperature and 150C. Sb evaporated onto Cu at 150 C is also shown – in this case the diffraction pattern shows no trace of Sb diffraction, as the Sb has completely alloyed with the Cu.

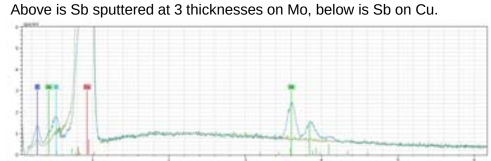


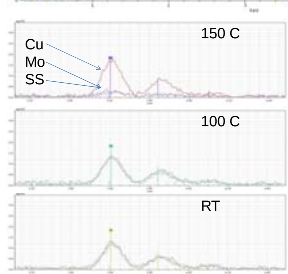
Sb out-of-plane (reflection) diffraction for sputtered Sb films on Mo. The expected peak heights for untextured Sb are shown. The room temperature substrate exhibits a clear [003] fiber texture (with a nearly complete absence of [012],[104] & [110]), while the 150C substrate is less clearly textured but has larger Sb grains (smaller peak widths).

X-ray Fluorescence



Energy dispersive x-ray spectroscopy (EDS) in a scanning electron microscope is used to measure the thickness and spatial uniformity of Sb films deposited on various substrates by evaporation and sputtering. Above is Sb sputtered at 3 thicknesses on Mo, below is Sb on Cu.





15 keV electrons used for all EDS spectra

EDS shows the thickness variation of antimony films simultaneously evaporated on copper, molybdenum, and stainless steel (SS). At 150C substrate temperature, the thickness on Mo and SS only 10% of that on copper (27 nm on Cu, 2.7 nm on Mo, 3 nm on SS). The coating thickness on SS and Mo is highly non-uniform. At room temperature and 100C, the thicknesses on all three substrates is equivalent (21 nm), and all three coatings are uniform to within 5%

CONCLUSIONS AND FUTURE

Brookhaven National Laboratory, Lawrence Berkley National Laboratory and Stonybrook have embarked on a collaborative effort to use the tools of modern user facilities to understand and improve the performance of accelerator photocathodes. The growth of the cathodes will be studied with in-situ x-ray analysis; diffraction will be used to understand grain size and texture, and fluorescence will be used to look at stoichiometry and contamination. This program will involve testing these cathodes in RF photoinjectors and returning them to the diagnostic tools for post-operational analysis. Cathodes with 6% quantum efficiency have already been achieved, and methods have been investigated to control the antimony film crystalline properties. The cathodes have been found to be quite robust, operating for weeks at 1 mA/mm² current density, and demonstrating a 50% yield lifetime of 20 hrs at 2 pBar partial pressure of water.

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