**Abstract**

Enhancing the lifetime of cold cathode performance requires that radical improvements in high quantum efficiency and lifetime be achieved simultaneously. Previous advances have been made in delivering increases in efficiency, but at considerable expense of the other. This combined with the competing physical processes underlying traditional approaches to cathode design and optimization. In pursuit of this goal, the unique approach here aims to decouple the competing mechanisms so that both high efficiency and long lifetime can be achieved via integration of atomically thin two dimensional (2D) nanomaterials with high-performing existing photocathode technologies.

**Driving Science Question**

The required advances in cold cathode performance require that radical improvements in lifetime and efficiency be achieved simultaneously. Previous work has successfully deposited Bialkali antimonide photocathodes on free-standing atomically thin substrates of graphene. This advances an ultimate goal of enhancing the lifetime of photocathodes without sacrificing the high quantum efficiency by using an atomically thin protection layer.

**Background**

**High quantum efficiency (QE) ...but susceptible**

Semiconductor antimonide cathodes performance

Cathodes lifetime versus water pressure

**Atomically thin protection!!**

Our project concept

**Our project goal**

**Signature feature for K₂CsSb was observed at ~2.4 eV (black arrow). Extracted work functions were all consistent with a value for K₂CsSb, which were 2.8, 3.8, and 3.8 eV for graphene, SiS, and Ni substrate regions, respectively, as shown in inset.**

**Synchrotron XRD (CHESS)**

**Synchrotron XRF (CHESS)**

**Concluding Summary**

In summary, Bialkali antimonide photocathodes were successfully grown on freely suspended graphene substrates of few monolayer thickness. The large-area uniformity, quantum efficiencies, specific spectral response features, and comparisons to experimental reference standards and calculation results all indicate a high compatibility of the photocathodes with thin graphene layers. Additional material characterization using XRD and XRF directly revealed grains of K₂CsSb in such photocathodes when deposited on graphene, further supporting this compatibility. Variations in the number of graphene layers, their stacking methods, and additional pre-deposition annealing variations had small effects on the QE magnitudes of the resultant photocathodes, yet highlighted areas for measurable improvements by minimizing defects in the graphene films. The results demonstrate that high QEs can be achieved for K₂CsSb on thin graphene substrates that are as thin as three atomic layers. This is a promising step toward fabrication of photocathodes with enhanced lifetimes via atomically thin protection layers as well as photocathodes on optically transparent yet electrically conductive substrates.