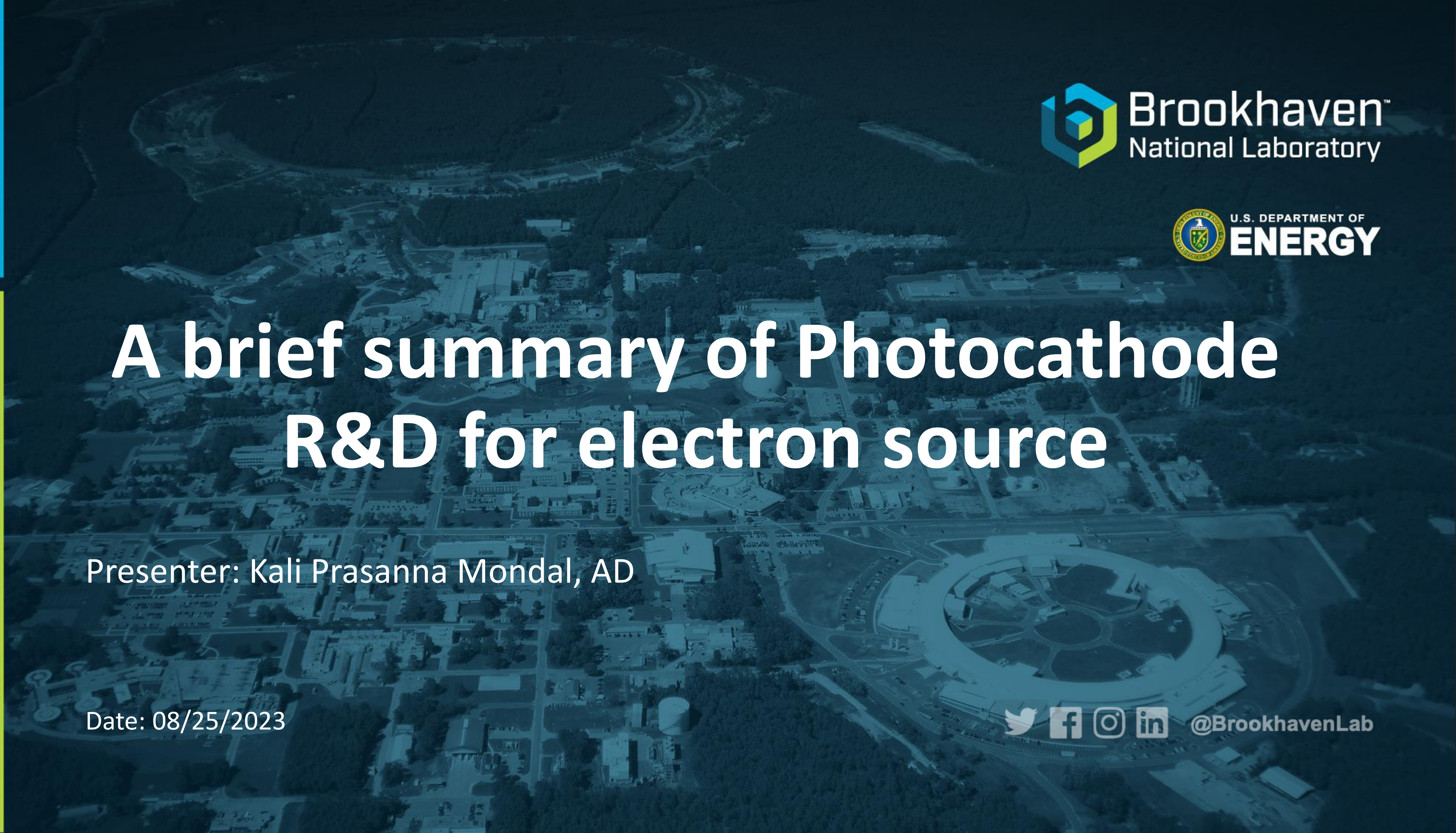

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U.S. DEPARTMENT OF ENERGY

A brief summary of Photocathode R&D for electron source

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Photocathode

- ❑ Photocathode: Convert photon to electron (photoelectric effect), electron emit in vacuum
- ❑ Cathode is the origin of the generated electrons and can be a metal, a semiconductor.
- ❑ The thermionic and the field emission are mature methods and work robustly. However, photoemission offers more advantages, for example that the electron bunches can be time structured
- ❑ The choice of suitable photocathodes for high-brightness electron beams depends on many factor: a high quantum efficiency (QE) at convenient laser wavelength, long lifetime, fast response time and low thermal emittance.
- ❑ Metal cathodes such as copper (Cu), magnesium (Mg) and lead (Pb) are used as the first cathodes when an accelerator facility is commissioned. But the fast development of the particle accelerator devices and the strong desire to achieve higher bunch charges and currents leads to the usage of semiconductor photocathodes such as cesium telluride (Cs_2Te), alkali antimonide (K_2CsSb) or gallium arsenide (GaAs).

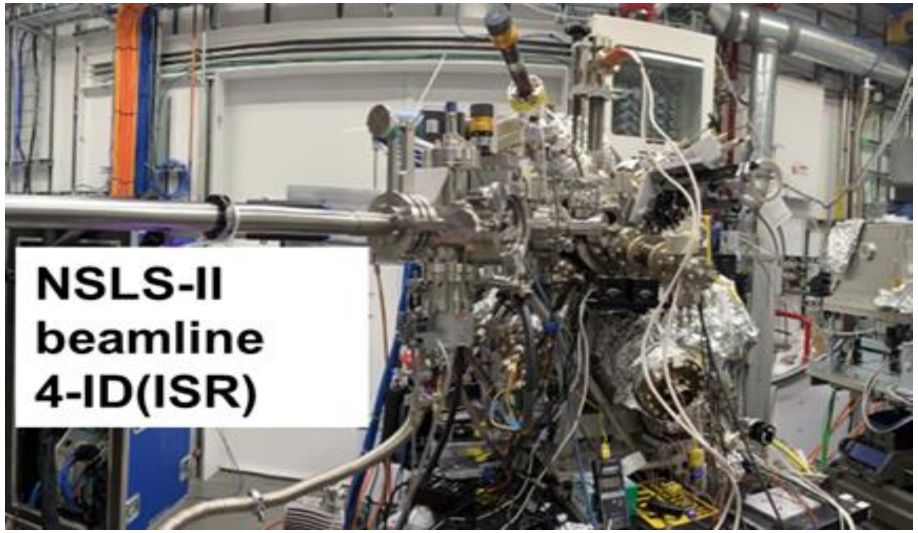
Epitaxial growth of Photocathode

- ❑ Epitaxy: The name epitaxy has Greek roots: “epi” means “on” and “taxis” means “in ordered manner”. Epitaxy refers to the growth of a single crystalline film on a single crystalline substrate.
- ❑ Epitaxial Growth of Photocathode: Large or single crystal photocathode generate low mean transverse energy due to smooth surface and low grain boundary scattering rate.
- ❑ Epitaxial growth with lattice matching substrate is essential to make large/single crystal photocathode.

Our goal

- ❑ Our main goal is to grow epitaxial semiconductor photocathodic thin film and achieve high quantum efficiency.

The BNL UHV photocathode growth system at beamline 4-ID, Integrated In situ and Resonant Hard X-ray Studies (ISR), NSLS-II for in situ and real time x-ray characterization. schematic of X-ray techniques (XRR, XRD, GISAXS, XRF) used to characterize the photocathode properties.

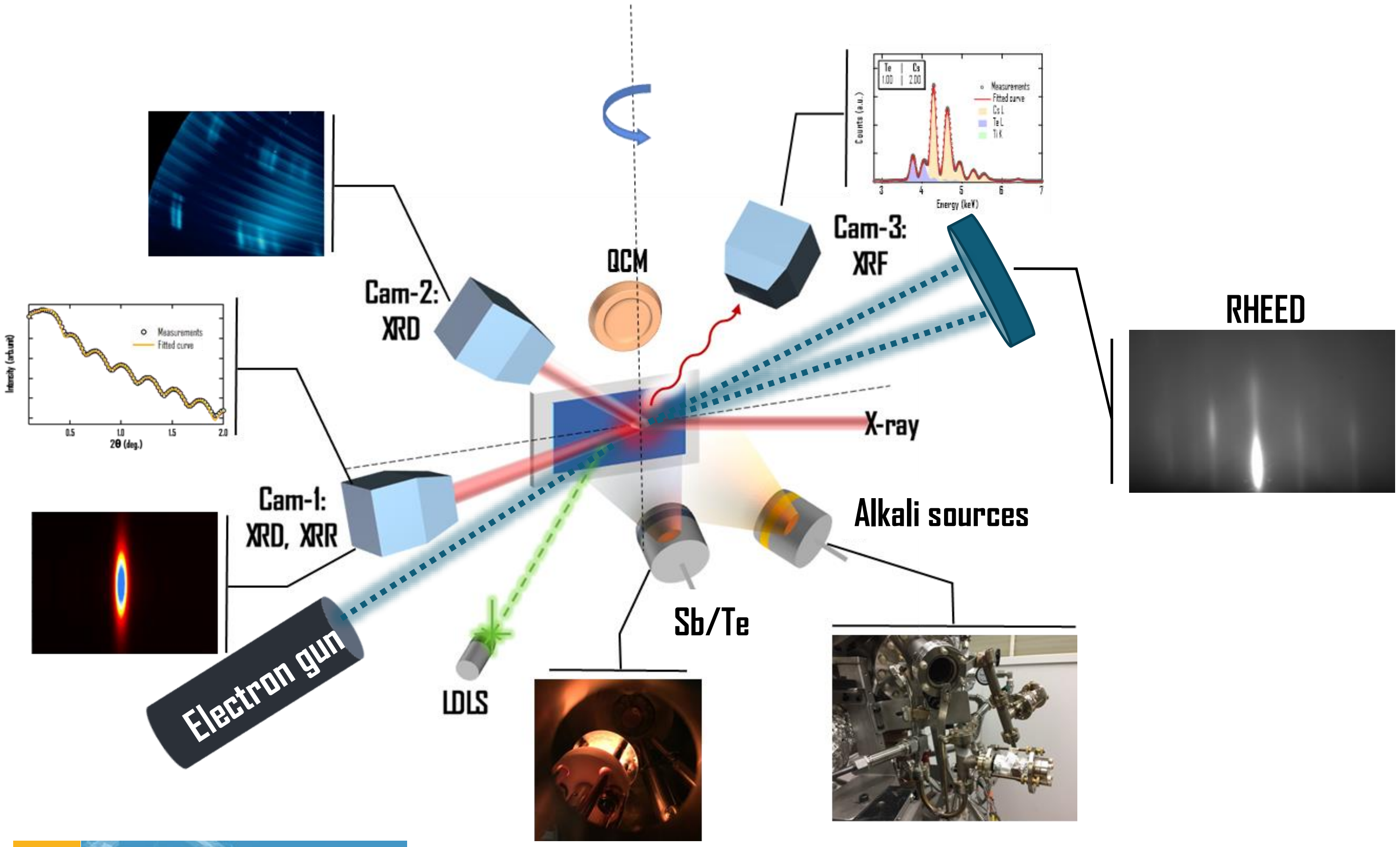


Evaporators:

- Thermal Sb/Te
- Alkali metals
- PLD Sb/Te

Characterization:

- QCM
- XRD
- XRR
- GISAXS
- XRF
- QE
- RHEED



4-ID ISR
NSLS-II National Synchrotron Light Source II

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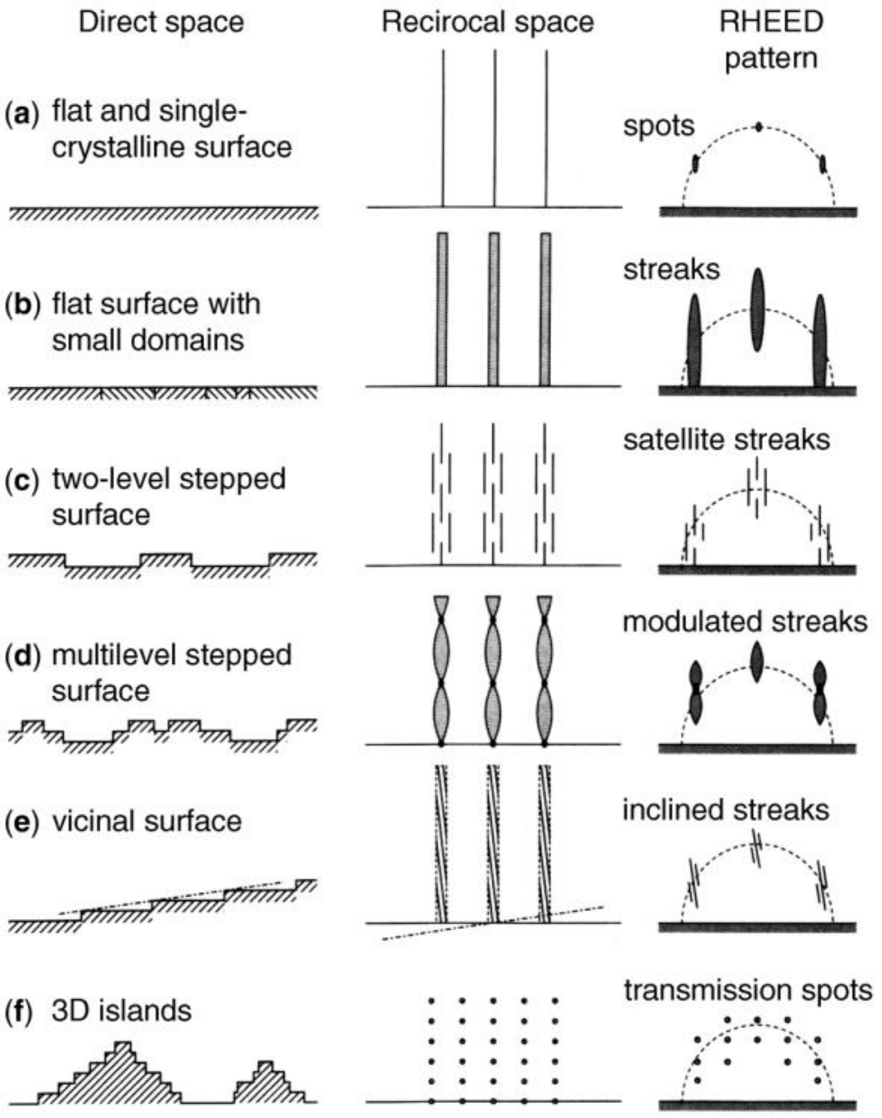
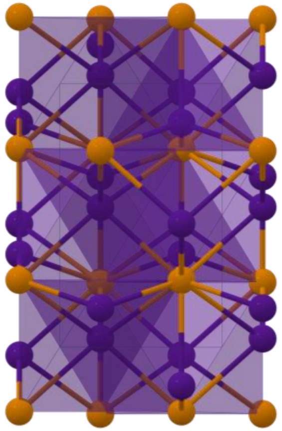
RHEED of Photocathode

- ❑ RHEED provides -surface symmetry, real space lattice spacing, crystalline degree of perfection
- ❑ Photocathodic thin film, K_2CsSb, Cs_3Sb, Cs_2Te grown on 4H-SiC, Graphene/4H-SiC, 3C-SiC.
- ❑ RHEED has been performed after completion of each growth.
- ❑ Our goal is to
  - ➢ Study crystalline structure of photocathodic thin film after each growth
  - ➢ Also, study of angular dependence of crystalline structure with in-plane rotation
  - ➢ Find out lattice mismatch, strain of thin films

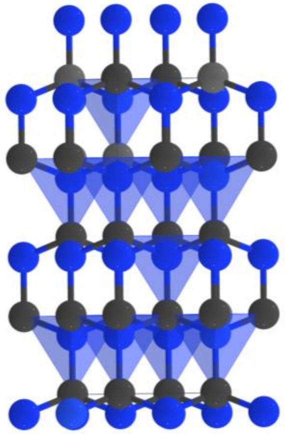


Schematics of various kinds of realistic surfaces, in real-space morphology, in reciprocal space, and their RHEED patterns [Hasegawa, 1925]

Cs_2Te,
Orthorhombic



4H-SiC (0001),
Hexagonal



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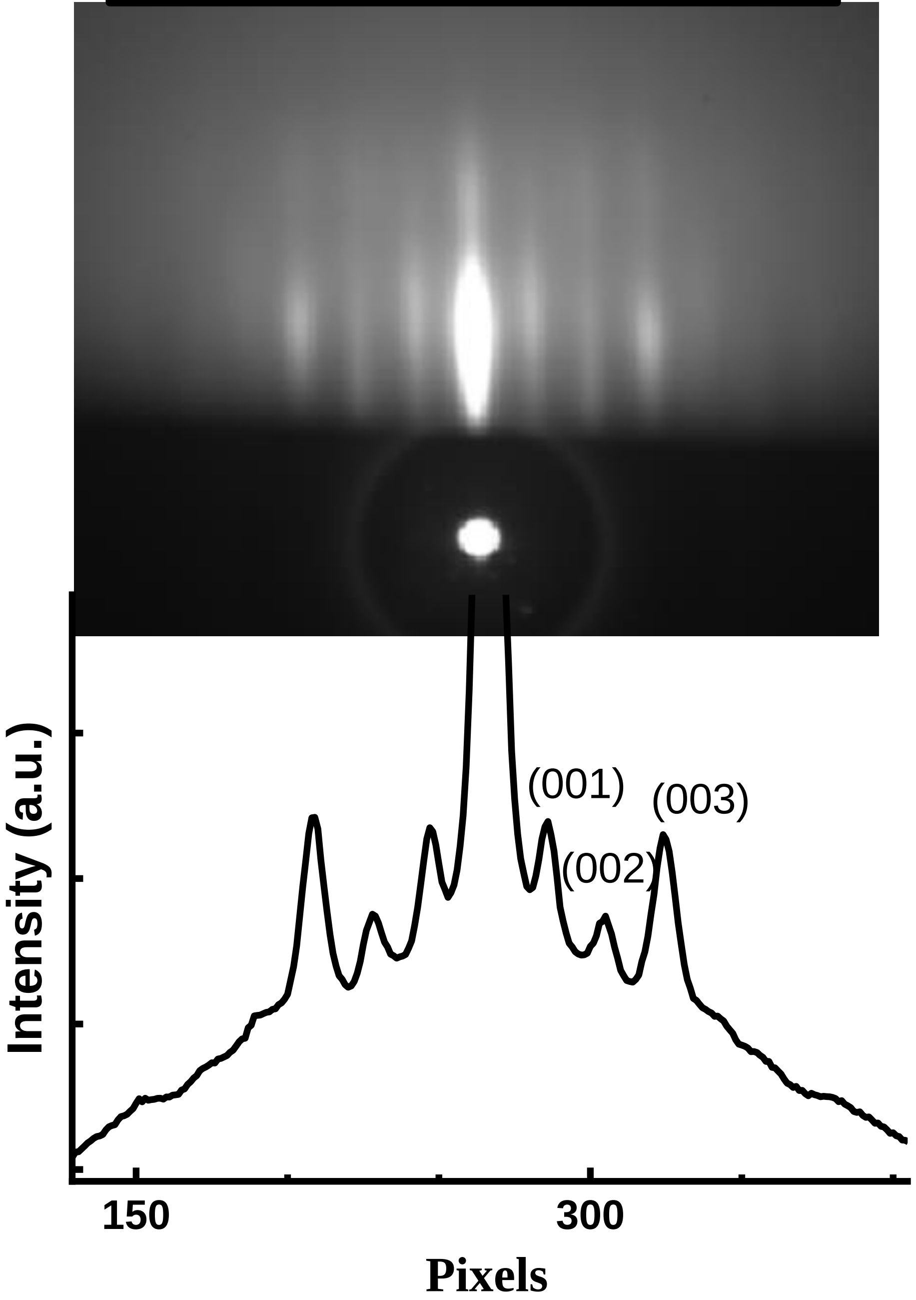
RHEED of Cs_2Te/4H-SiC

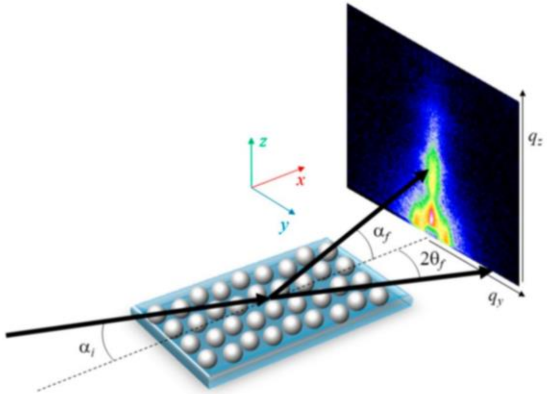


RHEED of Cs_2Te/4H-SiC

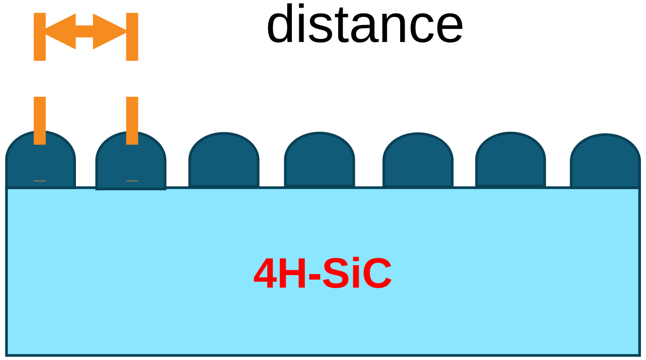
- RHEED image shows epitaxial growth.
- Streaks represent smooth surface with small domains.

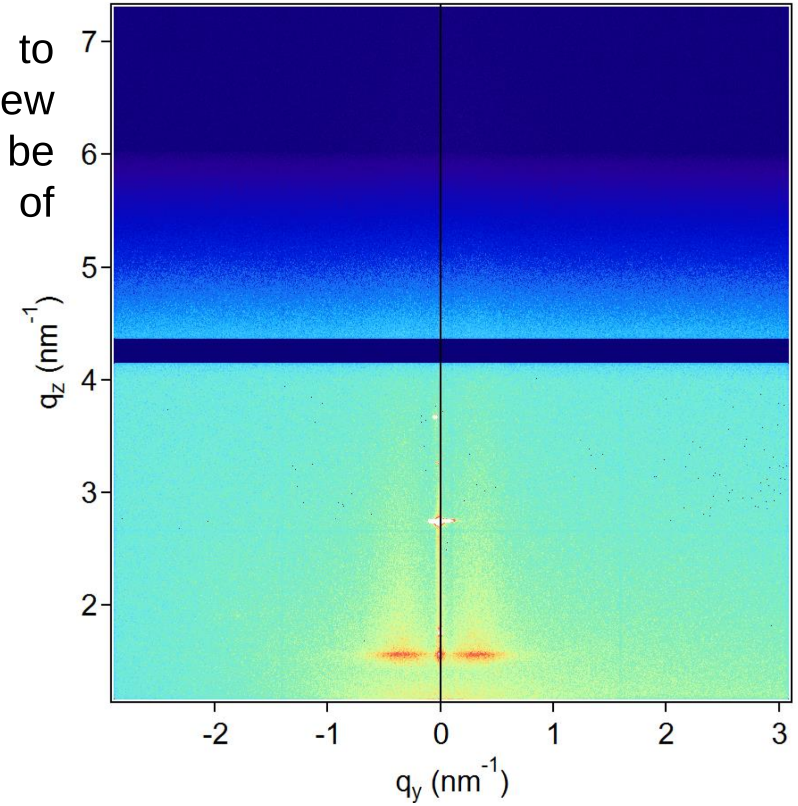
GISAXS: Photocathode on single crystal

- ❑ Morphology and distribution of either islands on a substrate or buried particles.
- ❑ Structural details of thin film like correlations, Shape, Size of density inhomogeneities at surfaces or at buried interfaces.
- ❑ Depth sensitivity from surface to buried interfaces up to a few hundreds of nanometers can be probed by varying the angle of incidence.

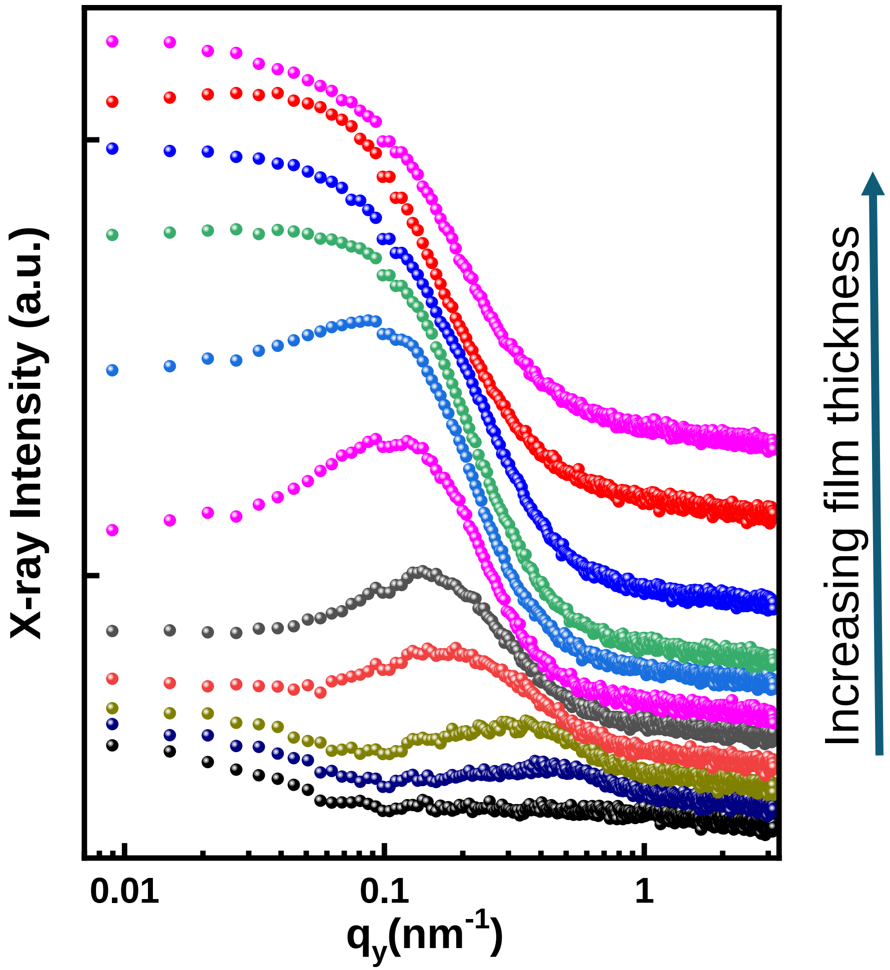


L , Average particle distance





GISAXS of Cs_2Te/4H-SiC



GISAXS of Cs_2Te/4H-SiC

- ❑ Average particle distance increase from 14 nm to 157 nm.
- ❑ Layer by layer thin film is forming.

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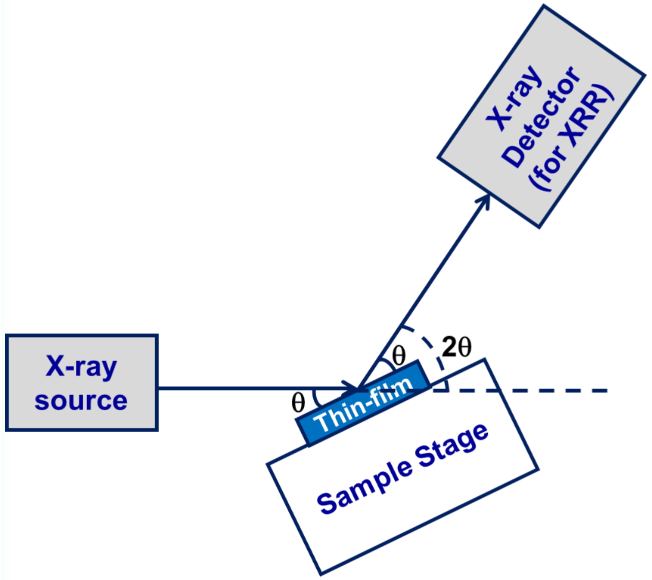
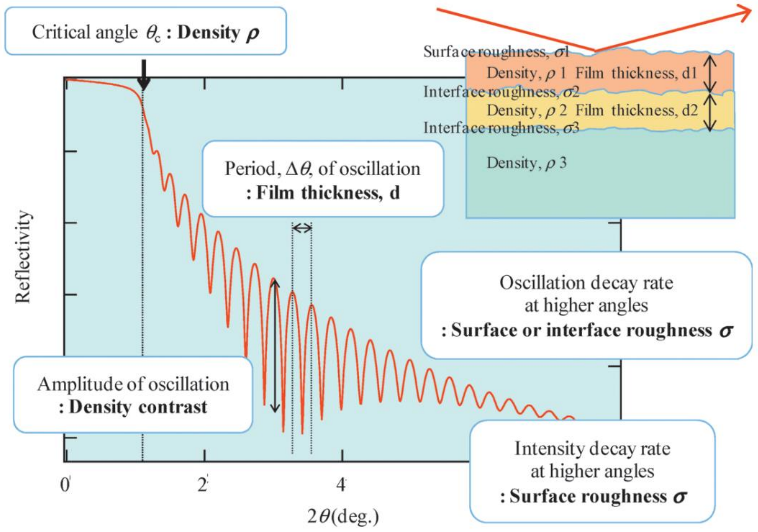
XRR of Photocathode

XRR provides thin-film’s

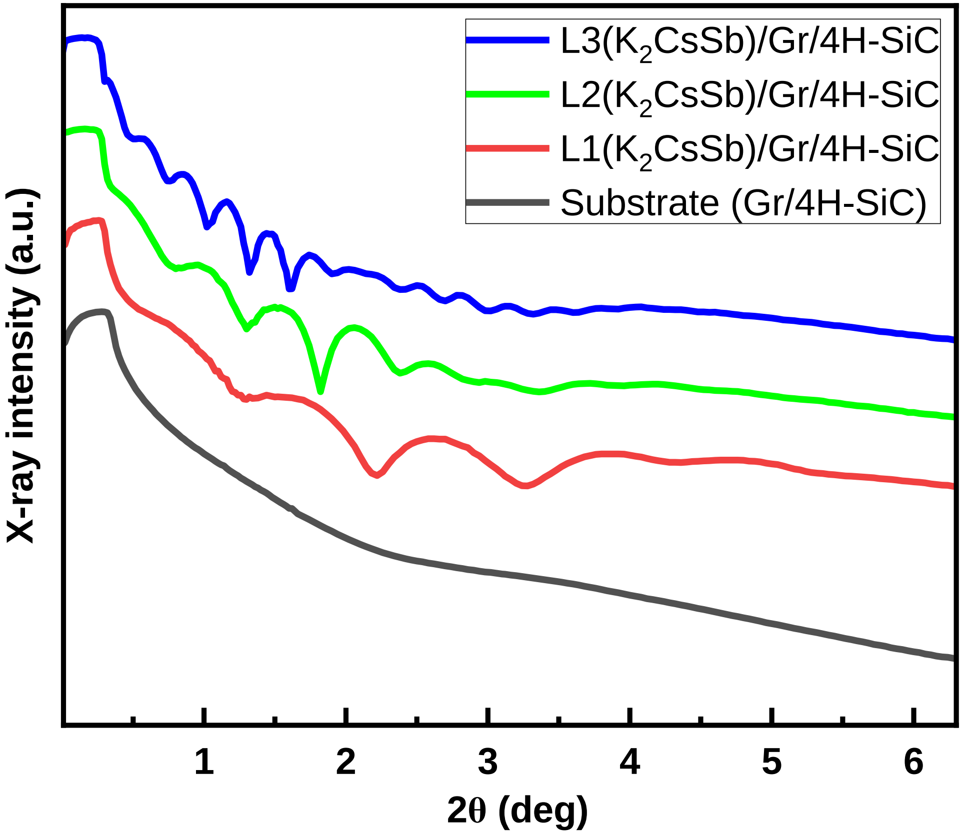
- Film thickness ∝ 1/Δθ
- Electron density (ρ_e), $\theta_c \propto \sqrt{\rho_e}$
- Roughness, R_{flat}*exp($-4kz^2\sigma^2$)



Schematic of XRR



Information provided by XRR [Yasaka, 2010]



XRR of K_2CsSb

- L1 thickness ~5.8 nm, L2 thickness~ 12 nm, L3 thickness ~ 22.5 nm.

Conclusion

- ❑ Successful in growing epitaxial thin film of photocathode.
- ❑ RHEED provides
  - ➢ Epitaxial growth of photocathode
  - ➢ Film is forming is smooth
- ❑ GISAXS provides
  - ➢ Layer-by-layer growth
- ❑ XRR provides
  - ➢ Photocathodic film thickness, roughness, electron density
- ❑ QE measurements provide QE of photocathodic thin film.
- ❑ XRD provides crystalline structure not only from the surface but also from bulk.

Thank You

I want to thank my Supervisor Dr. Mengjia Gaowei and our group members of our electron source group.