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U.S. DEPARTMENT OF ENERGY

EWPPA 22, Milano, Italy

High crystalline cesium telluride photocathode on atomically thin graphene via co-deposition

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Sep. 22, 2022

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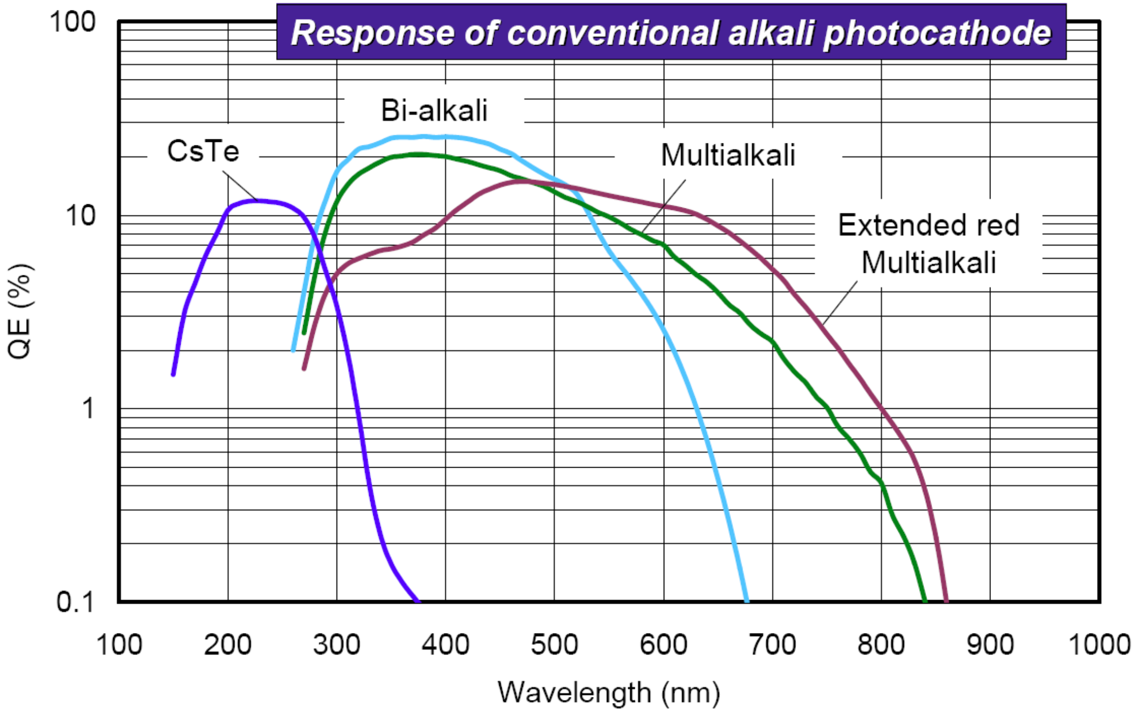
Introduction: CsTe photocathode as electron source

- Cesium telluride (CsTe) photocathodes has been the first hand choice for electron sources by worldwide accelerators, such as LCLSII, AWA, various FELs, etc...

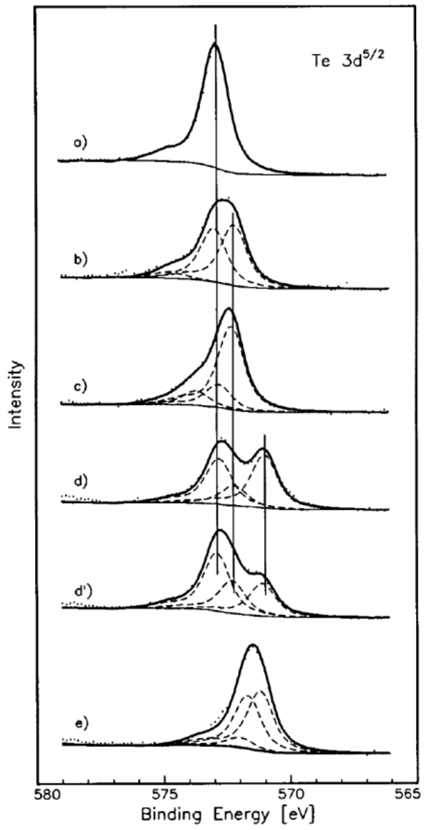
- Perfect balance between lifetime and quantum efficiency

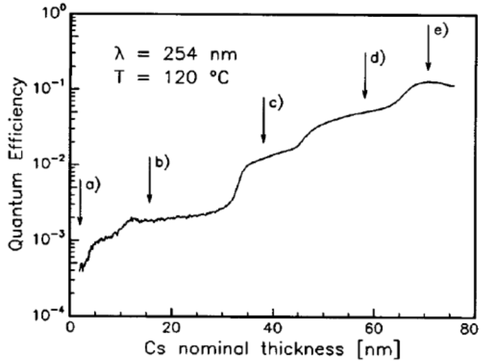
- Less requirement of vacuum level than GaAs and multialkali photocathodes, robust in high gradient environment



Characterizing the deposition of Cs-Te

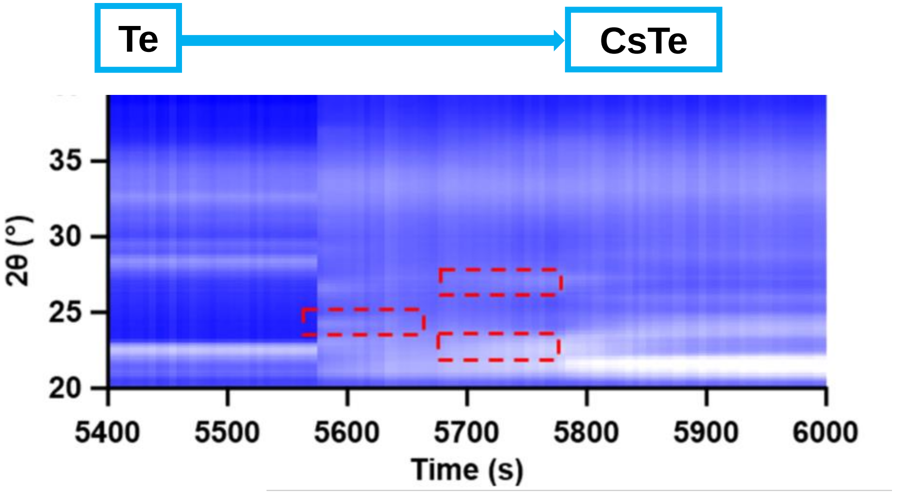
Sequential growth: 10 ~ 20 nm of Te + 60 ~ 80nm of Cs @ 120 °C → QE : 15 % ~ 18% @ 250 nm

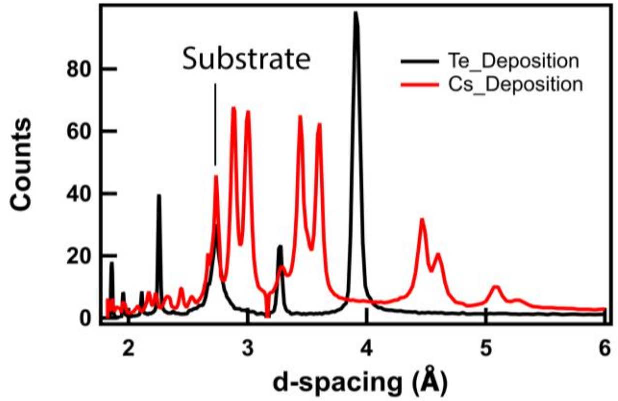




A. di Bona *et al*, Auger and x-ray photoemission spectroscopy study on Cs2Te photocathodes, *Journal of Applied Physics* 80, 3024 (1996)

X-ray diffraction analysis



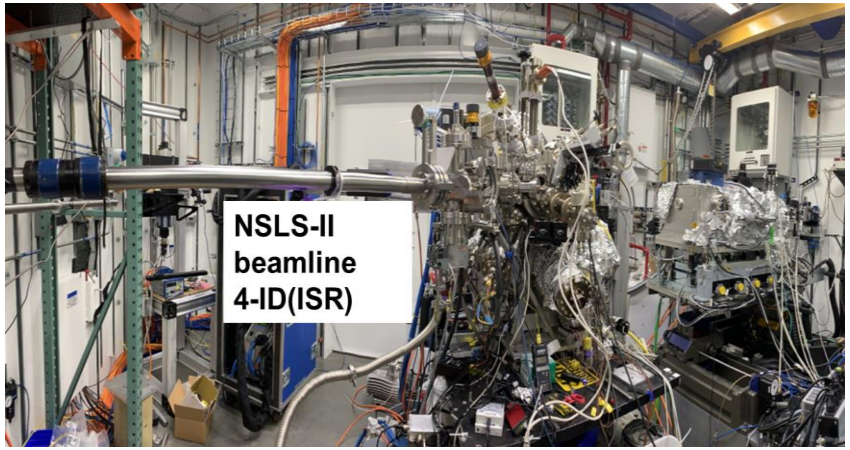


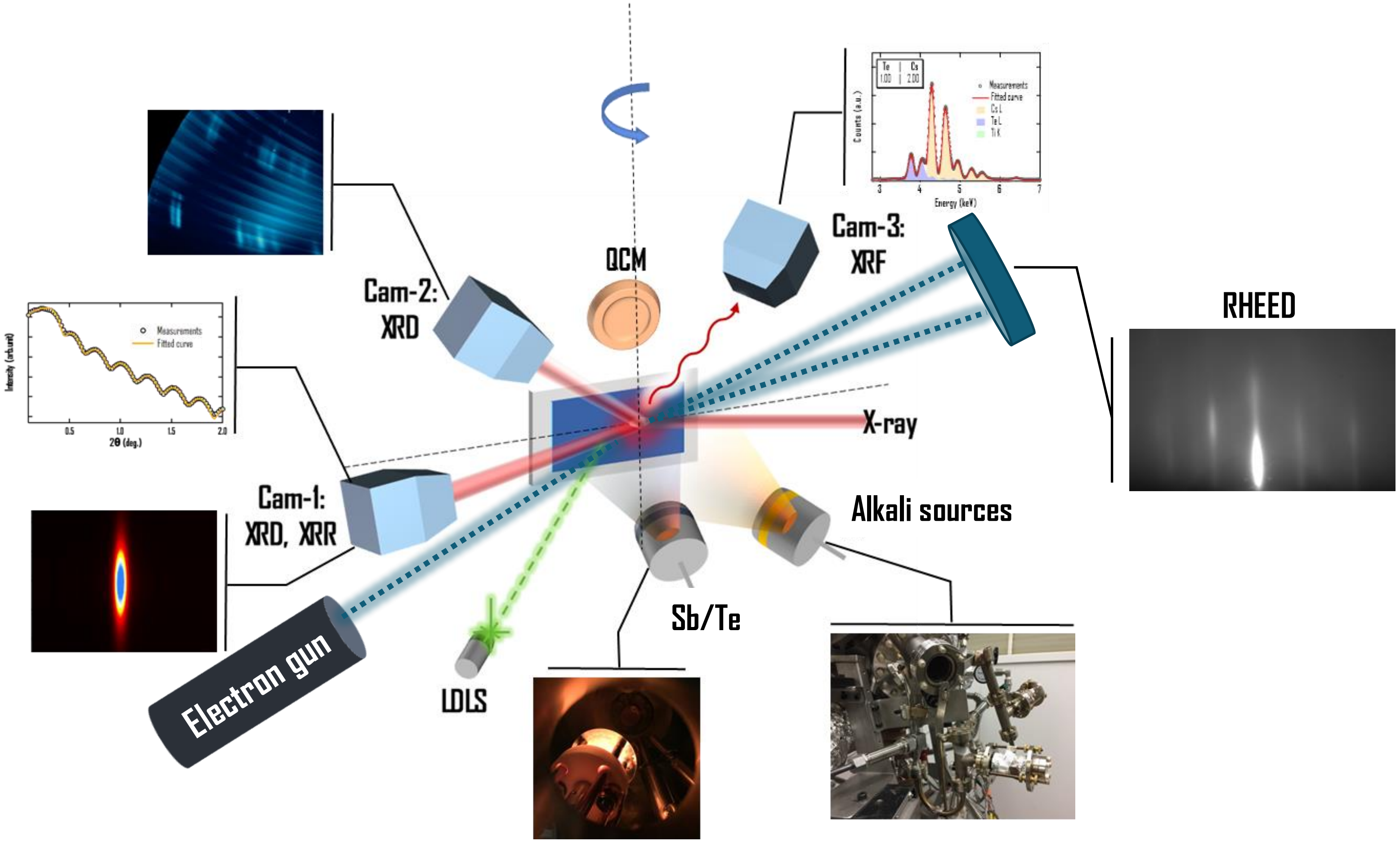
- ❑ Intermediate phases appeared and disappeared, then a stable product of CsTe forms.
- ❑ Nearly all of the crystalized Te are dissolved.
- ❑ Low counts in diffraction peaks
- ❑ Multiple phase of Cs-Te compound co-exist

M Gaowei, J Sinsheimer, D Strom, J Xie, J Cen, J Walsh, E Muller, J Smedley, "Codeposition of ultrasmooth and high quantum efficiency cesium telluride photocathodes", Physical Review Accelerators and Beams, 2019, 22, 073401.

INFN

Cathode Material development @ BNL





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

Characterization:
- QCM
- XRD
- XRR
- XRF
- QE
- RHEED

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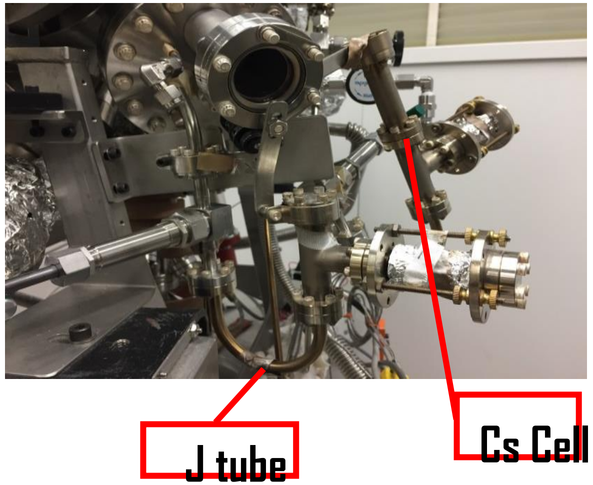
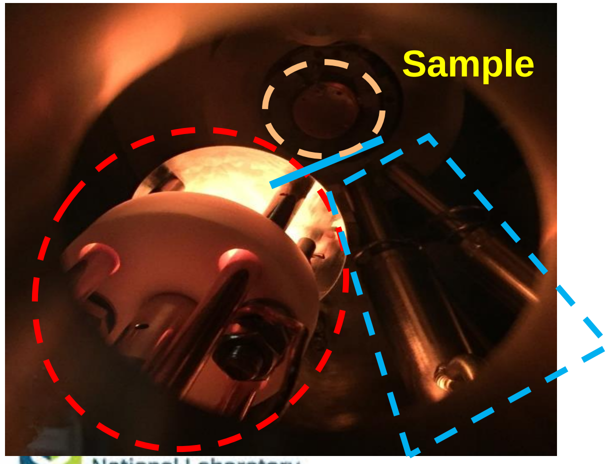
Co-deposition of Cesium telluride

Cs effusion cell

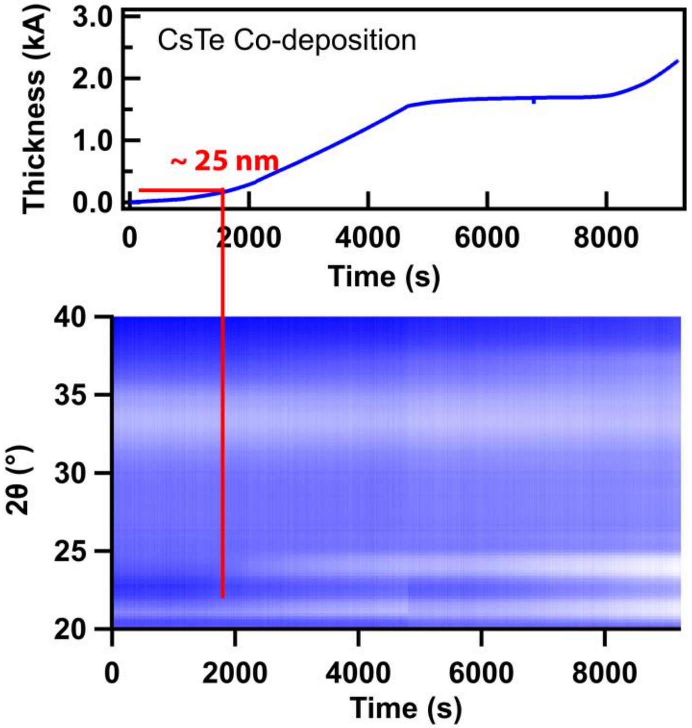


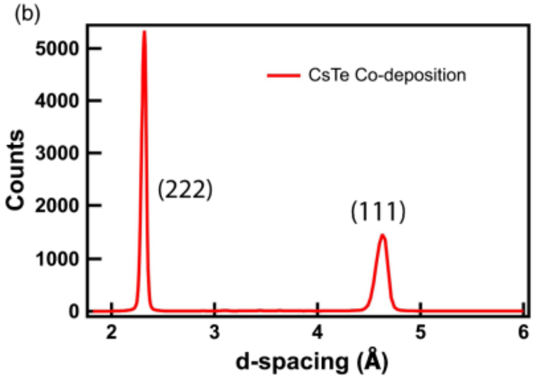
Te evaporator



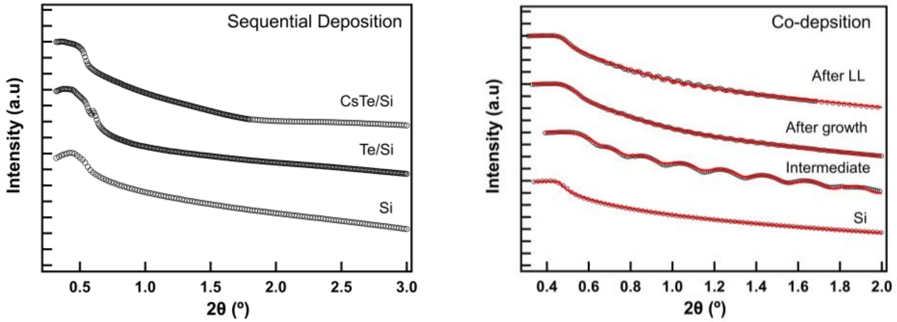
Cs Guiding tube

XRD: co-deposition Cs_2Te

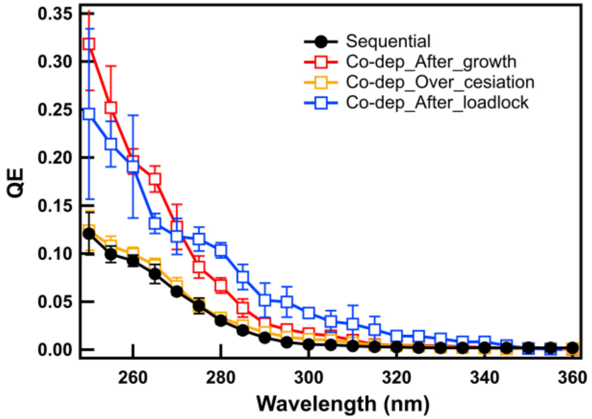




XRR after growth



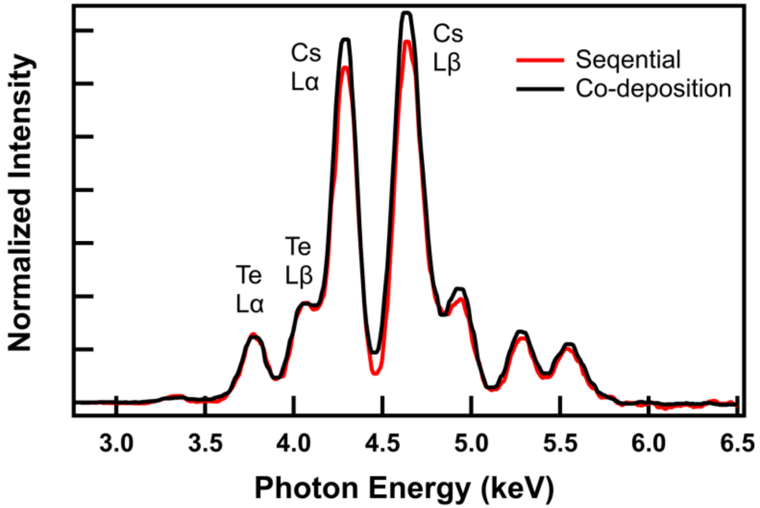
	Thickness (Å)	Roughness (Å)
After Load Lock	968.3 ± 2.9 (total Cs_2Te)	19.1 ± 0.2
After growth	1026.1 ± 1.6 (total Cs_2Te)	19.10 ± 0.07
Intermediate layer	245.5 ± 1.7	9.55 ± 0.14
Si Substrate	-	3.75 ± 0.02



M Gaowei, et al. Physical Review Accelerators and Beams, 2019, 22, 073401.

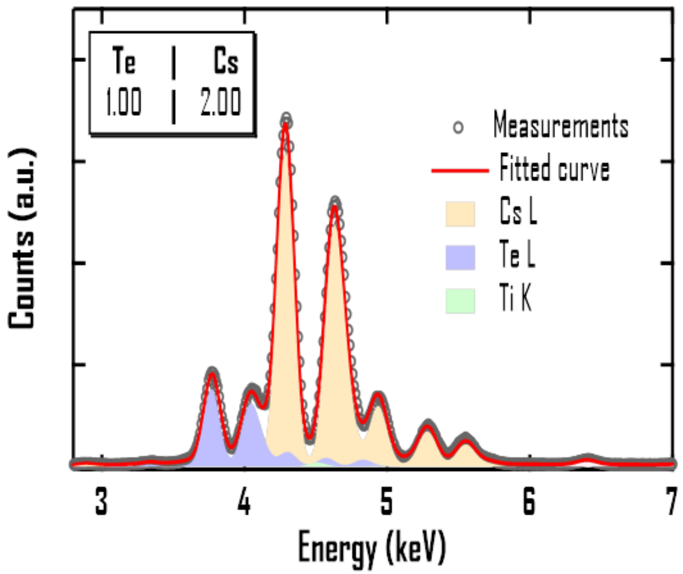
Co-deposition of Cesium telluride

X-ray fluorescence



- ❑ At same substrate temperature; co-dep method incorporates more Cs;
- ❑ Both spectra are normalized with Te L peaks.
- ❑ The fitted stoichiometry for both sequential and co-dep sample is found to be lower than the believed Cs_2Te.

Co-deposition with improved recipe



- ❑ Reduced rate of Te to perform a more controlled growth.
- ❑ The fitted stoichiometry for this co-dep sample is found to be Cs : Te = 2 : 1.

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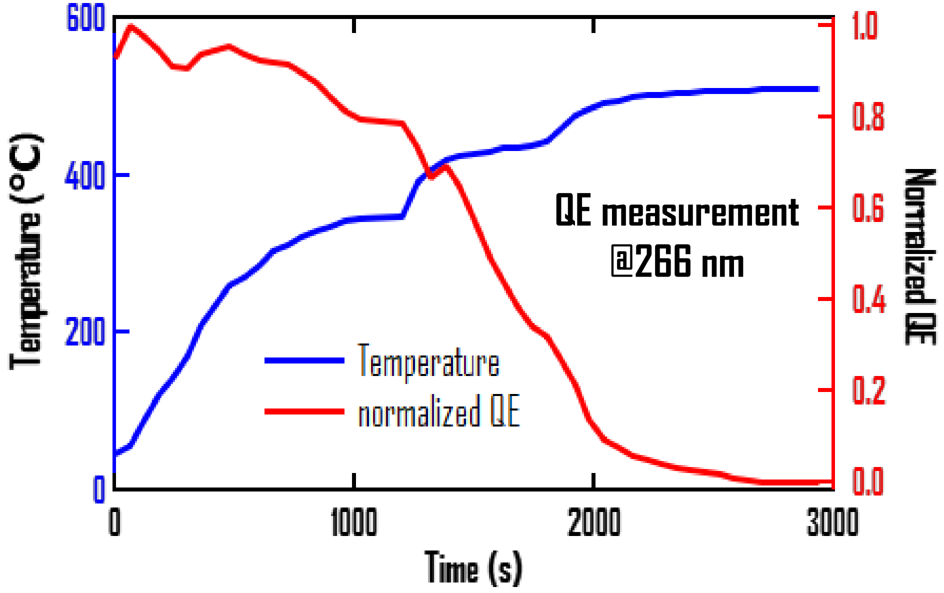
Decomposition Analysis of the Co-dep sample

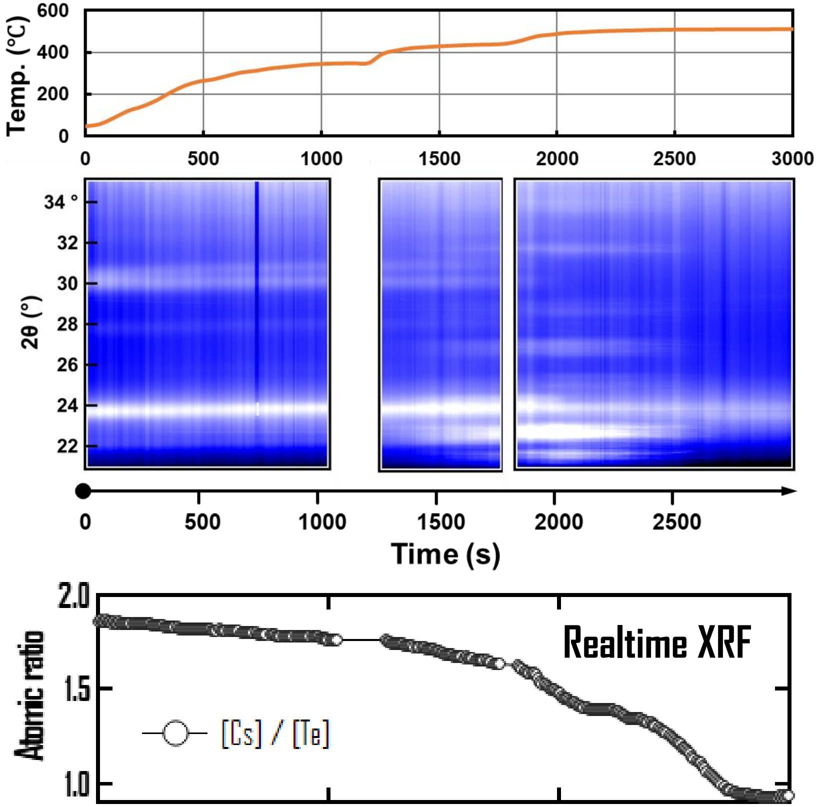
Realtime Decomposition Analysis



Decomposition undergoes two stages:

- De-cesiation process in 370℃ - 420℃
- Cs_2Te to $Cs_{1.5}Te$
- QE drops dramatically

Realtime XRF vs XRD



- ❑ De-crystallization process after 420℃
- ❑ Fully decomposed above 500℃

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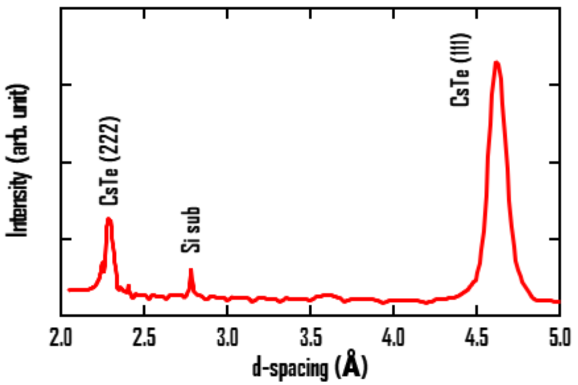
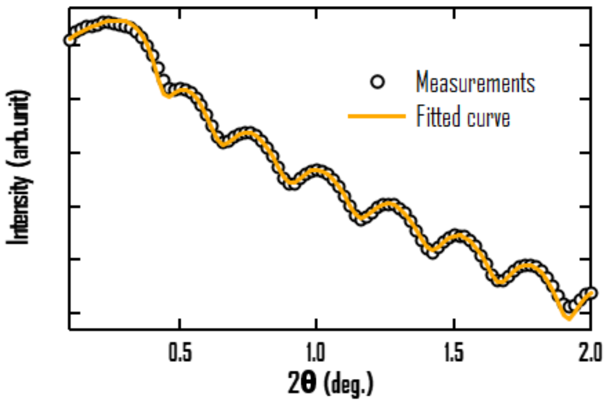
Co-deposition of Cesium telluride

- ❑ Incorporates more Cs than the sequential ones
- ❑ Single crystalizing phase of Cs_2Te, better crystallization
- ❑ Low surface roughness (2 nm for 100nm film and 1 nm for 30 nm film)
- ❑ Better QE (20% @266 nm)

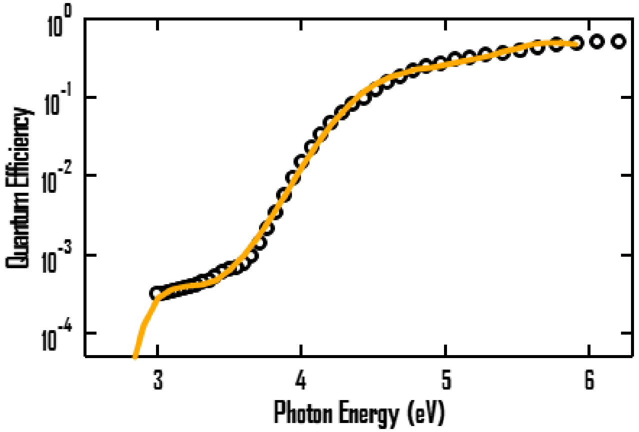
X-ray Diffraction



X-ray reflectivity



Quantum Efficiency



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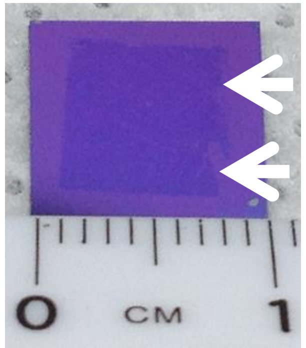
Graphene substrate preparation

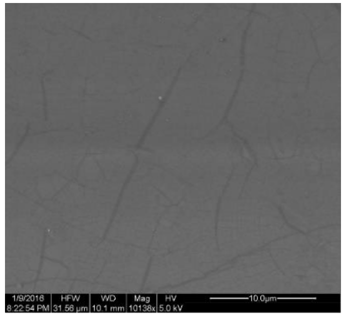
Graphene synthesis and characterization by curtesy of Hisato Yamaguchi, LANL

Chemical vapor deposition

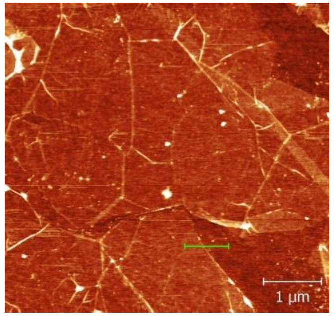


Optical microscope image

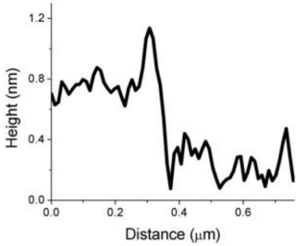
SEM



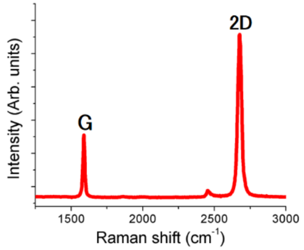
AFM



Height profile



Raman spectrum



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Quantum Efficiency Enhancement of Bialkali Photocathodes by an Atomically Thin Layer on Substrates

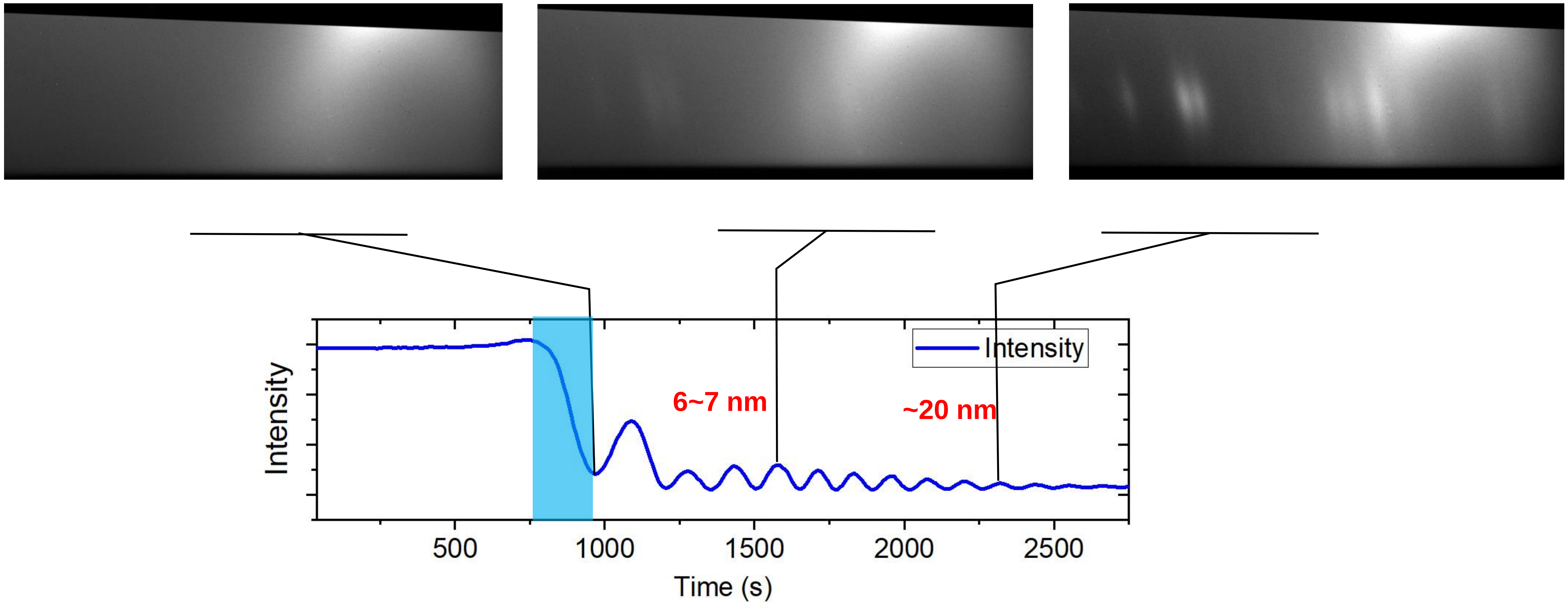
Hisato Yamaguchi, Fangze Liu, Jeffrey DeFazio, Mengjia Gaowei, Lei Guo, Anna Alexander, Seong In Yoon, Chohee Hyun, Matthew Critchley, John Sinsheimer, Vitaly Pavlenko, Derek Strom, Kevin L. Jensen, Daniel Finkenstadt, Hyeon Suk Shin, Masahiro Yamamoto, John Smedley, and Nathan A. Moody*

Nucleation of cesium telluride: XRD evolution

Diffraction pattern started to appear

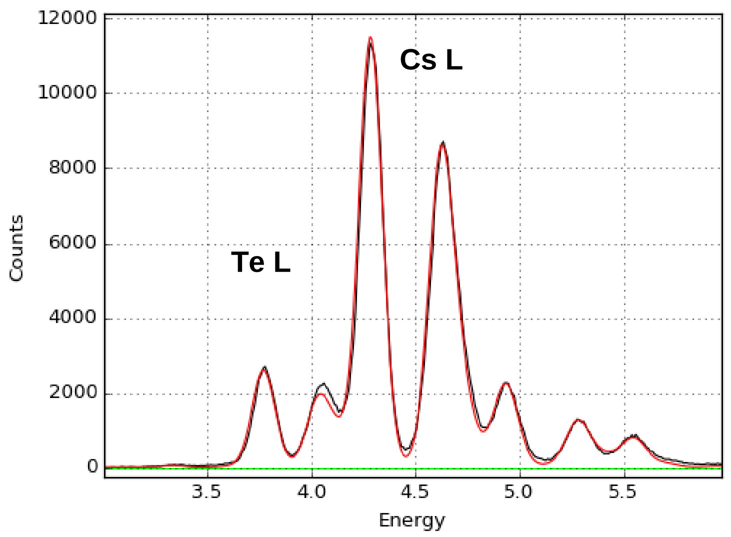
Diffraction arcs indicating textured film

Si

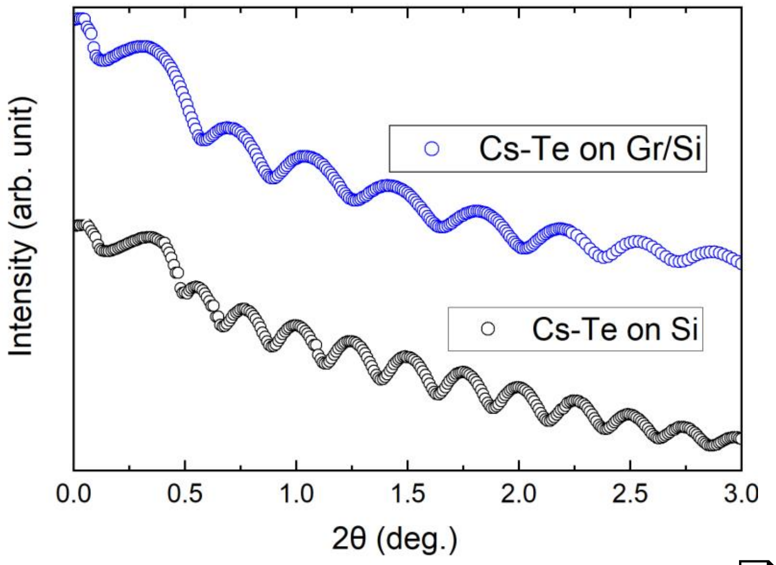


Nucleation of cesium telluride: Post growth Characterization

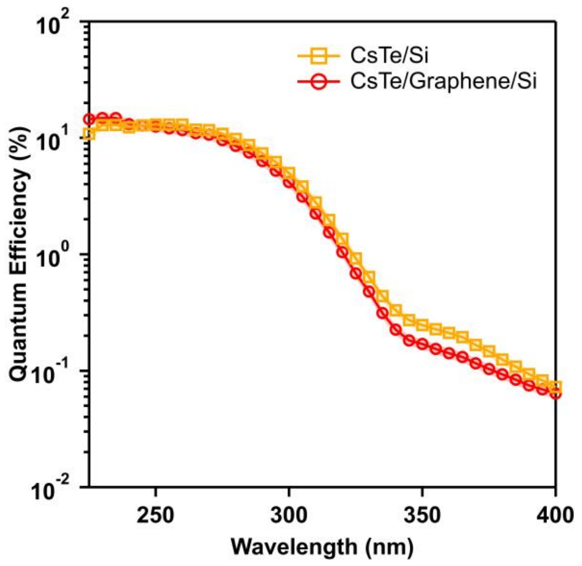
X-ray fluorescence



X-ray reflectivity



QE



	Cs:Te	Thickness (Å)
Cs_2Te on Si	2.24:1	23.7 nm
Cs_2Te on Graphene	2.36:1	18.6 nm

- Similar QE for films on both Graphene and Si.
- 10% at 266 nm, lower than our previously reported QE for co-deposition

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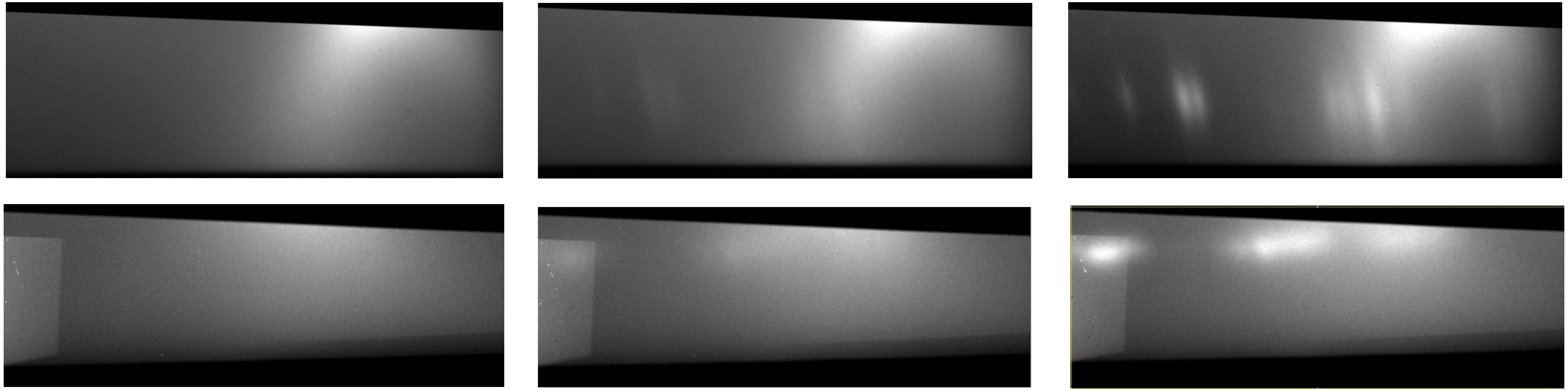
Nucleation of cesium telluride: XRD evolution

Diffraction pattern started to appear

Diffraction arcs indicating textured film

Si

Gr/Si



- Crystallization starts around the same thickness
- Cs_2Te on Gr is more textured than on Si, ordered structure appear in early stage of the growth

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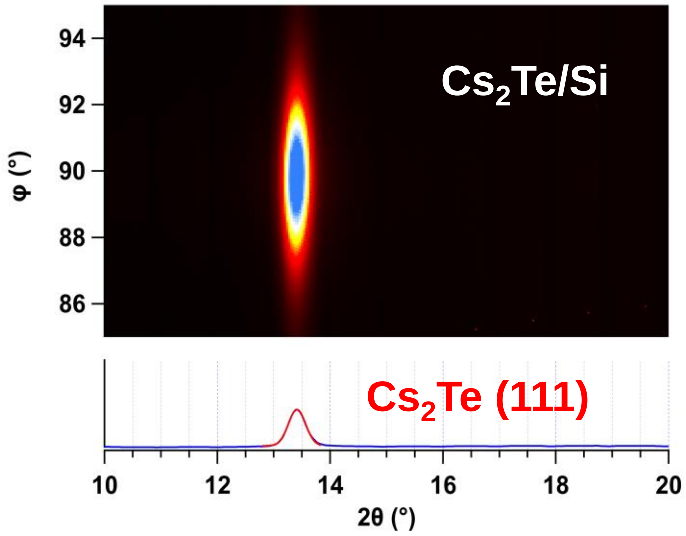
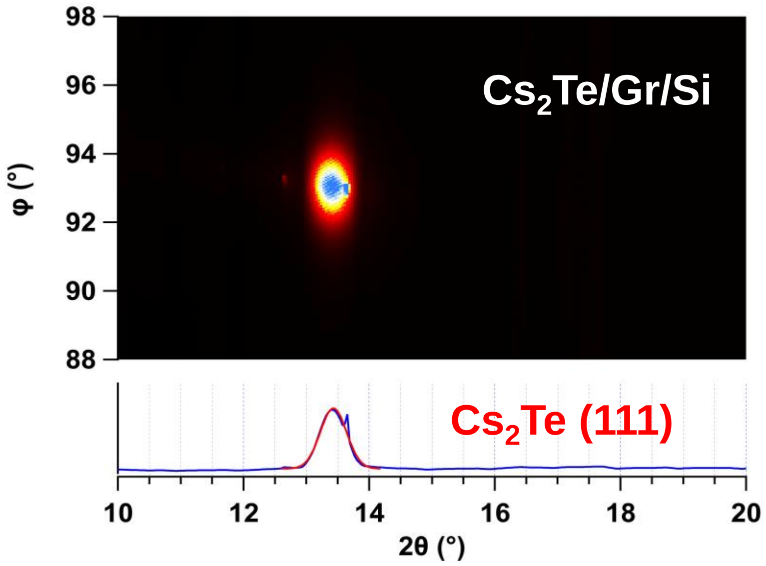
Nucleation of cesium telluride: Post growth Characterization

X-ray Diffraction: post growth

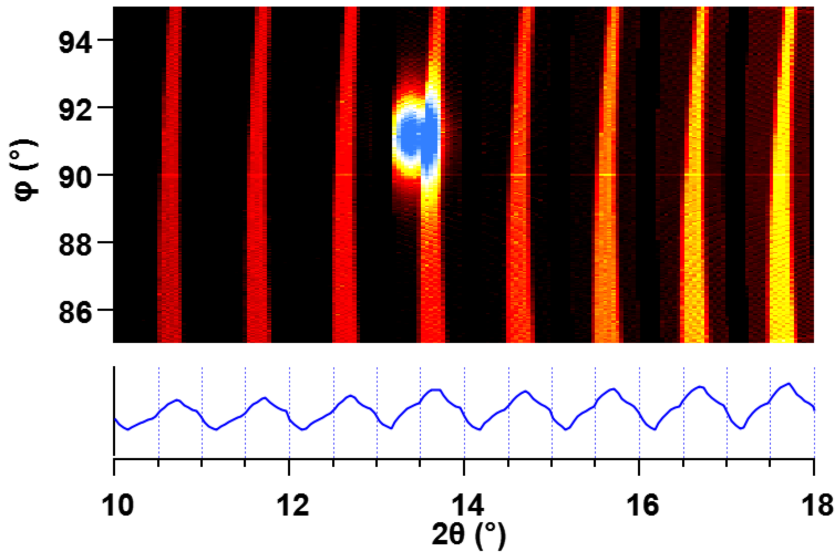


Grain size: 16.2 nm



Grain size: 11.8 nm

$Cs_2Te/Gr/Cu(100)$



Grainsize needs further analysis, estimated to be similar to Gr/Si

- Grain size is over 60% of film thickness
- Cs_2Te on Gr is more textured than on Si

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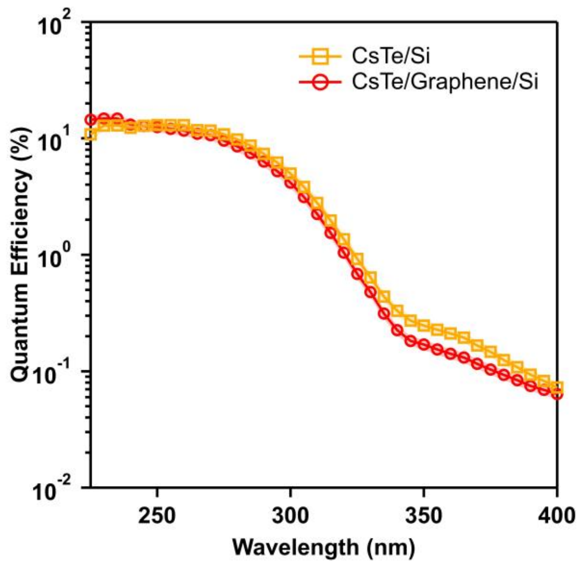
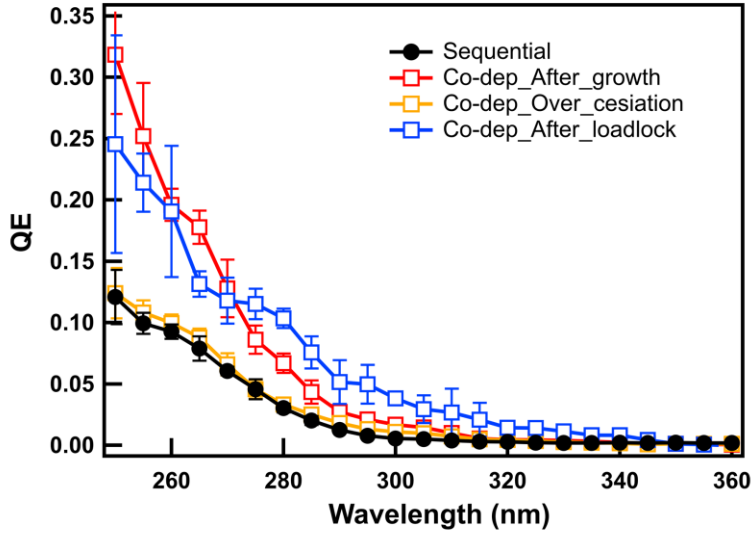
Nucleation of cesium telluride: QE

Si vs Gr/Si



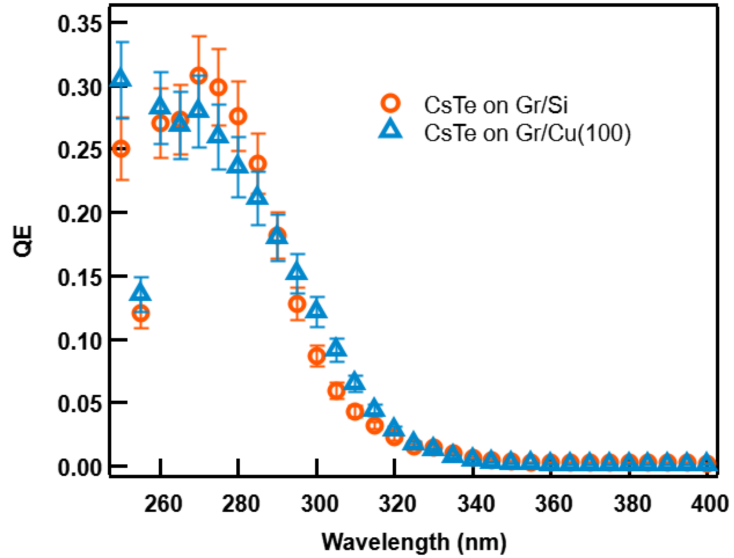
- Similar QE for films on both Graphene and Si.
- 10% at 266 nm, lower than our previously reported QE for co-deposition

CsTe on Si: w/ vs w/o excess Cs



- Excess Cs could result in dramatic QE drop.
- QE can be recovered if introducing oxygen content

Gr/Si vs Gr/Cu (100)



- High QE can be achieved on Gr/Cu substrate (Application!!)

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Summary

- Co-deposition of cesium telluride photocathodes are deposited on atomically thin graphene substrate.
- Nucleation of Cs_2Te crystalline phase was observed and the nucleation on graphene is more oriented than that on the Si substrate.
- The crystalized film is textured in early stage of the growth.
- The use of graphene as a substrate for cesium telluride is a promising route to produce cathode film with better crystallinity and better cathode performance.

ACKNOWLEDGMENT

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