Epitaxial Alkali-antimonide Photocathodes on Lattice-matched Substrates

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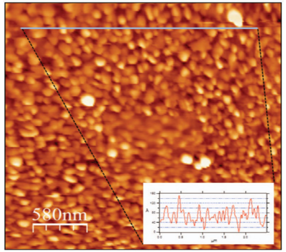
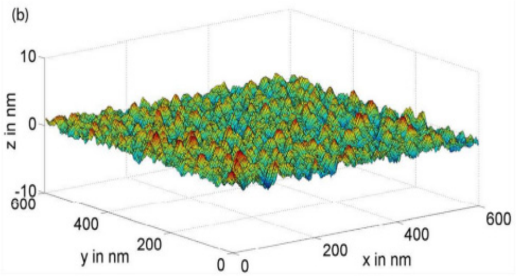
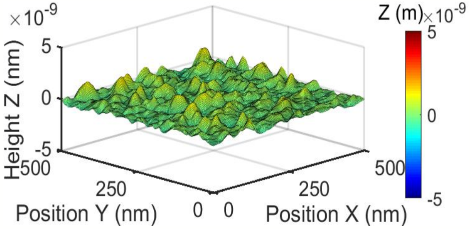
Outline

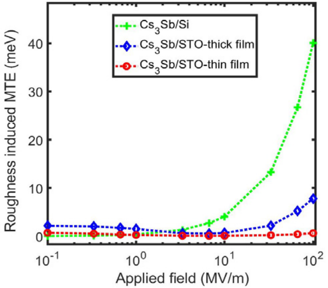
➢ Introduction
- Why alkali-antimonides?
- History of growths



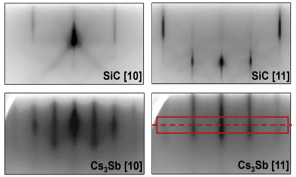


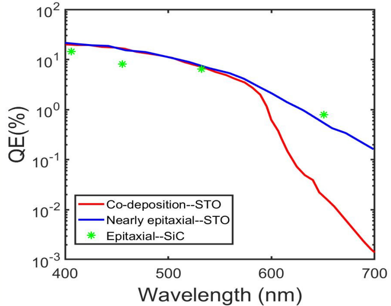
➢ Co-deposition on lattice-matched substrates
- AFM and KPFM data from Cs_3Sb/STO
- Roughness induced intrinsic emittance/ MTE





➢ Epitaxial efforts on alkali-antimonide photocathodes





➢ Conclusion and future steps

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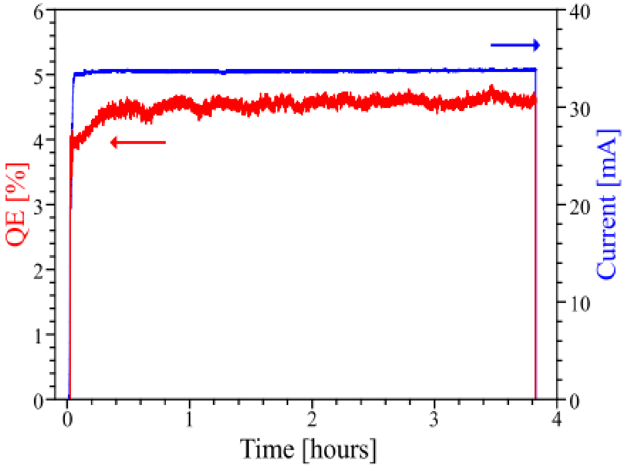
Why alkali-antimonides?

➢ High QE, long lifetimes

High current applications

- **Energy Recovery Linacs**
- **Electron beam cooling**

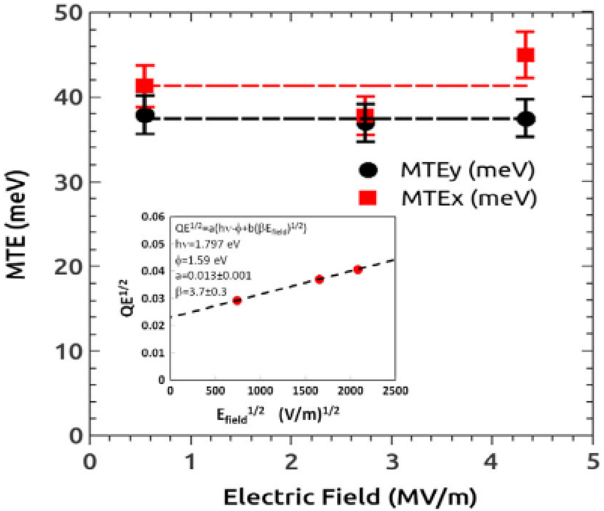


B. Dunham et. al., Appl. Phys. Lett. 102, 034105 (2013).

➢ Low MTE

Low emittance applications

- **X-ray Free Electron Laser**
- **Ultrafast Electron Diffraction**



L. Cultrera et. al., PRAB. 18, 113401 (2015).

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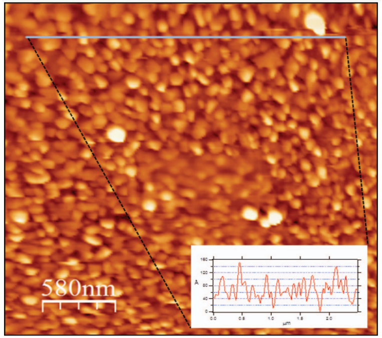
History of (bi)alkali-antimonides growths

- **Sequential deposition technique**

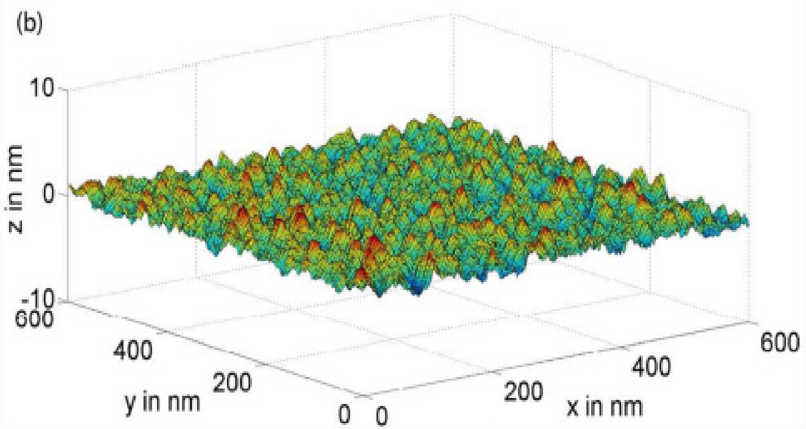


rms roughness ~ 25 nm

S. Schubert et al., APL Mater. 1, 032119 (2013)

- **Co- deposition technique**

rms roughness ~ 0.6nm



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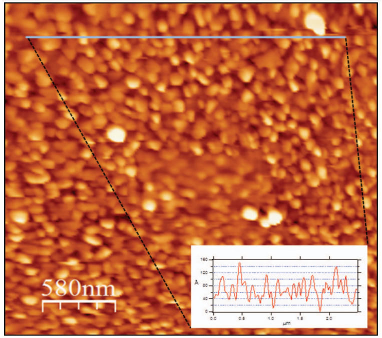

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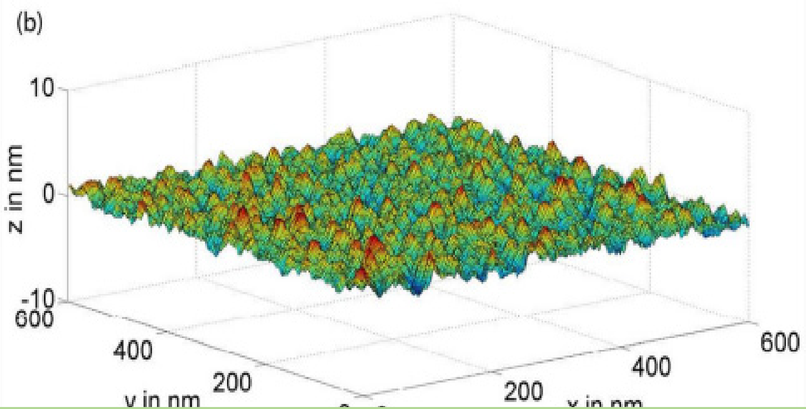

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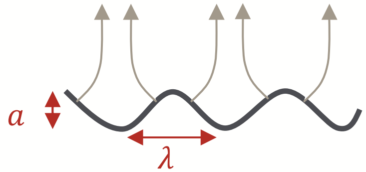
How does roughness impact MTE? How to reduce roughness?

Impact of Roughness on MTE

Physical roughness



$$\mathrm{MTE}_{field} = \frac{\pi^2 a^2 E_0 e}{2\lambda}$$

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Chemical roughness

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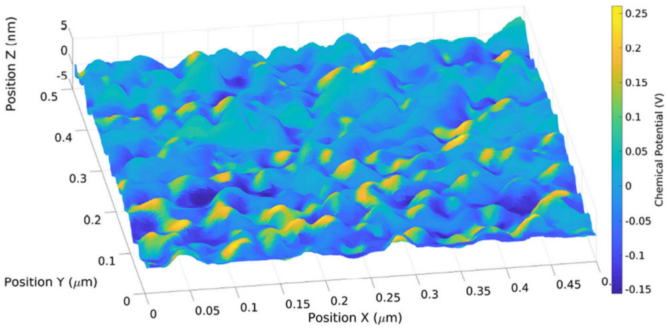
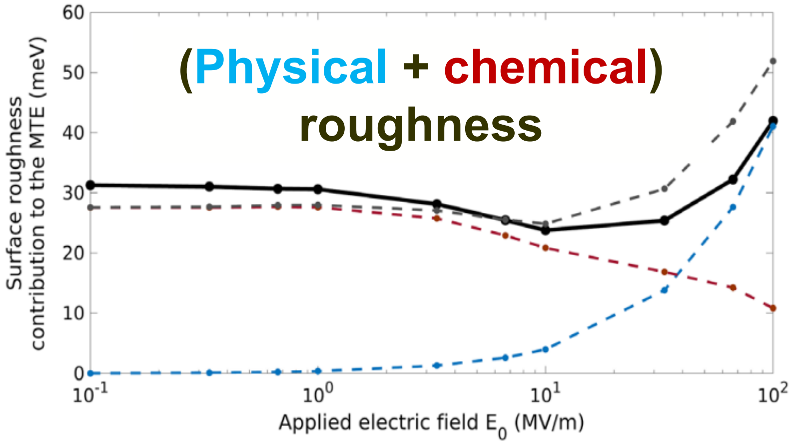
S. Karkare and I.V. Bazarov, Phys. Rev Applied, 4, 024015 (2015).

Non-trivial, non-monotonic dependence on accelerating field gradients!





G. Gevorkyan et al. Phys. Rev. ST- Accel and Beams, 21, 093401 (2018)

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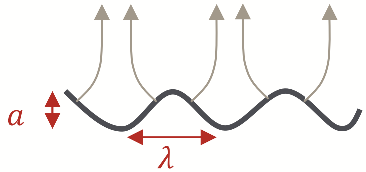

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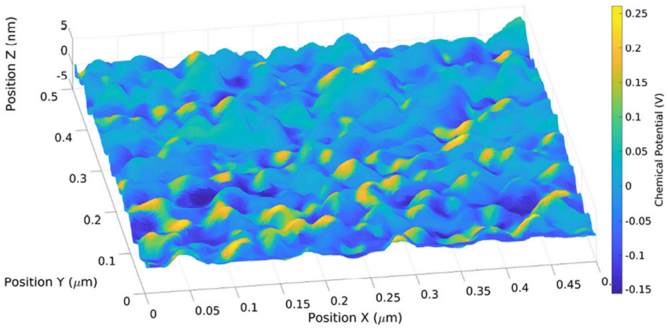

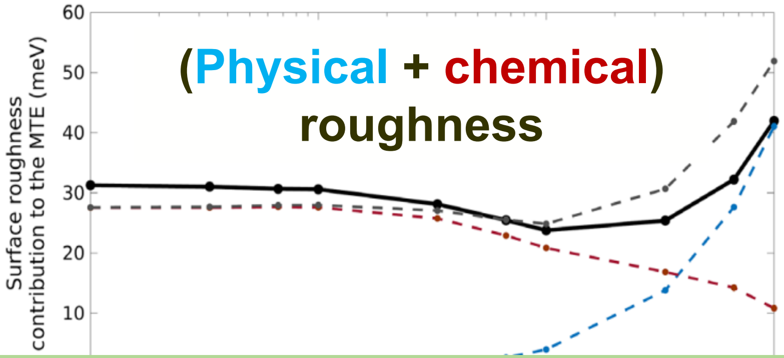

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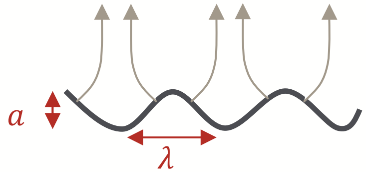
How can we reduce roughness further?

Impact of Roughness on MTE

Physical roughness



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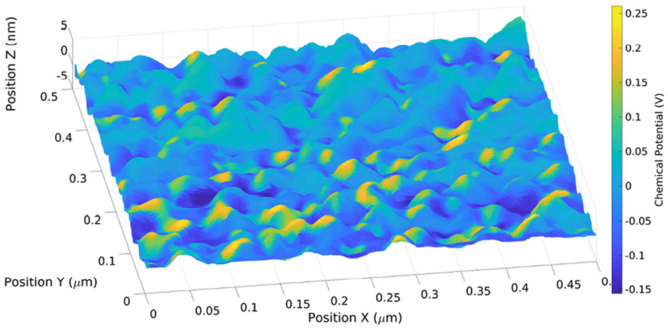

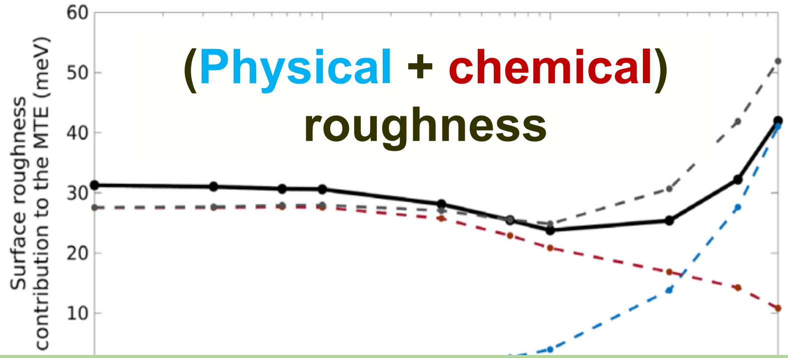

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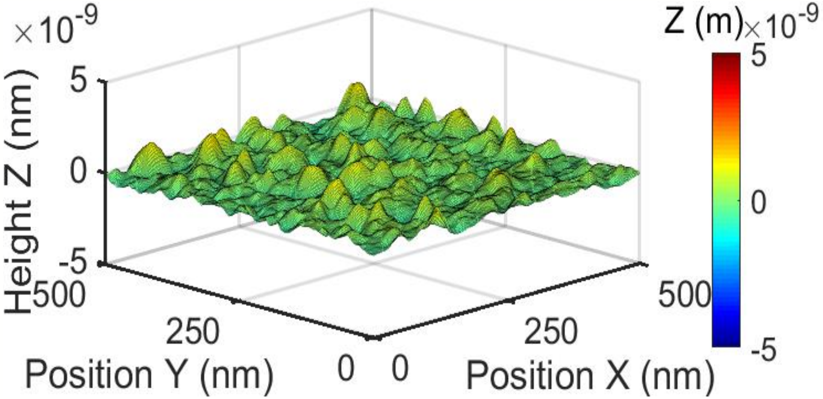
Grow on lattice-matched substrates?

AFM and KPFM images of Cs_3Sb/STO cathodes



rms roughness ~ 0.3nm

P. Saha et al., Appl. Phys. Lett. 120, 194102 (2022)

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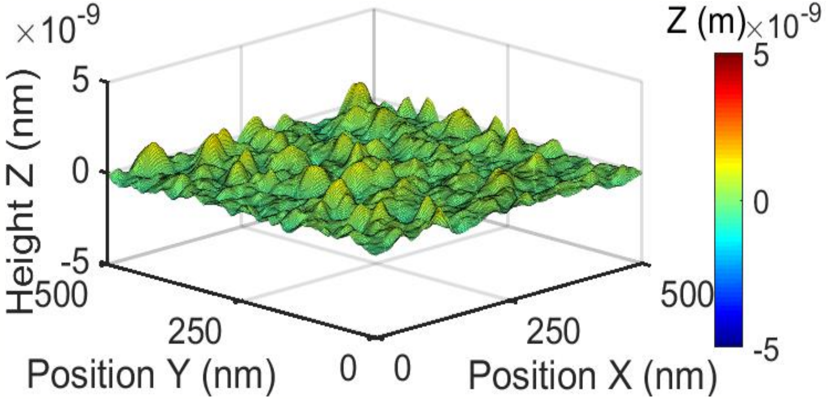

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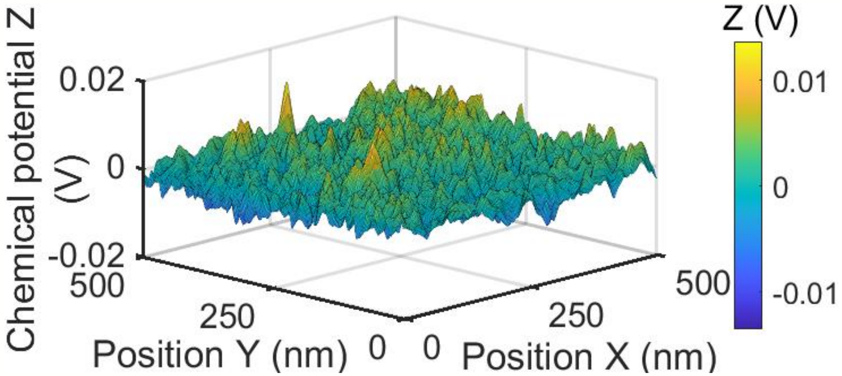

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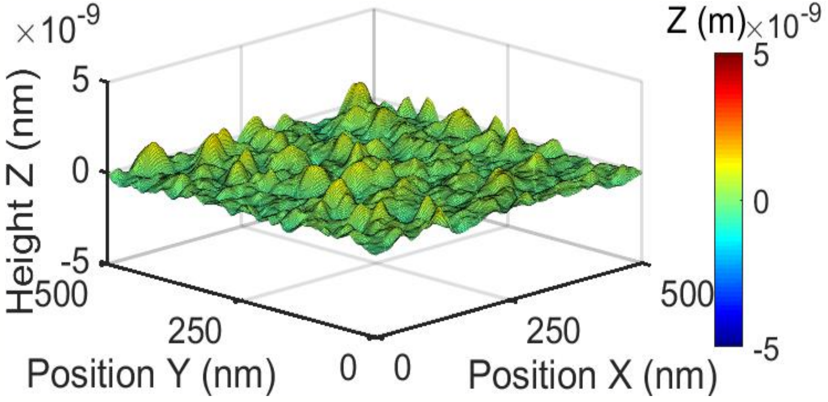

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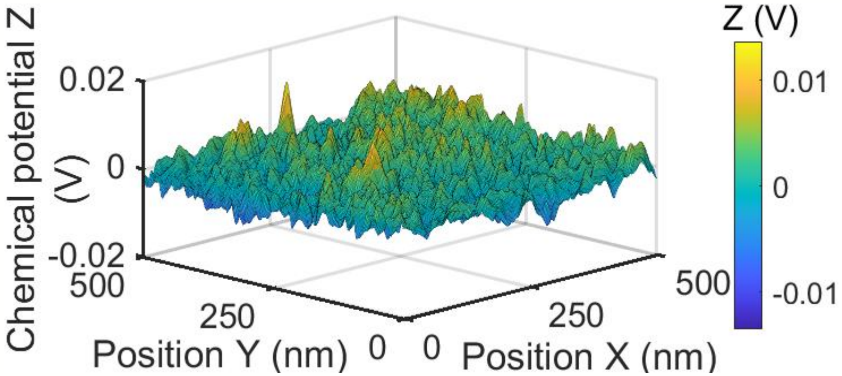

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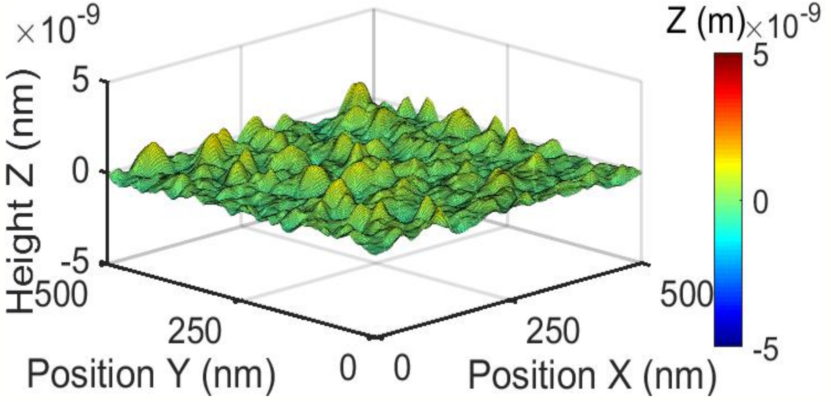
Atomically flat and chemically homogeneous Cs_3Sb cathodes measured on STO.

P. Saha et al., Appl. Phys. Lett. 120, 194102 (2022)

AFM and KPFM images of Cs_3Sb/STO cathodes

Arizona State University



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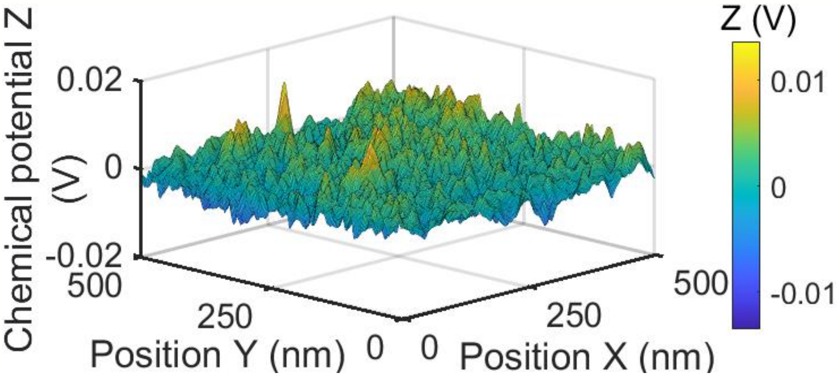

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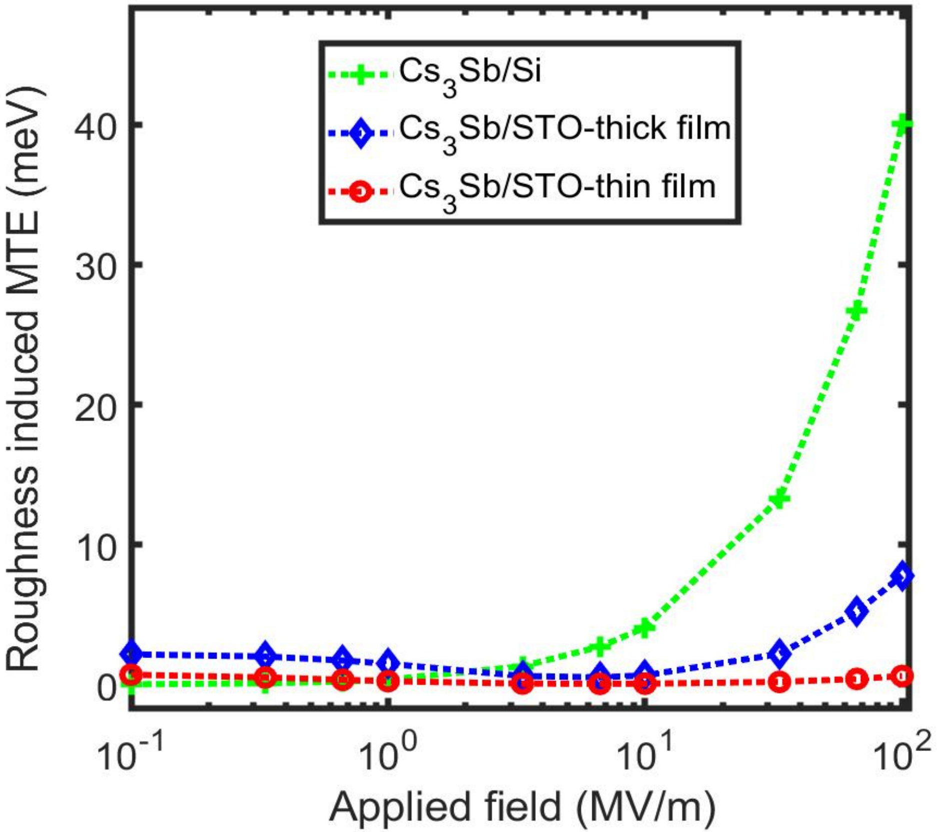

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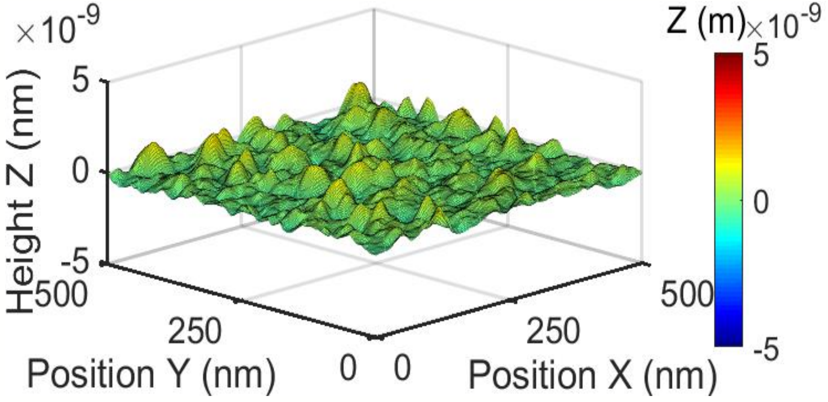

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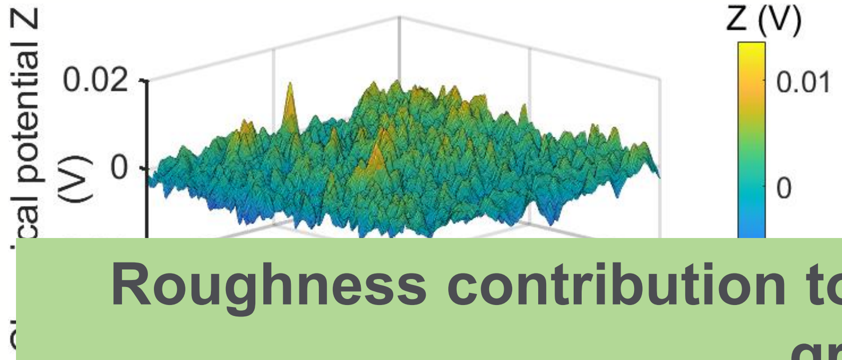

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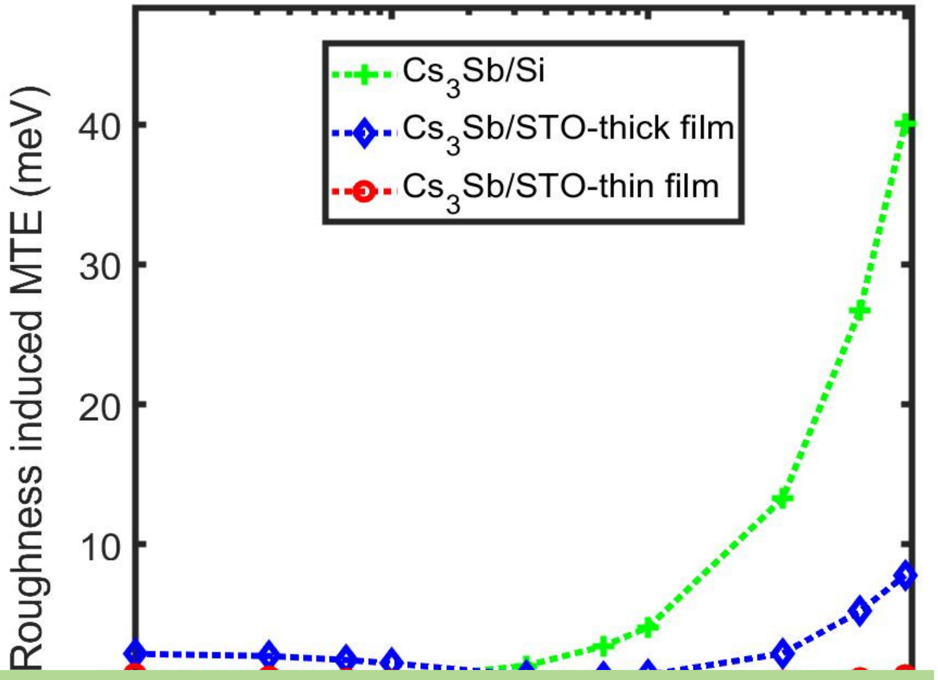
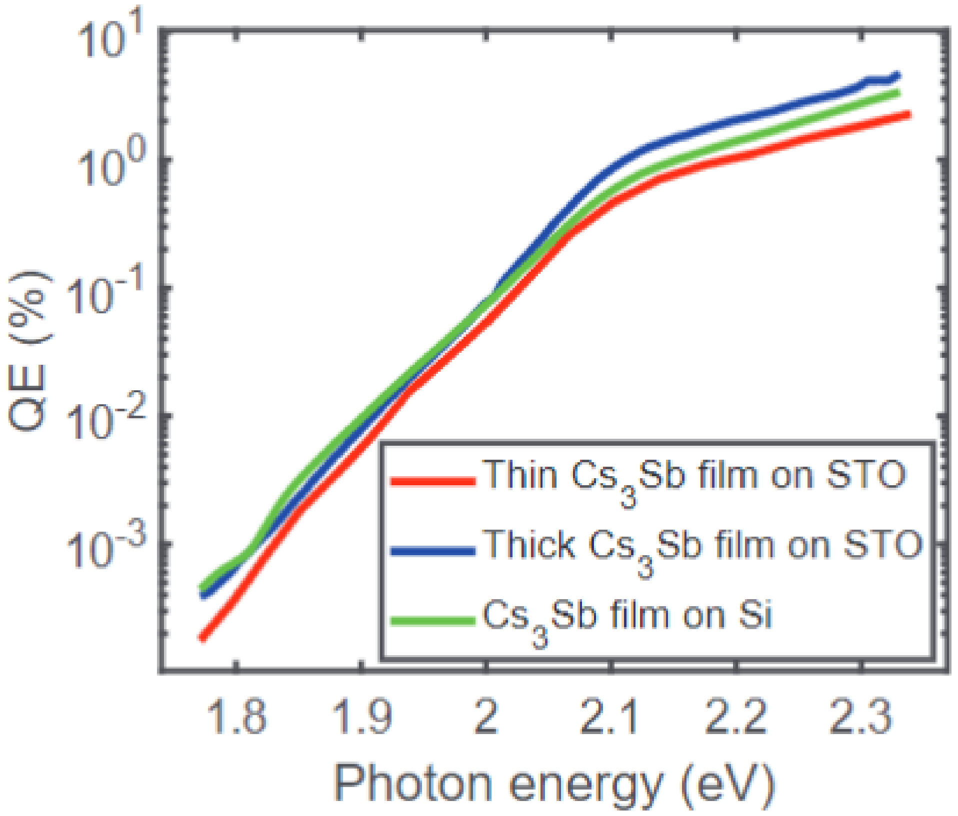


Roughness contribution to MTE inconsequential at all field gradients!

P. Saha et al., Appl. Phys. Lett. 120, 194102 (2022)

QE Spectral Response



- **Low QE ~ 10^-2 beyond threshold of 2.1 eV.**
- **Higher fluence needed to extract higher charge densities for such low QE , it may lead to MTE degrading effects like non-linear photoemission and laser induced heating…**

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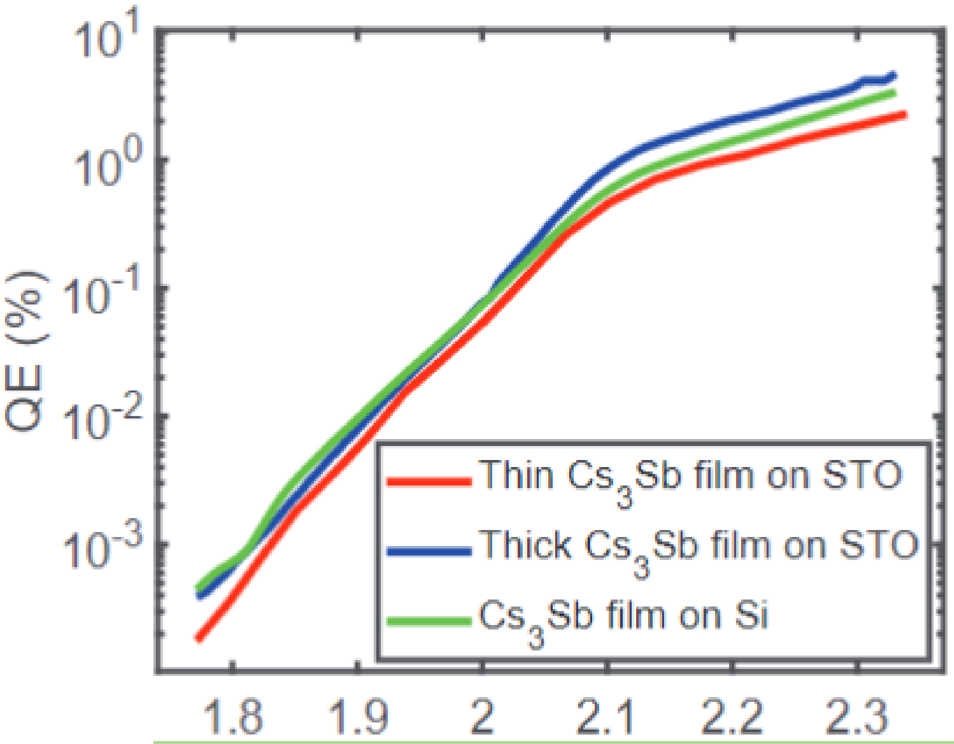

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Is Epitaxy the way to go?

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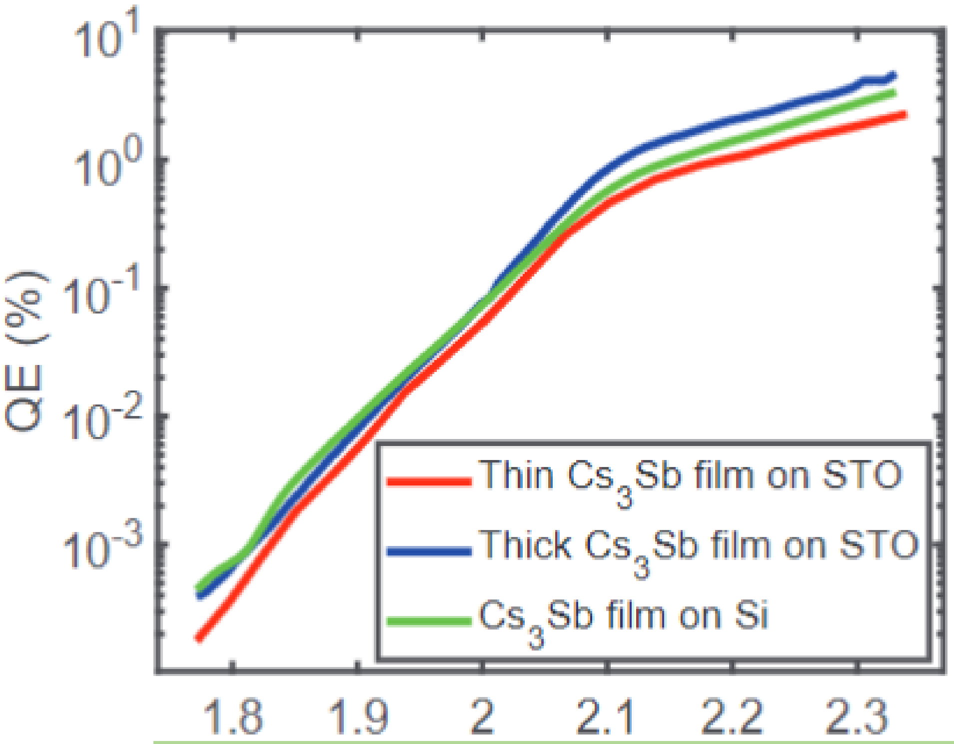

- **Low QE ~ 10^-2 beyond threshold of 2.1 eV.**
- **Higher fluence needed to extract higher charge densities for such low QE , it may lead to MTE degrading effects like non-linear photoemission and laser induced heating…**
- **Use epitaxy to grow ordered heterostructures with fewer defects, which may lead to higher QE.**

Is Epitaxy the way to go?

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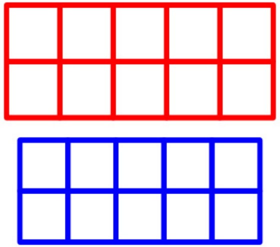
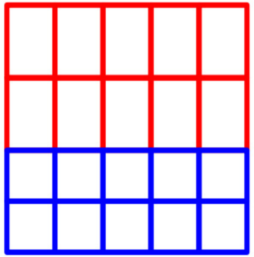
What is Epitaxy?

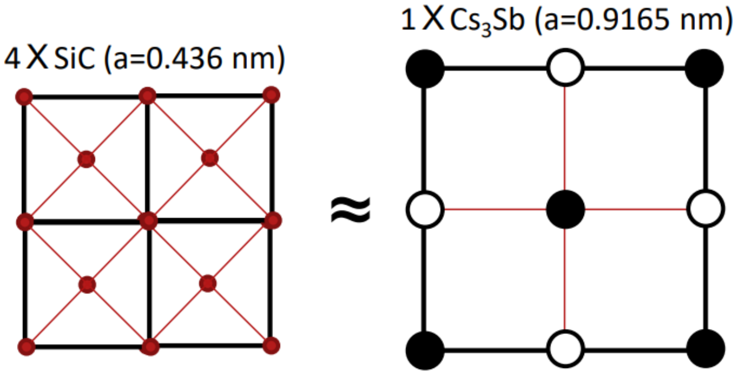
crystalline layers are formed with one or more well-defined orientations with respect to the crystalline seed layer



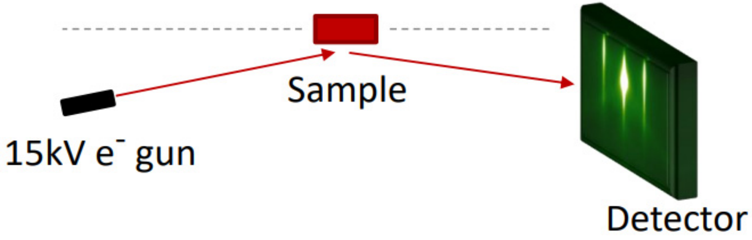
The lattice of the film (red) is almost the same as the substrate (blue)



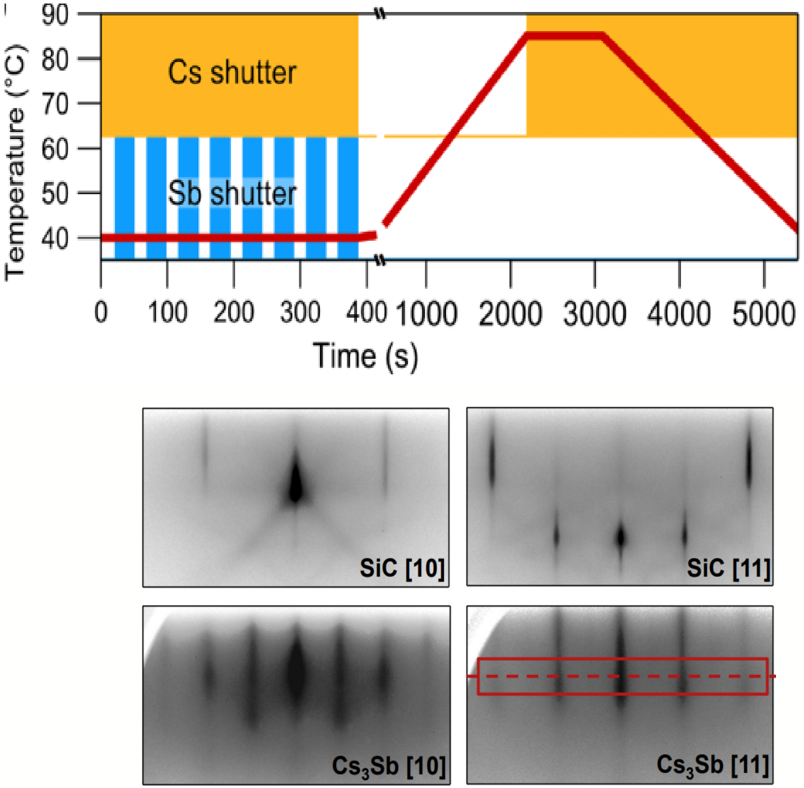
The lattice of the epitaxial film (red) distorts to minimize the strain energy where it bonds to the substrate (blue)



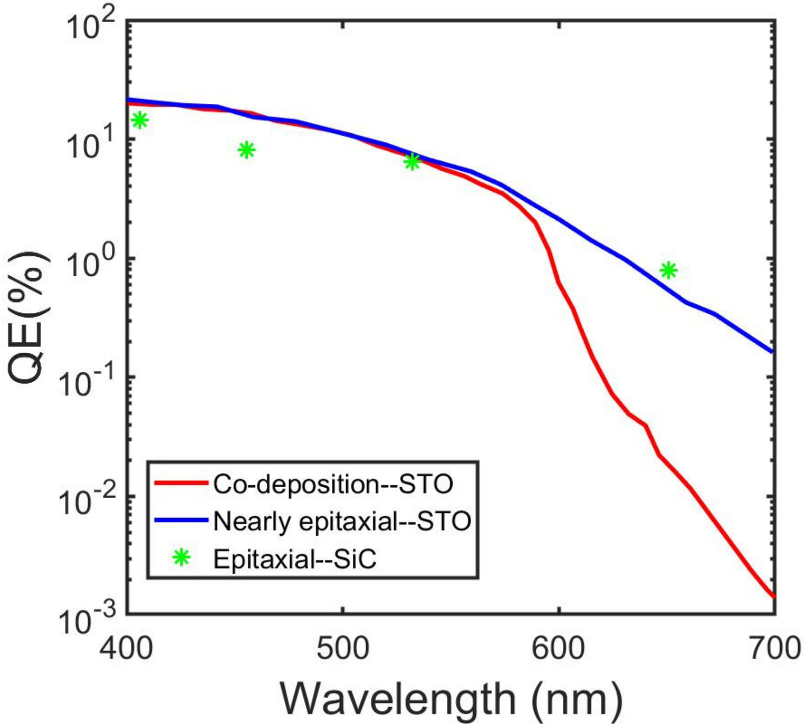
Reflection High Energy Electron Diffraction (RHEED)



Epitaxial efforts on Cs_3Sb cathodes



Spectral response of QE



C. Parzyck, A. Galdi et. al., Phys. Rev. Lett. 128, 114801 (2022).

Conclusion and Future steps

- Single crystalline Cs_3Sb cathodes are grown epitaxially on lattice-matched substrates.

- Measure MTE from such cathodes.
- Optimize epitaxial growth technique of Cs_3Sb cathodes on different substrates to enable controlled doping like in III-V semiconductors.
- Perform optical characterization of single crystal cathodes.
- Use epitaxy to grow heterostructures of alkali-antimonides.
- Enable the use of single crystalline cathodes in electron guns for e.g. the cryocooled DC ASU gun. See next talk by Gevork for more updates!