Progress in CdSeTe absorber and As doping

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U.S. DEPARTMENT OF ENERGY

Colorado State University

NSF

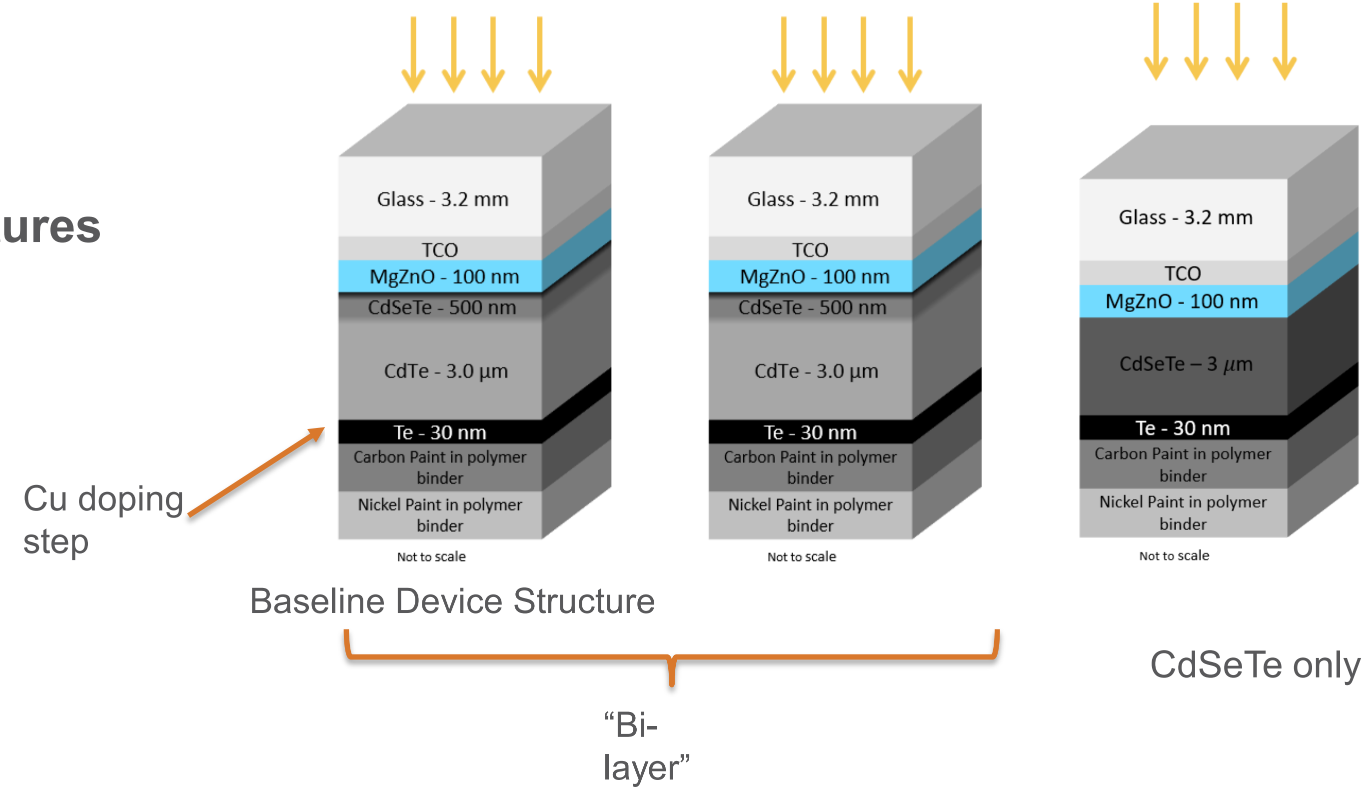
BACKGROUND

1. Research presented here is based on two completed 3-year SETO projects and two completed Ph.D projects of Carey Reich and Adam Danielson.

2. Results on: (i) MZO/CdSeTe interface, (ii)bulk absorber and doping, (iii)back interface and (iv) back contact. Data from optimum process conditions are presented.

Tracking recombination losses

Device Structures

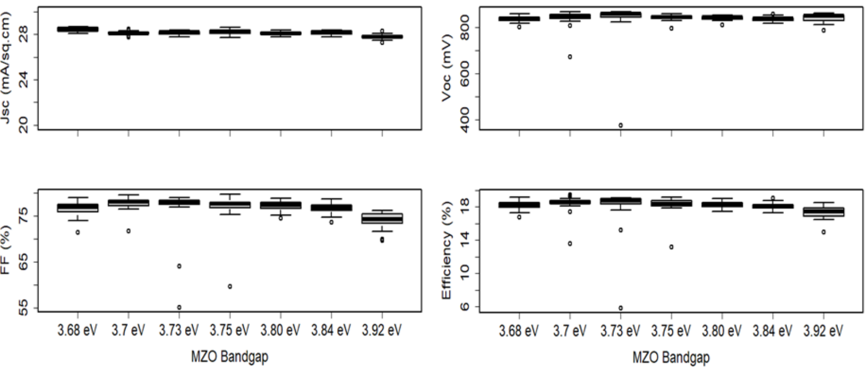


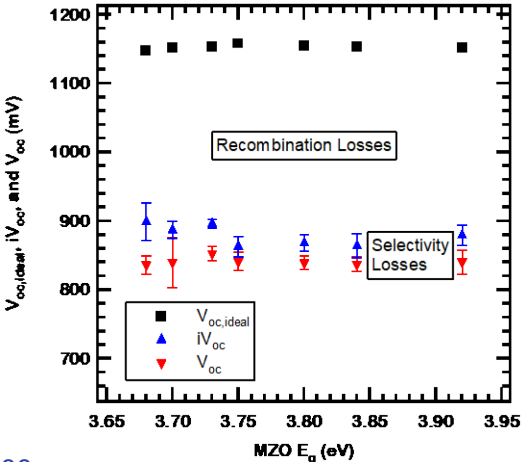
CdSeTe= CdSe0.33Te0.67

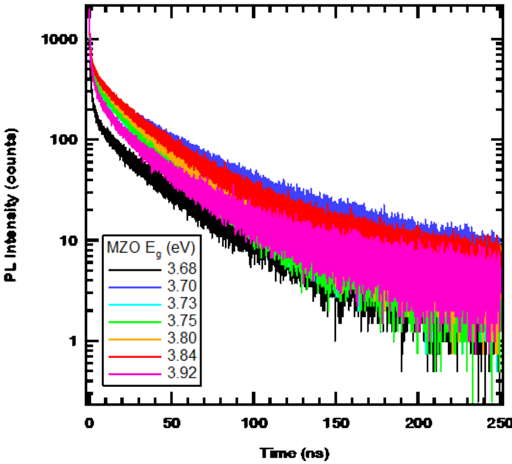
Tracking recombination losses – MgZnO Interface

Baseline structure

Champion Cells η=18.5% - 19.5%, no AR



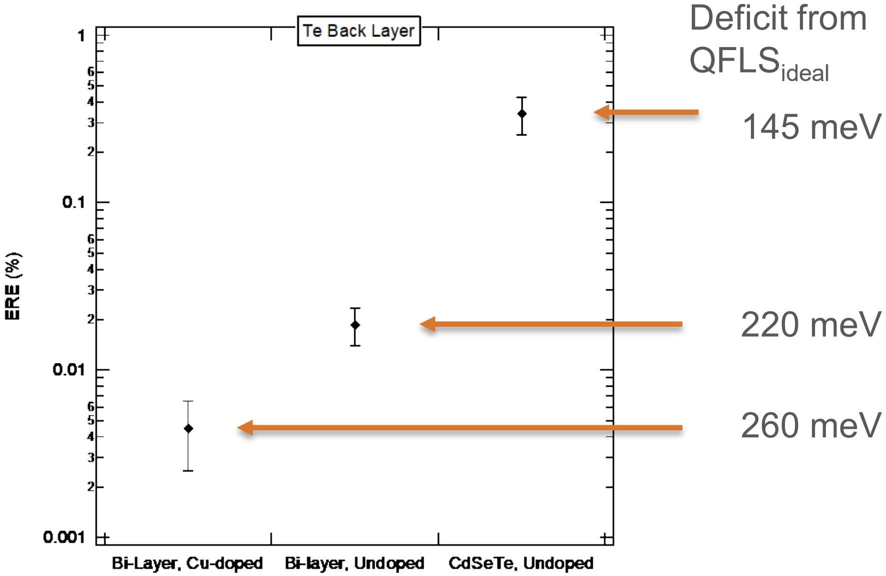


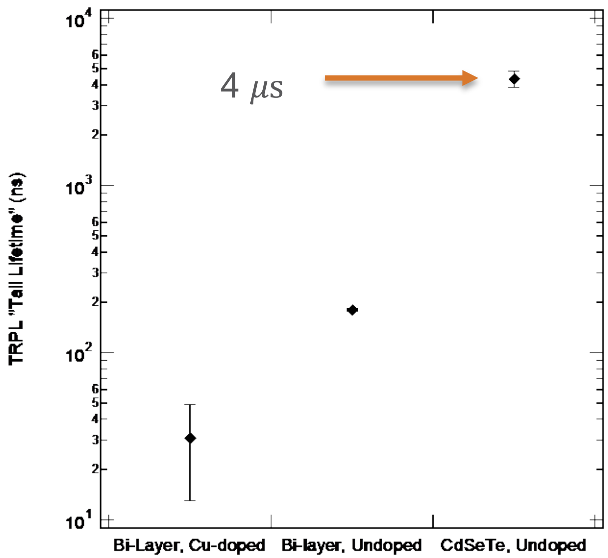


Data here presented in: https://doi.org/10.1016/j.solmat.2021.111388

JV shows insignificant differences between devices
CBO has little effect on V_{oc}, recombination as measured by ERE and TRPL
Average lifetime~55 nsec, S front ~10 cm/sec

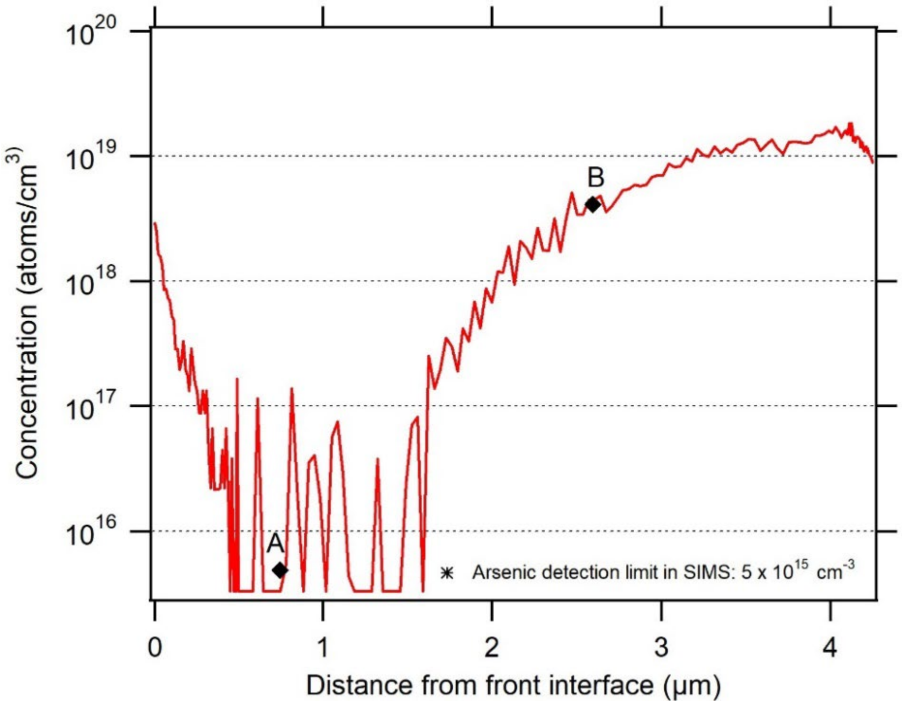
Tracking recombination losses – Bulk structure

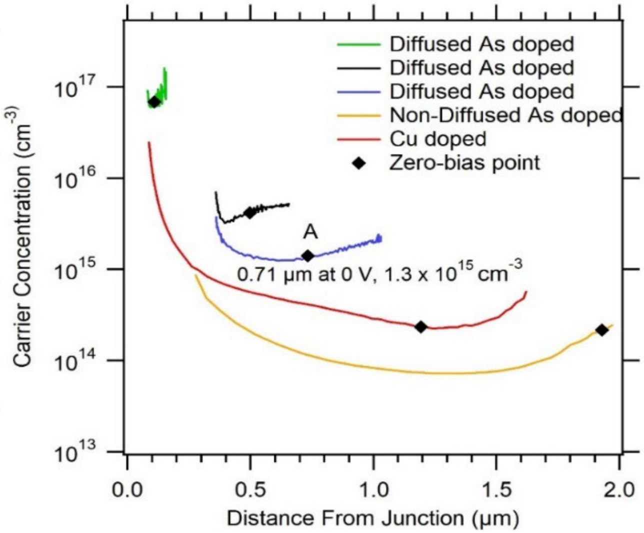


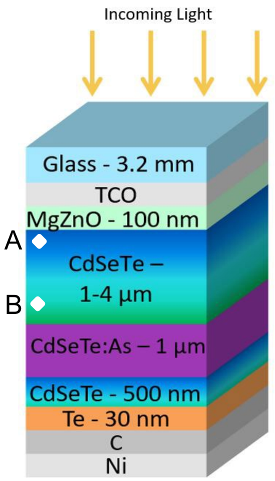


Reduction of implied voltage deficit by removal of Cu doping step and by use of only longer lifetime CdSeTe – total improvement of deficit from baseline ~115 mV. Higher lifetime in CdSeTe seen by CL and DFT modeling, only Te and no back electrode.

As Doping Results: CV/SIMS

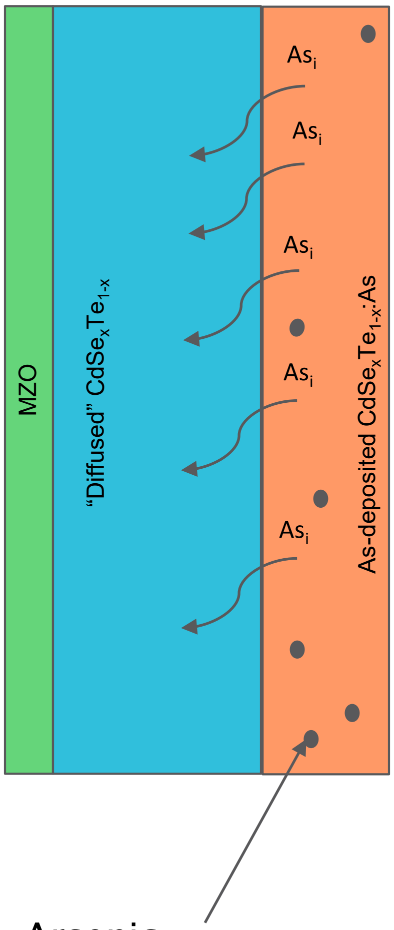






Arsenic activation exceeds 25%

Arsenic Doping Mechanism

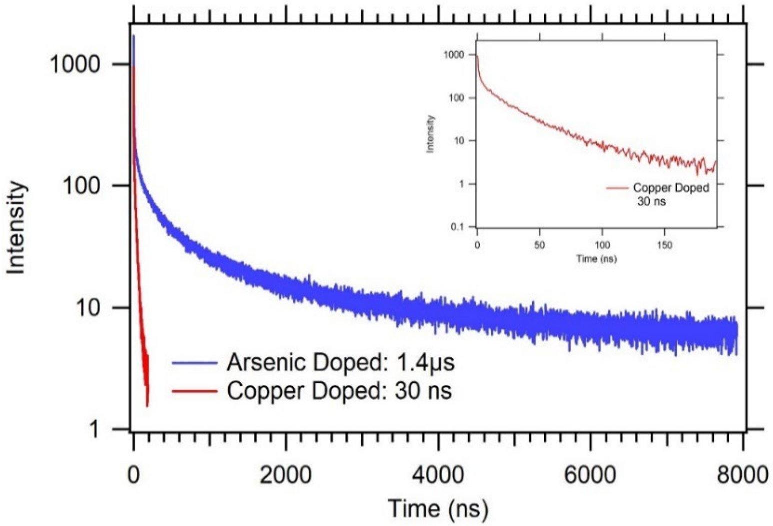


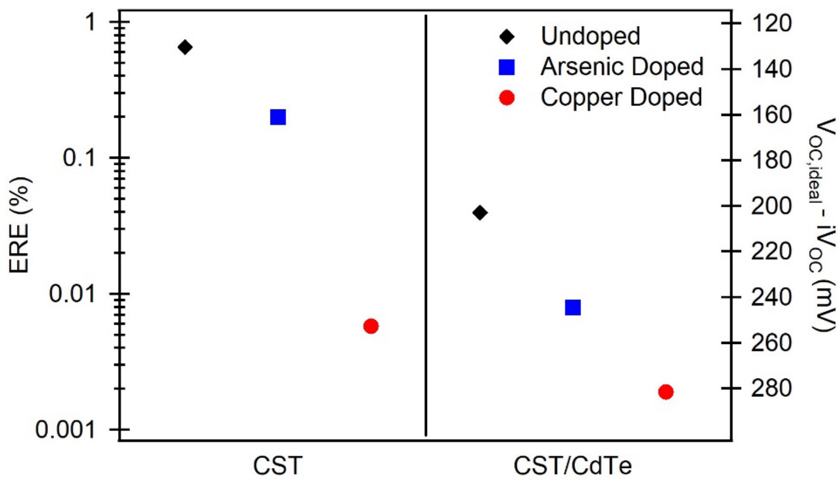
Arsenic clusters/complexes, mostly Asi-Aste complex

- Arsenic diffusion occurs from as-deposited layer to front $CdSe_xTe_{1-x}$ layer during $CdCl_2$ treatment *
- Only As_i is capable of diffusing into front $CdSe_xTe_{1-x}$
- Higher carrier concentration with CdSeTe than CdTe
- Graded doping profile
  - induces upward band bending in "diffused" $CdSe_xTe_{1-x}$ layer
  - Electron reflector
- As-deposited layer retains defects/complexes
  - Low doping activation
  - Recombination prone area

*-Cu doping will not survive CdCl2 treatment

Results: TRPL/ERE



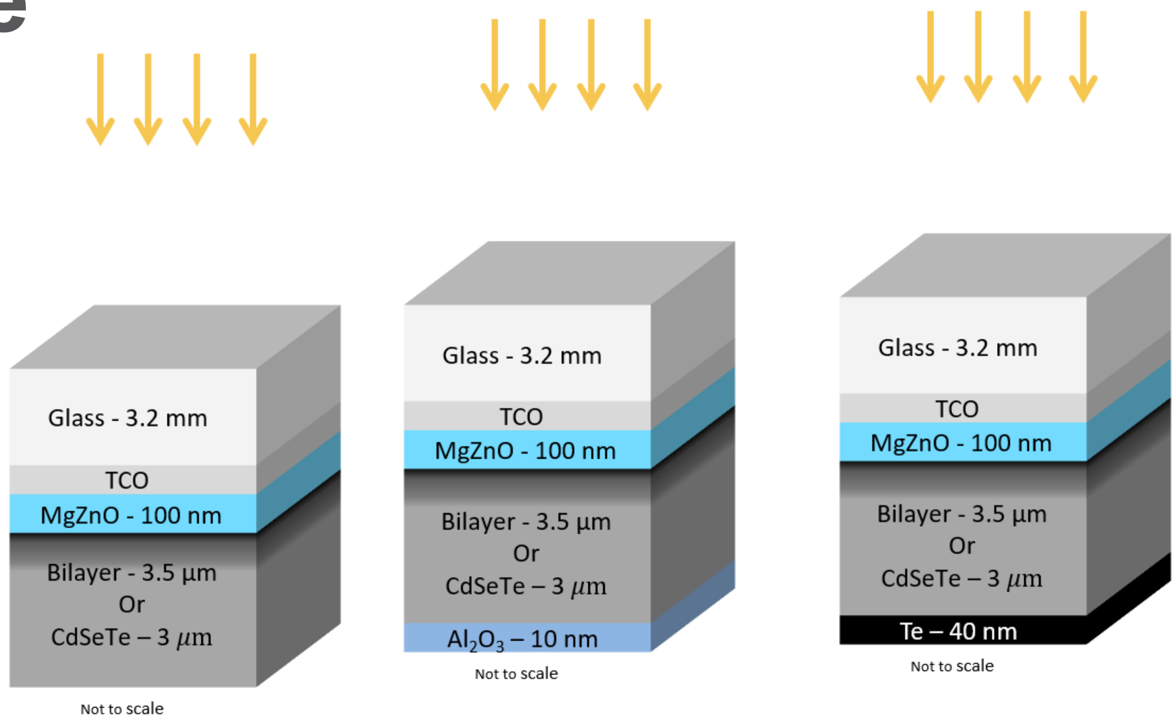


Full Devices

Arsenic doping yields higher lifetime, ERE than Cu

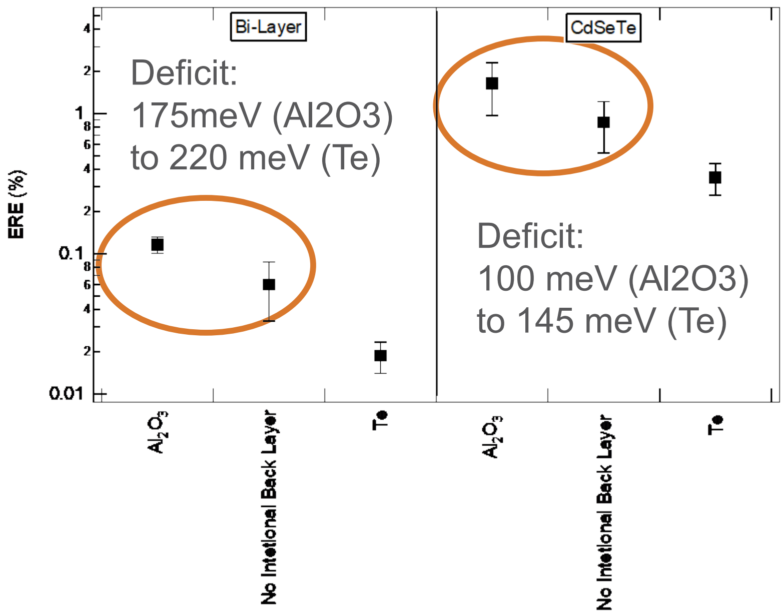
Tracking recombination losses – Rear Surface

Device Structures



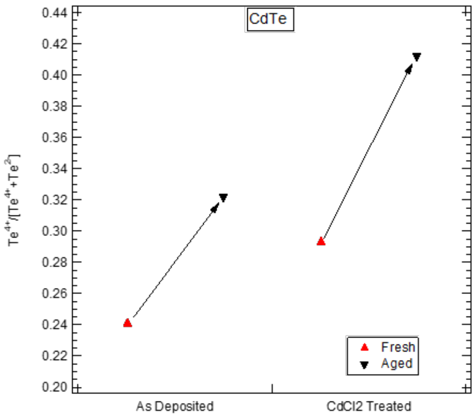
Just Films, not devices

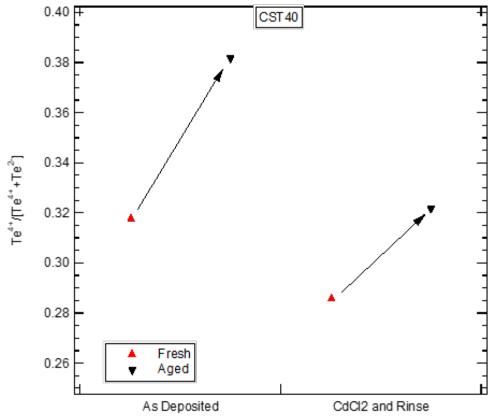
Tracking recombination losses – Rear Surface

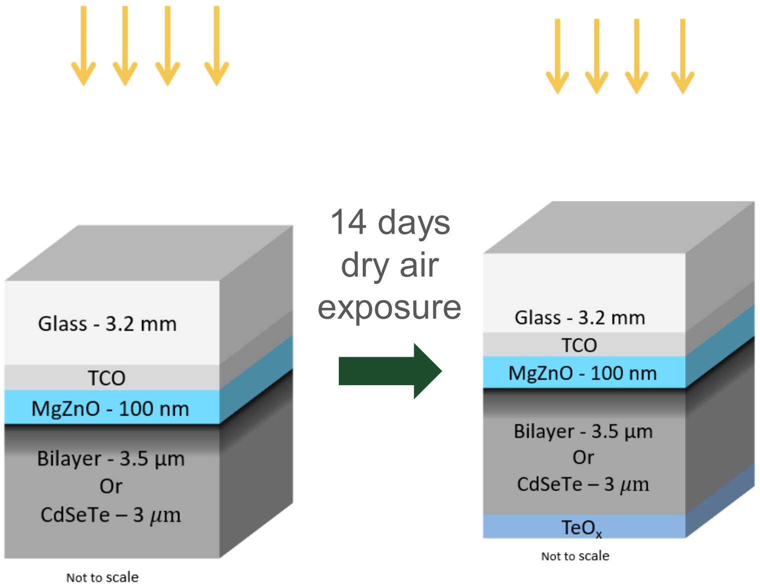


- **Te contact is detrimental to implied voltage due to it's large SRV, as suggested by comparison to a known passivating surface**
- ***No intentional back layer was better than expected***
  - TeO_x shown to passivate interfaces and can form in air [10.1109/JPHOTOV.2018.2870139, 10.1002/solr.202100173, https://doi.org/10.1016/j.solmat.2014.10.044]

Tracking recombination losses – Rear Surface

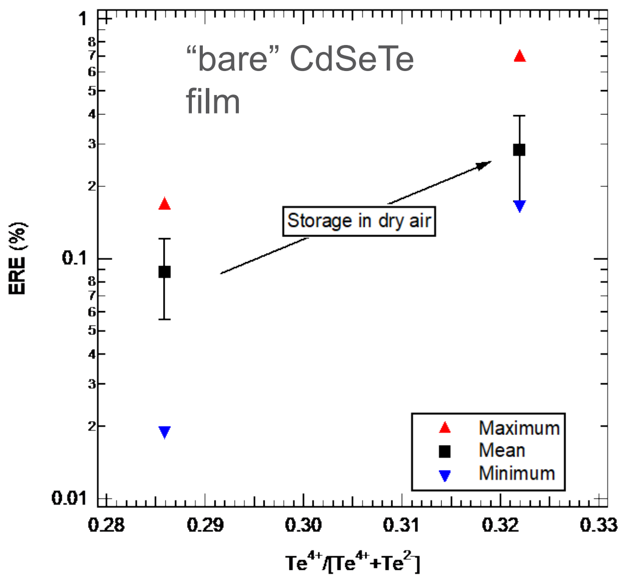




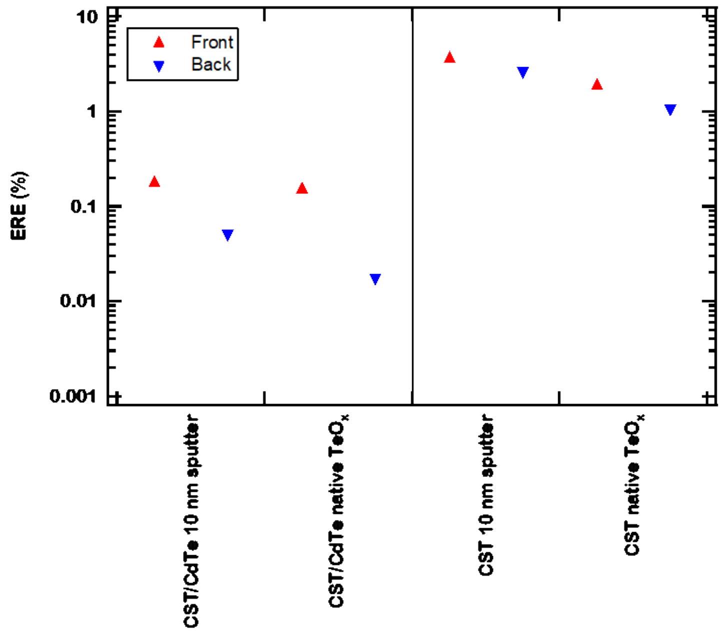


TeO_x is measured after 2 weeks dry air exposure on both CdTe and CdSeTe surfaces

Tracking recombination losses – Rear Surface

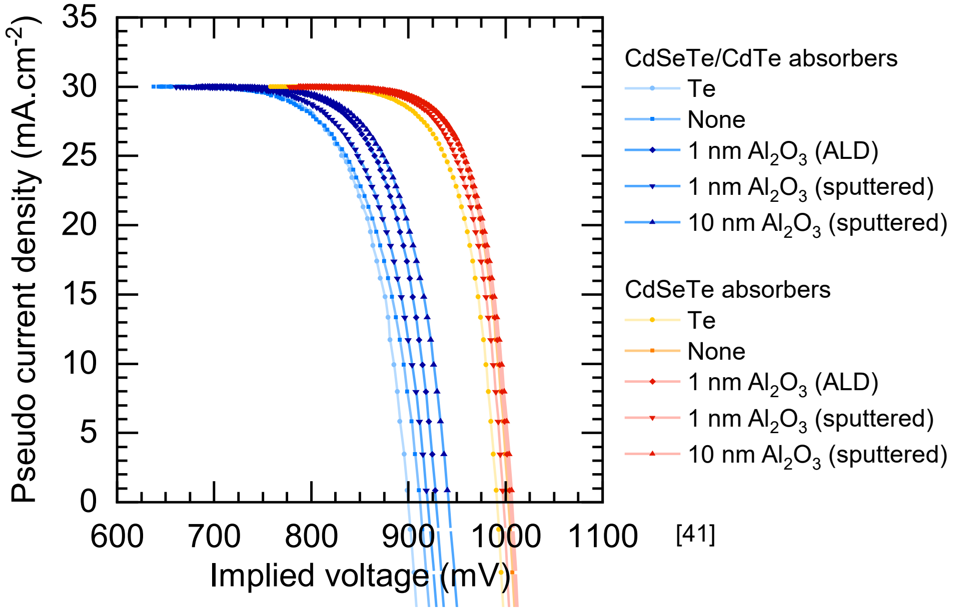


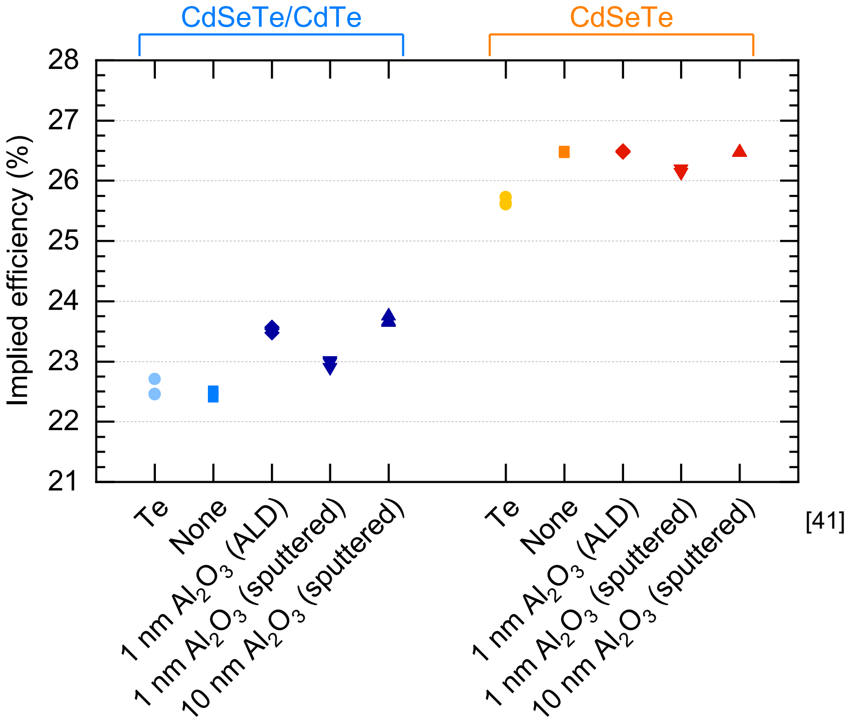
Increasing TeO_x at surface



- ERE increases in correlation with TeO_x fraction after air exposure
- ERE measured from the front and back are in good agreement for CdSeTe – difference in bilayer likely due to CdTe bulk recombination

Implied JV





Implied voltage of ~1 V and Implied Efficiency of > 25%* with CdSeTe-only absorber (*-corrected for sub Eg emission, 26.5% without correction)

CONCLUSIONS

1. MZO/CdSeTe interface has low surface recombination (S estimated ~10 cm/sec).

2. CdSeTe-only absorber has the highest lifetime to date (>4 microsecond)

3. Native TeOx layer passivates back surface (S estimated~10 cm/sec, order of magnitude estimate).

NEXT STEPS

1. Device modeling results show low hole mobility in CdSeTe. Improve hole mobility by processing.

2. Optimize As doping without defective as-deposited layer at the back.

3. Optimize the TeOx. Explore processing of TeOx than just native growth.

4. Device simulations suggest hole contact with conduction band above that of the absorber needed.

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Questions?