NREL/PR-5K00-80267

NREL
Transforming ENERGY

Emitter Reconstruction for Cleaved $CdSe_xTe_{1-x}$ Devices with Cu vs. As doping

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IEEE 48th PVSC meeting

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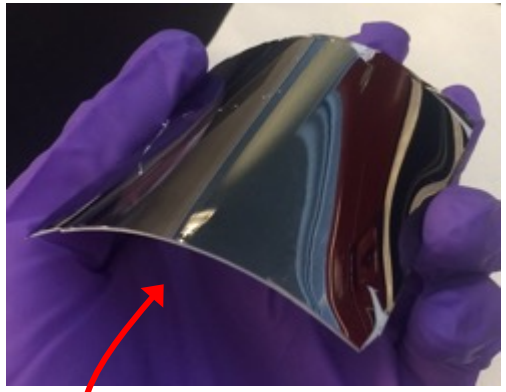
COLORADO SCHOOL OF MINES

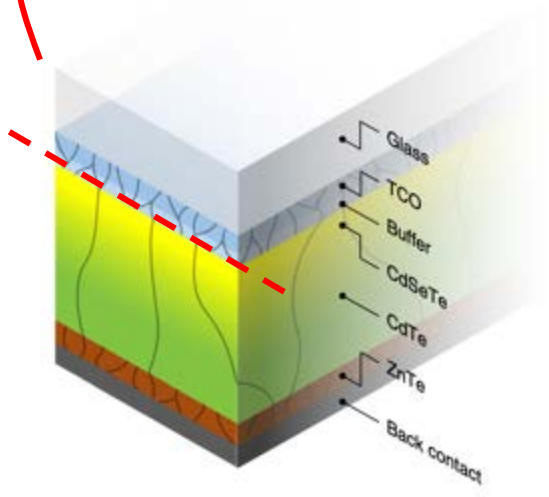
Overview

1. **Cadmium telluride (CdTe)**
2. **Cleave and reconstruction process: from superstrate to substrate**
3. **Reconstructed Cu vs. As doped $CdSe_xTe_{1-x}$**
4. **Understanding the differences through C-V & TRPL**

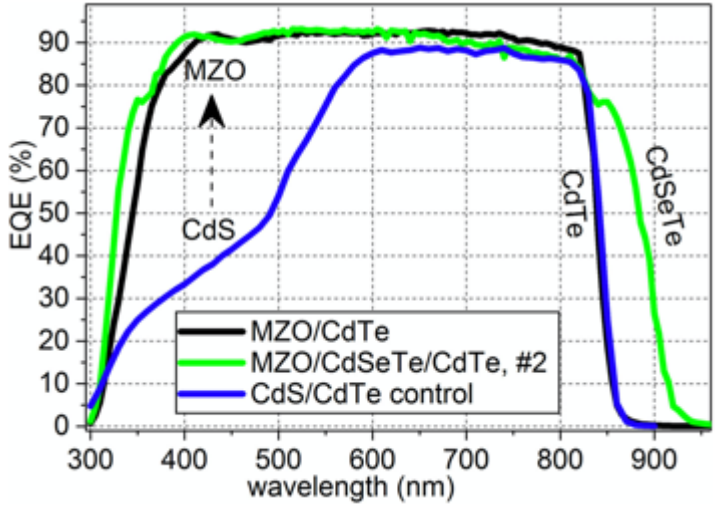
Cadmium telluride (CdTe)



- High capacity:
  - > 25 GW installed globally
  - 5% of global PV market
  - 40% of U.S. utility scale PV
- < $0.30/Wp, glass → module in hours
- 22.1% record cell efficiency



Metzger et al. DOI: 10.1038/s41560-019-0446-7



Ablekim et al. DOI: 10.1109/JPHOTOV.2018.2877982

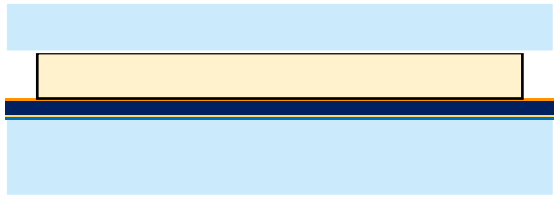
Recent improvements:

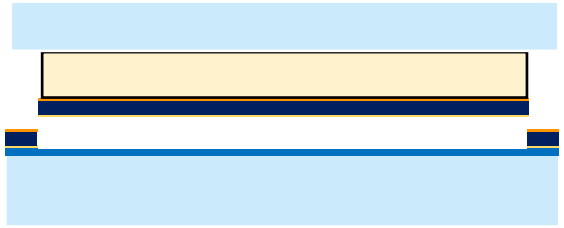
- CdS → MgZnO (MZO) buffer
- Se incorporation in absorber - graded $CdSe_xTe_{1-x}$ bandgap
- Cu → Gr-V (As) defect chemistry:

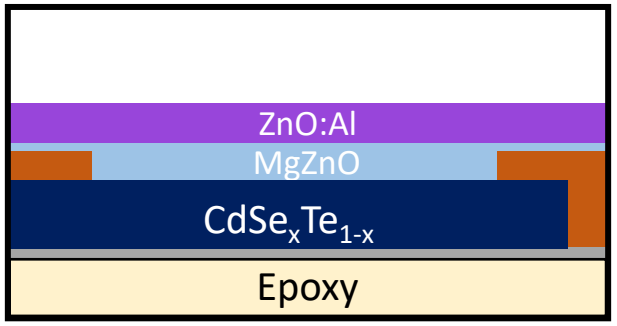
  $p_{absorber}$ ~ 10^{14} → 10^{16} cm^{-3}

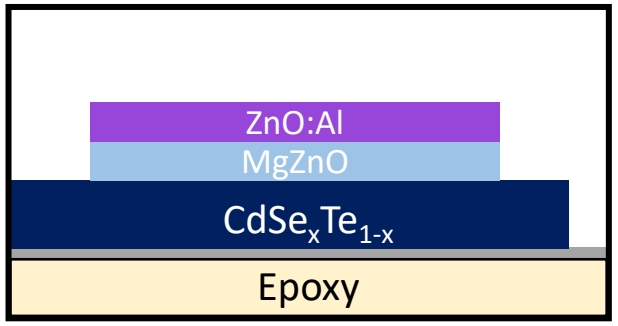
Results in > 20% efficiency

Cleave and reconstruction process



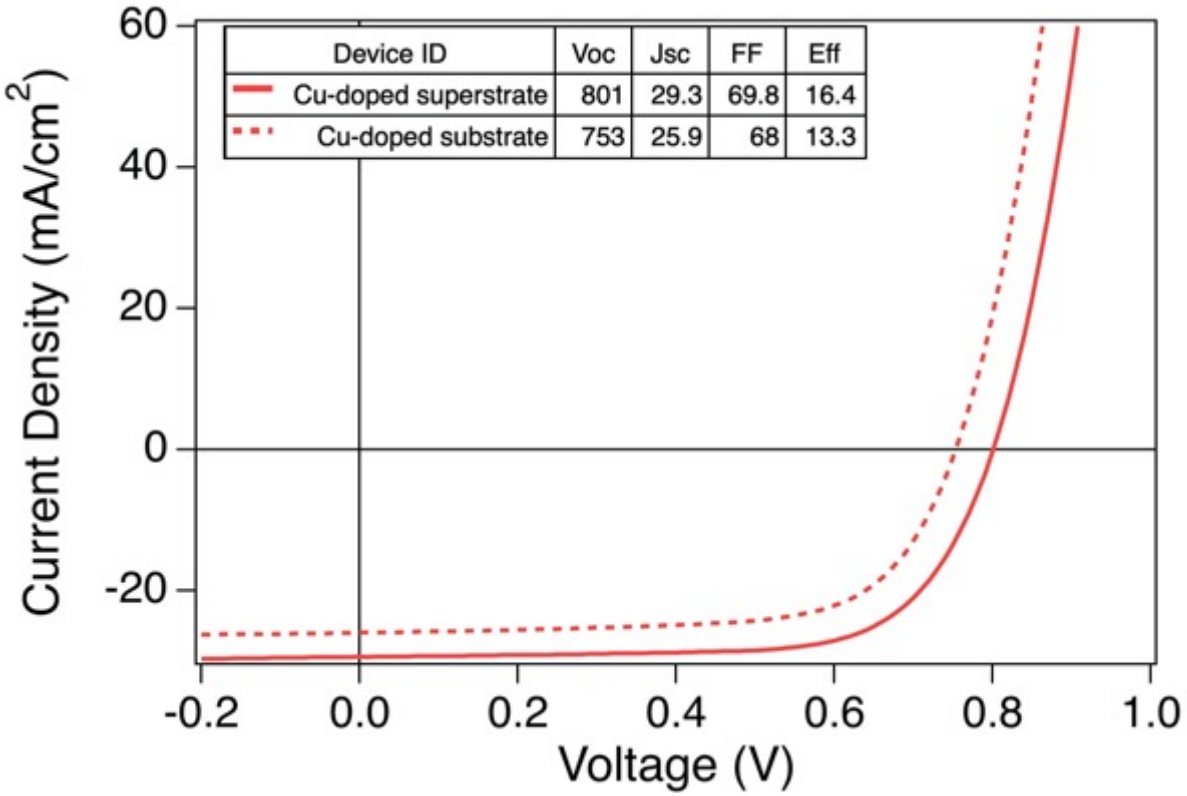






- In *superstrate* structure, MZO evolves during exposure to high temps/ harsh chemicals in subsequent growth steps → unclear what front interface looks like
- In *substrate* structure, the MZO does not evolve → can test front interface modeling more directly

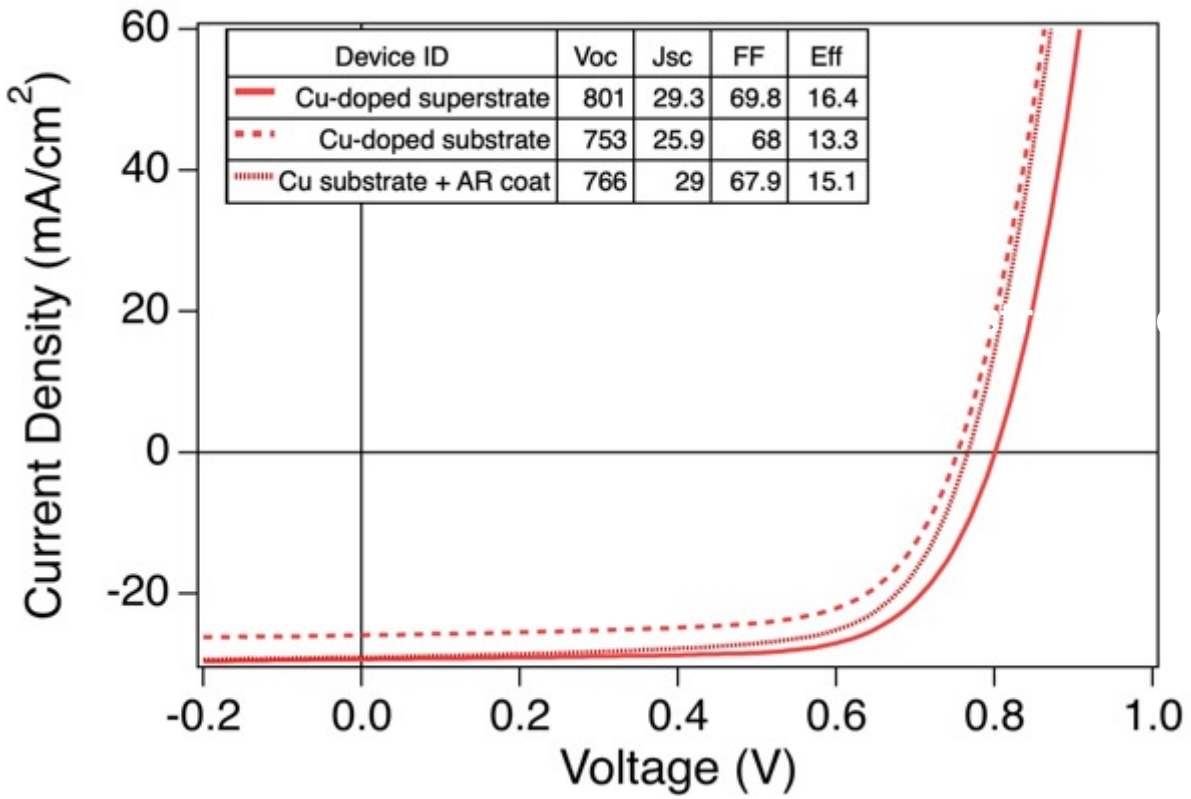
Reconstructed device performance



- Cu maintains > 80% original efficiency

McGott et al. In preparation.

Reconstructed device performance



- Cu maintains > 80% original efficiency
- With AR coating, obtain 15% efficient *substrate* CdTe device

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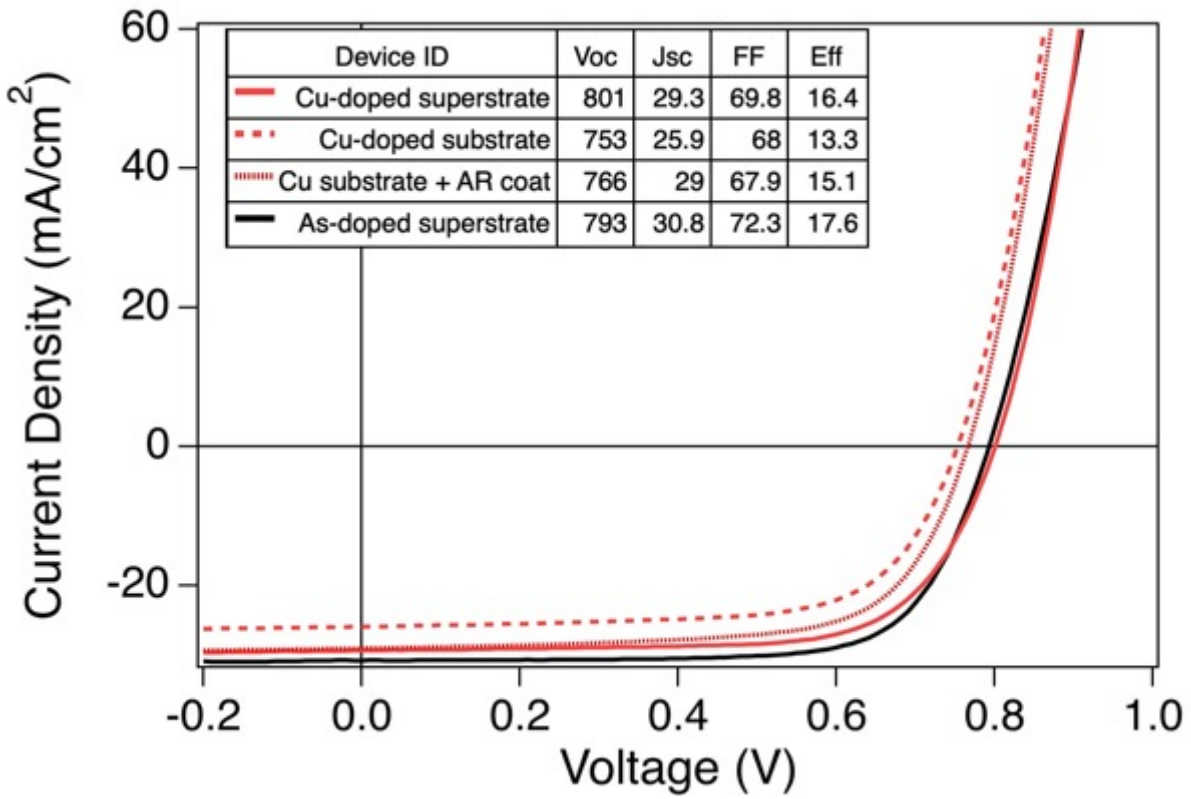

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- Gr-V device has better performance to start…

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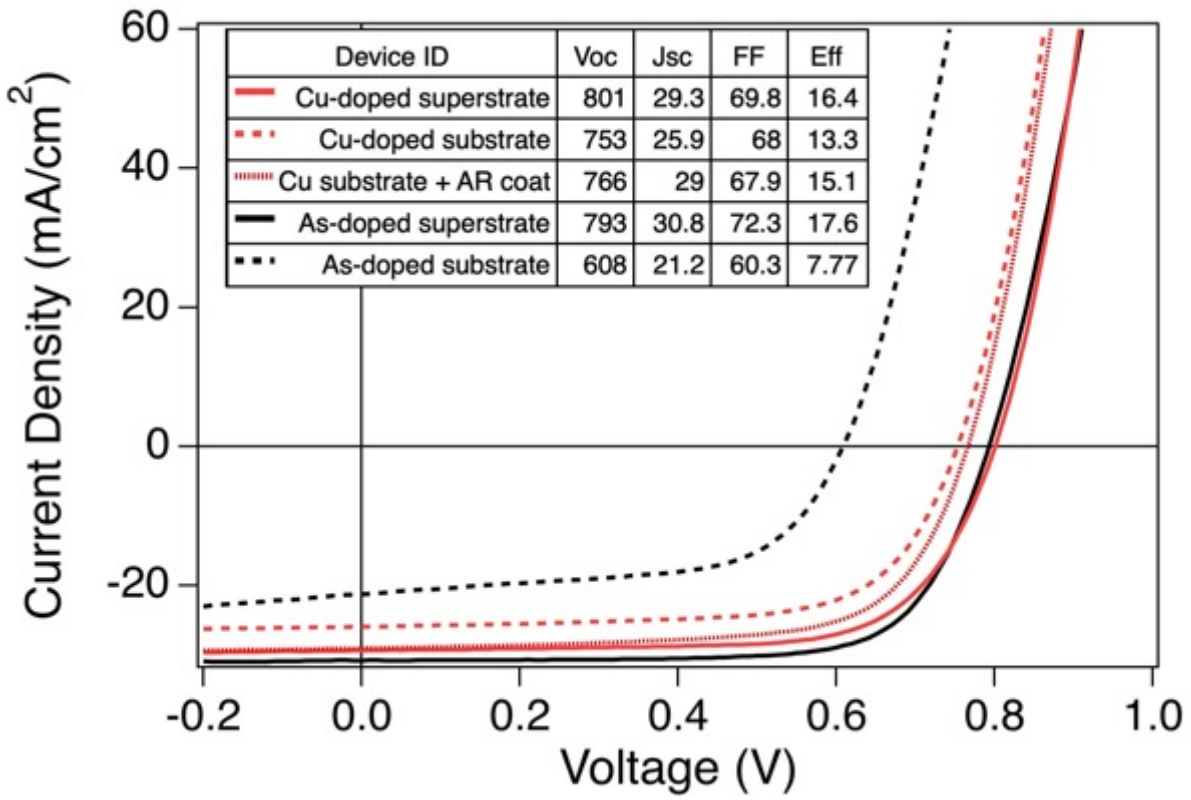
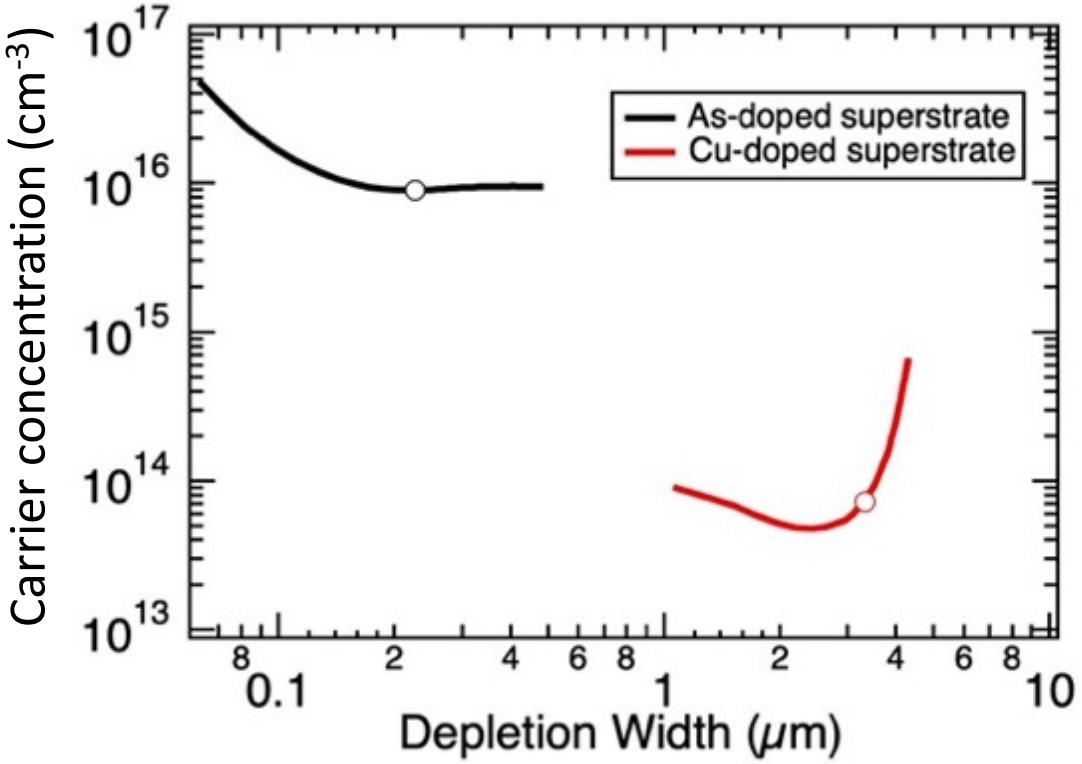
Reconstructed device performance



- Cu maintains > 80% original efficiency
- With AR coating, obtain 15% efficient *substrate* CdTe device
- Gr-V device has better performance to start… but drops by > 50% using same reconstruction process
  - (Low R_{sh}, J_{sc}, V_{oc}, FF)
- Use other characterization to understand the origin of difference

McGott et al. In preparation.

Why the difference? – C-V



	Superstrate (before reconstruction)	
	As-doped	Cu-doped
Carrier concen. (cm^{-3})	10^{16}	$8x10^{13}$
Depletion width (µm)	0.25	3.5 (film thickness)

McGott et al. In preparation.

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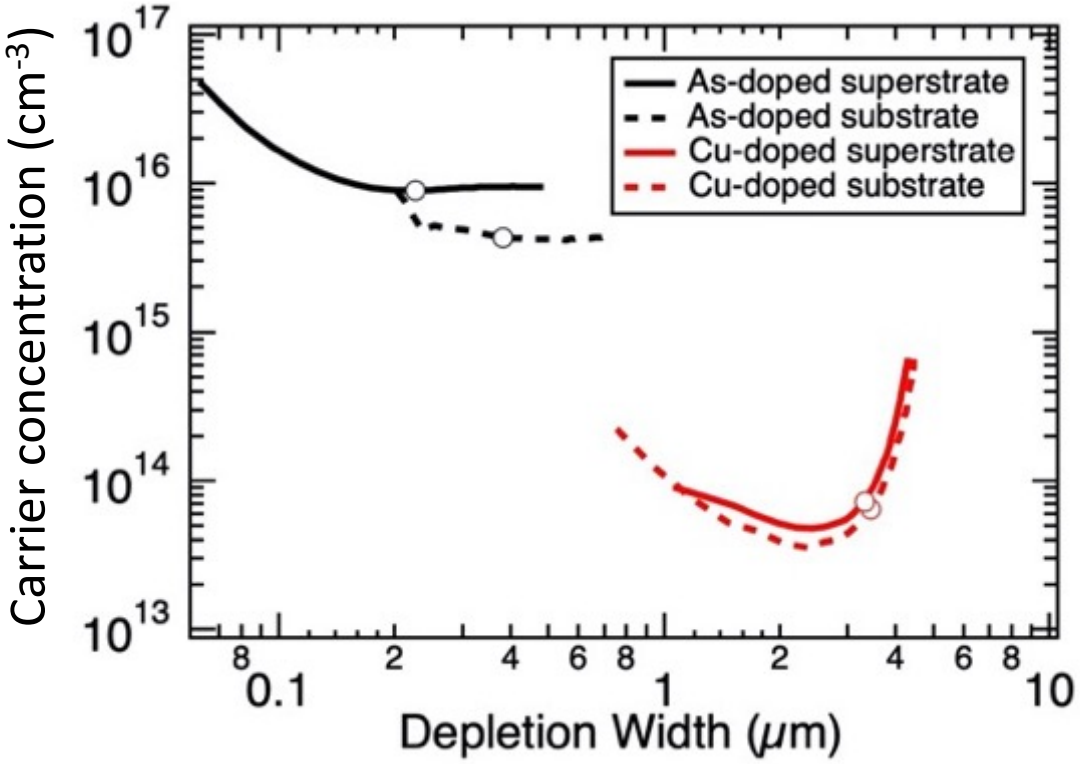
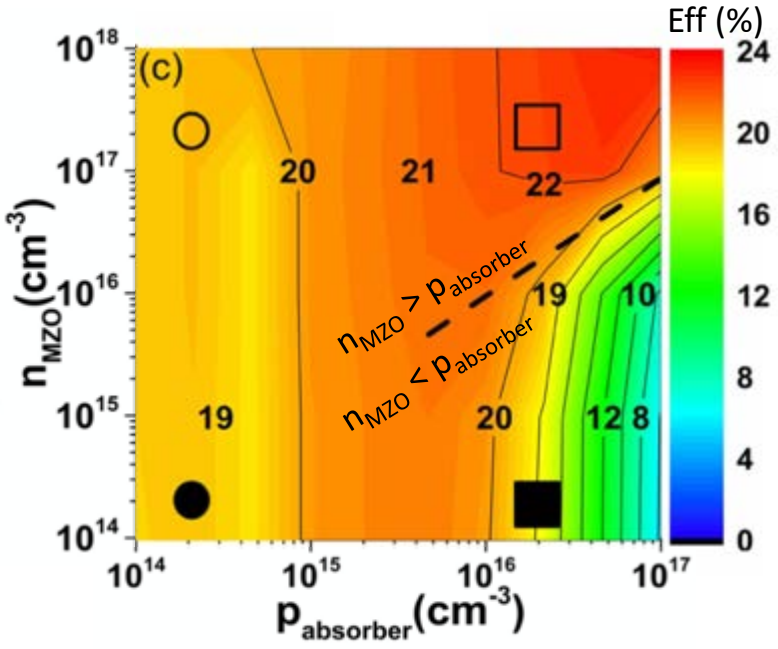


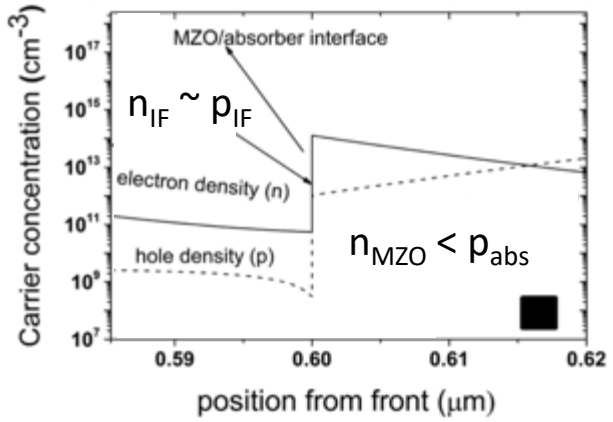
	Superstrate (before reconstruction)		Substrate (after reconstruction)	
	As-doped	Cu-doped	As-doped	Cu-doped
Carrier concen. (cm^{-3})	10^{16}	8×10^{13}	2×10^{15}	~8×10^{13}
Depletion width (µm)	0.25	3.5 (film thickness)	0.4	3.5

$n_{MZO} < 10^{16}$ cm^{-3} → $N_D \sim N_A$ $\quad N_{CV} = \frac{N_A \cdot N_D}{N_A + N_D}$ $\quad N_{CV} \sim \frac{N_A}{2}$

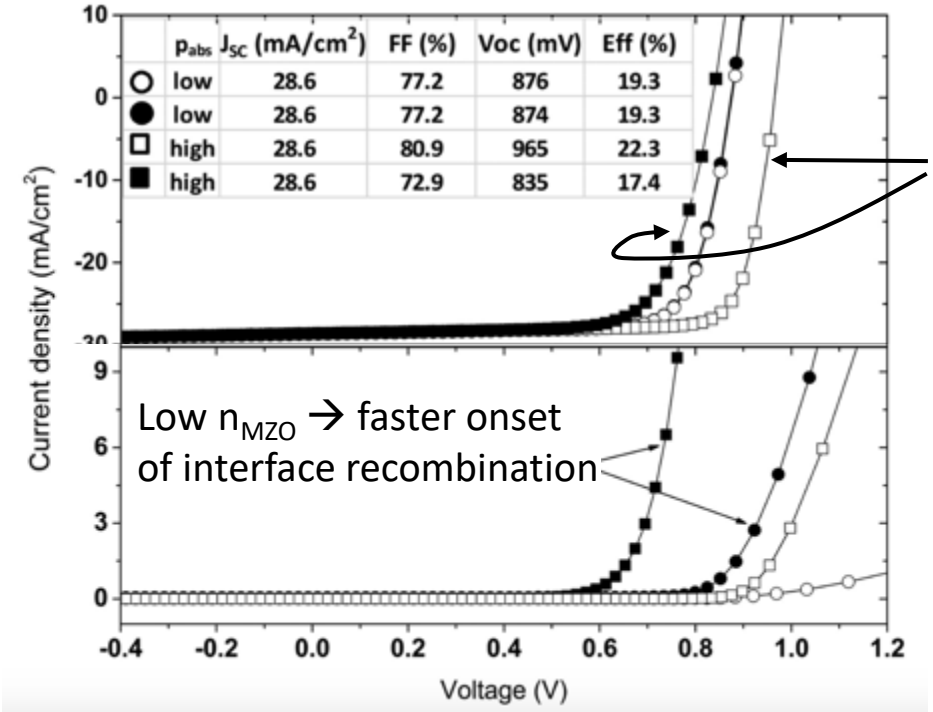
McGott et al. In preparation.

Effect of low emitter doping

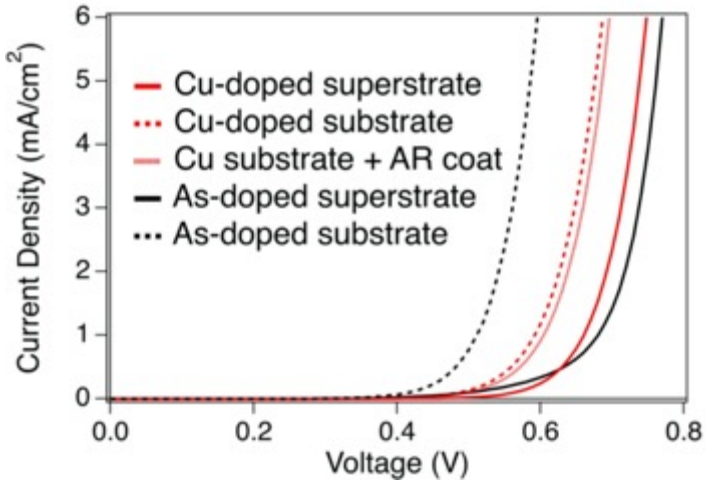




Low p_{abs} → n_{MZO} doesn't matter



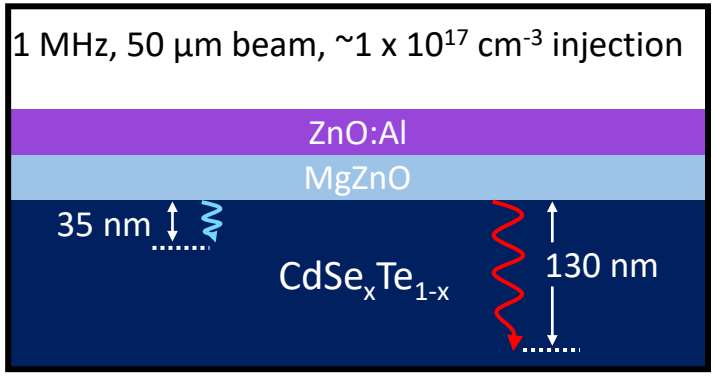
High p_{abs} → low n_{MZO} reduces V_{OC} and FF

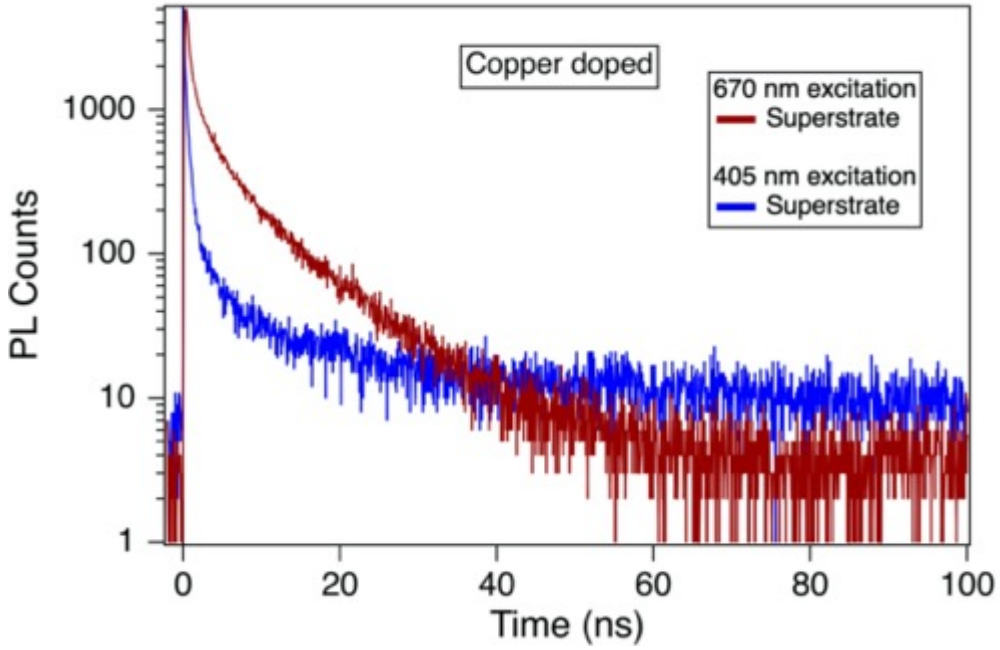


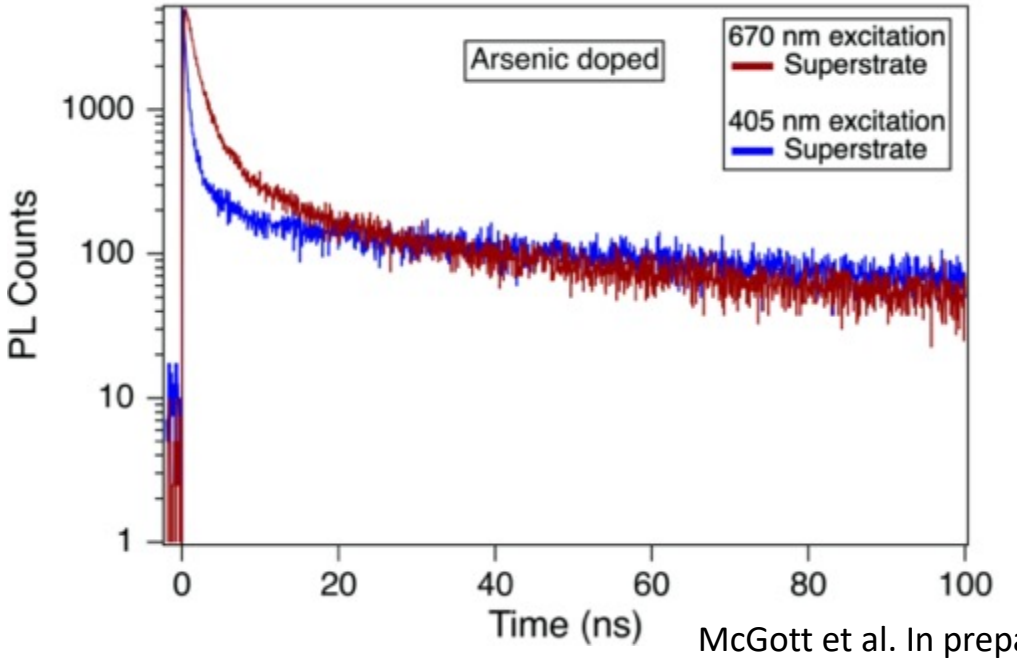
Pandey et al. DOI: 10.1109/JPHOTOV.2020.3017741

Why the difference? – TRPL

Time resolved photoluminescence (TRPL) with two excitation wavelengths (670 and 405 nm) probe different depths







McGott et al. In preparation.

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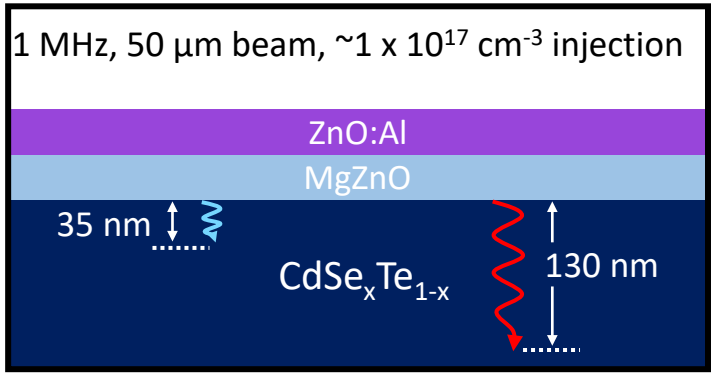
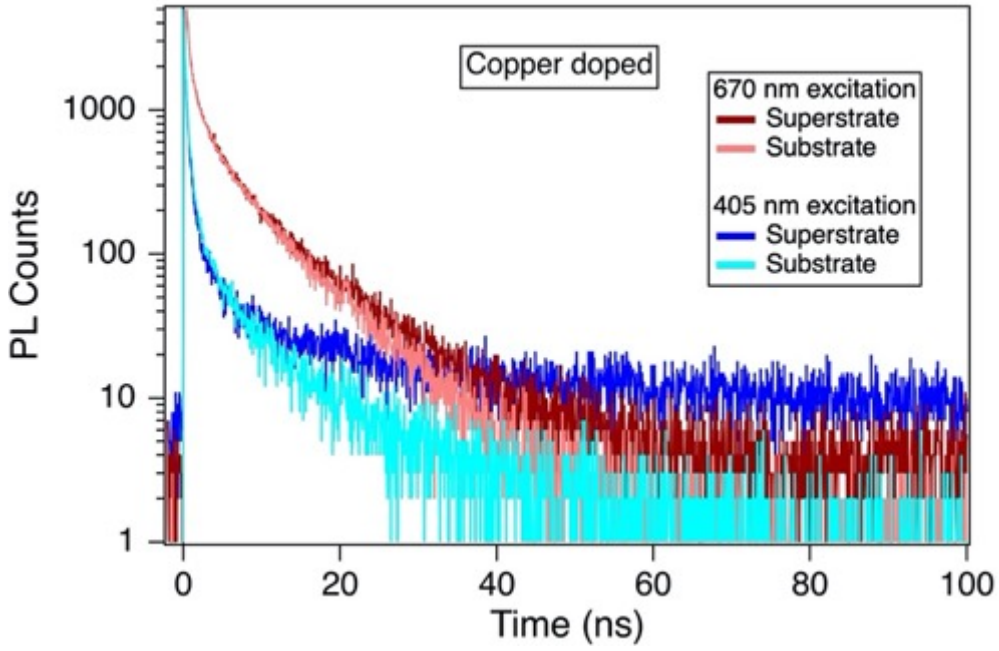
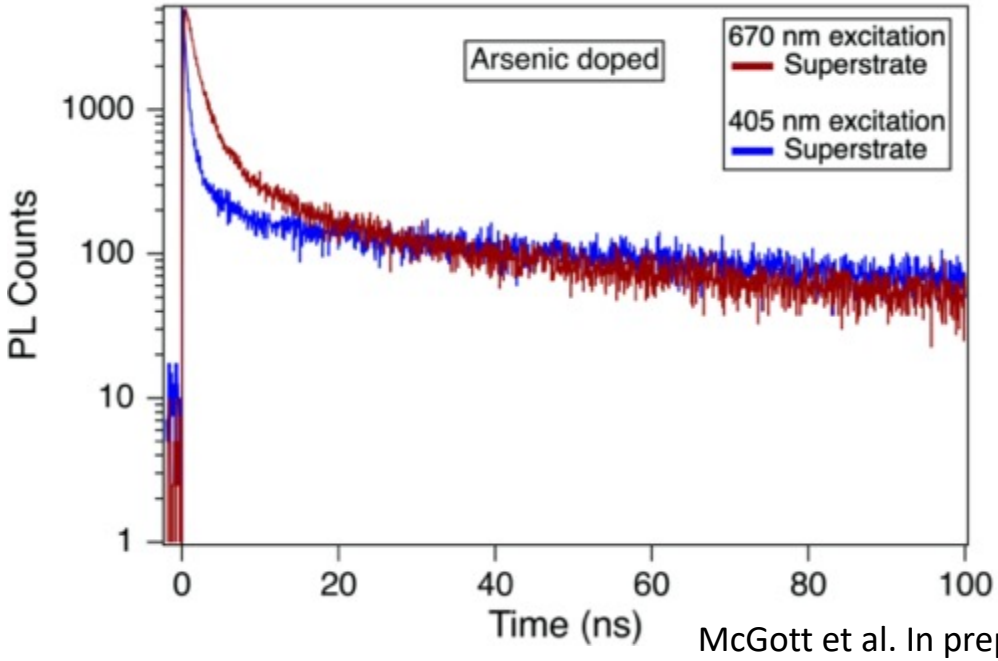


Cu-doped

- 670 nm: essentially unchanged
- 405 nm: surface shows more effect → possible damage during cleave/reconstruction





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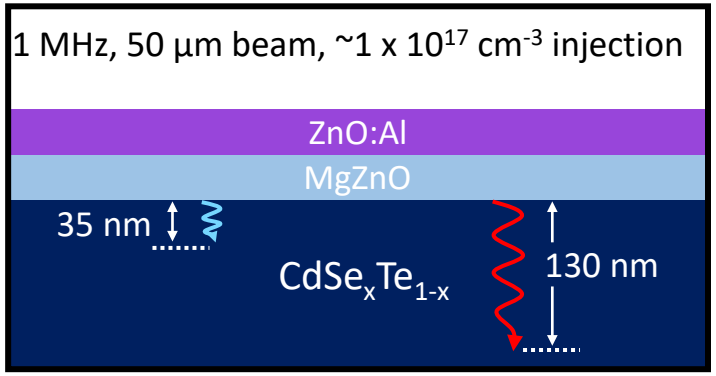

Cu-doped
- 670 nm: essentially unchanged
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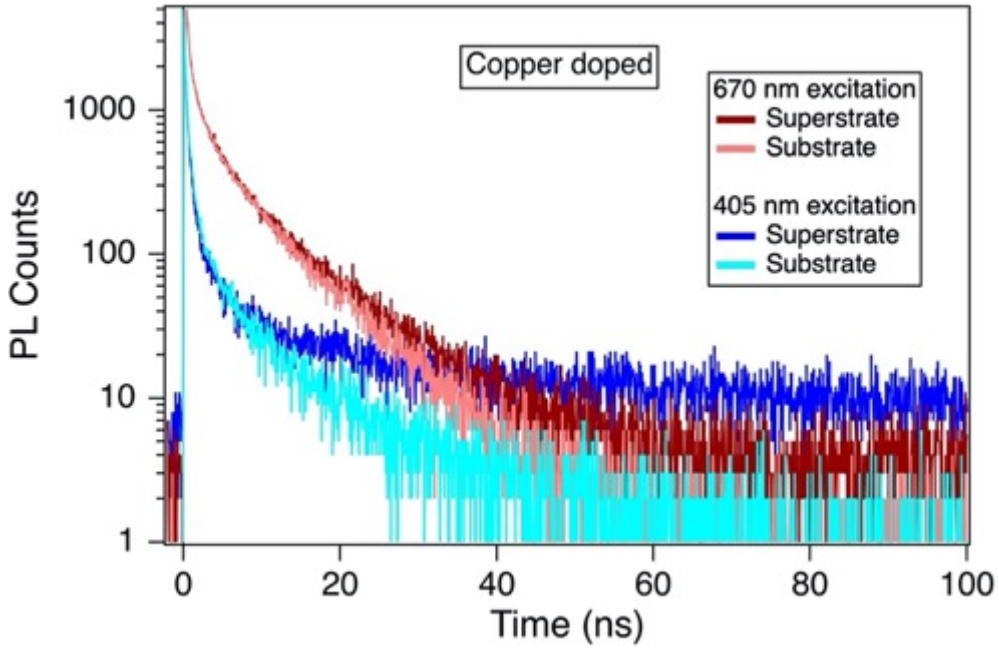
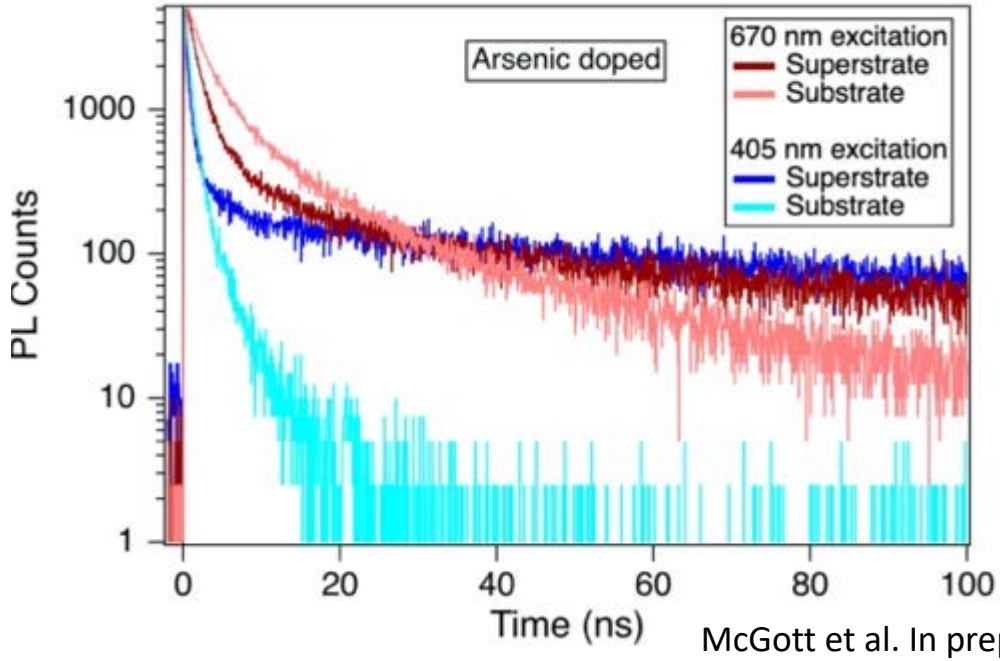
As-doped
- 405 nm: limited by interface recombination
- 670 nm: weaker junction field after reconstruction





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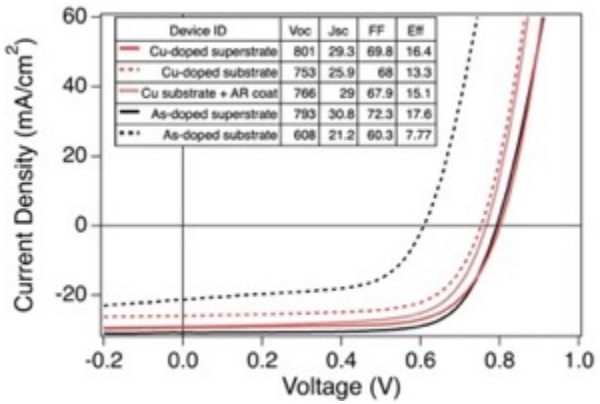
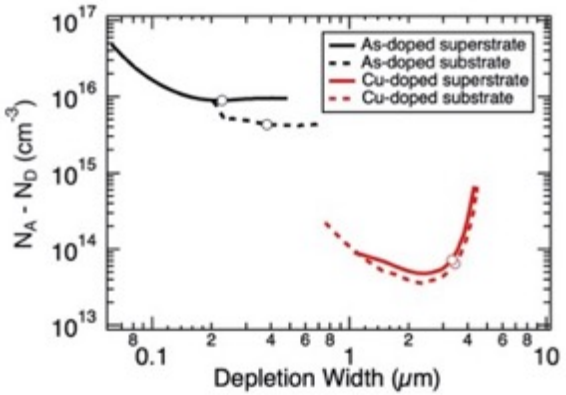
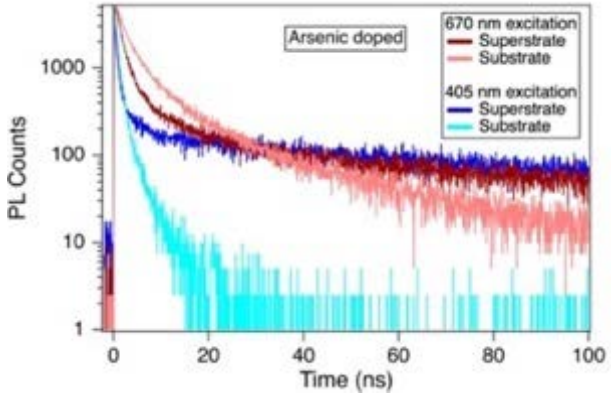
Summary







Key take-aways:

- Large drop in performance for reconstructed As-doped devices but not Cu-doped
- Causes:
  - As-doped device more sensitive to front interface to start (narrow depletion width)
  - Made more sensitive to interface after reconstruction (low N_D, weaker $E_{junction}$)
  - Interface recombination increased due to sputter damage and/or chemical reaction?
- Experimentally validated front interface modeling: *i*-MZO is not a good heteropartner for As-doped devices

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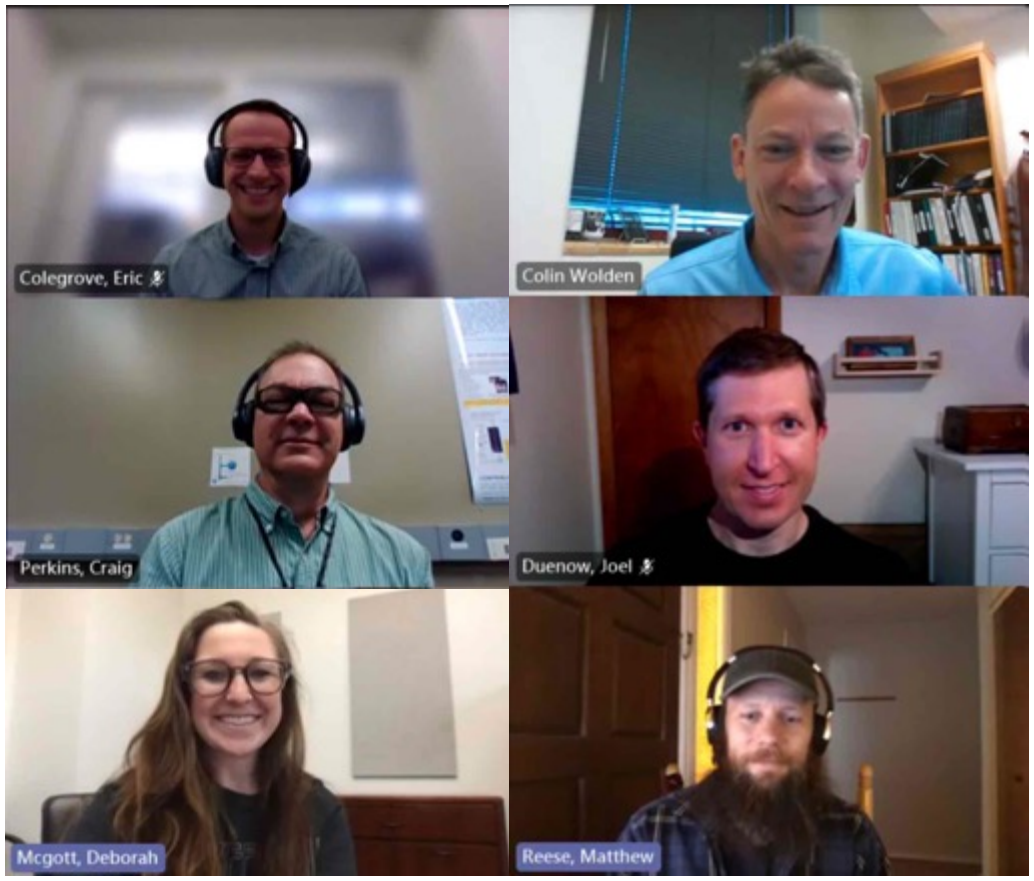
Thank you!



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