

# Demonstrating Band Tail Voltage Limitations in CZTSSe (PV-1)



A joint India-U.S. research consortium funded under the *Joint Clean Energy Research & Development Center (JCERDC)*

## Scientific Achievement:

For the first time, we clearly demonstrate that band-tail defects in CZTSSe result in reduced carrier collection at forward bias and  $V_{OC}$  limitations through voltage-dependent external quantum efficiency (EQE) analyses.

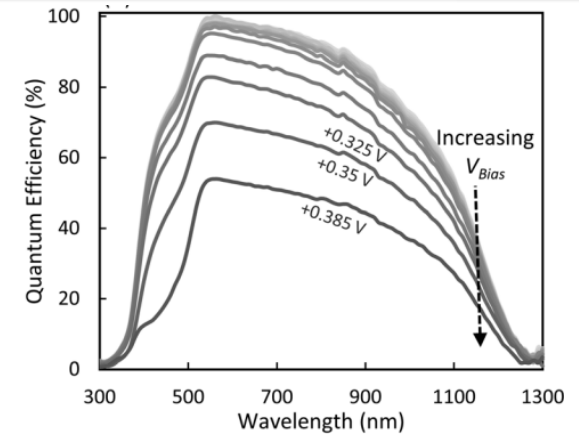
## Significance and Impact:

Currently, there is no consensus on why CZTSSe devices suffer from low  $V_{OC}$ . Through detailed analyses, we show band-tail-state-limited recombination describes voltage-dependent collection limitations, whereas other proposed models such as space-charge and interface-limited recombination do not. This suggests band-tail states must be reduced or a different absorb material will be needed to produce high-efficiency solar cells.

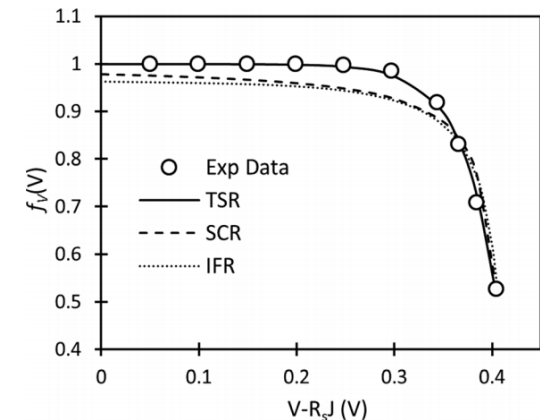
## Research Details:

Using a 9.3% CZTSSe device fabricated from nanocrystal ink, reverse and forward bias voltage-dependent EQE was performed and analyzed:

- Voltage-dependent collection was separated from diffusion-limited collection. An analyses method is demonstrated to separate the absorption coefficient, diffusion length, and mobility as a function of the back-surface recombination.
- The voltage-dependent collection is shown to be limited by a derived band-tail-state recombination (TSR) model, as oppose to existing space-charge (SCR) and interface-limited (IFR) recombination models.



Voltage-dependent IQE data for CZTSSe from -1 V to +0.385 V.



Collection efficiency vs.  $V-R_s J$  measured from EQE data (data points) and best fit for various  $V_{OC}$  limited models.

**Contact(s):** Mark Koeper ([mkoeper@purdue.edu](mailto:mkoeper@purdue.edu))  
Rakesh Agrawal ([agrawalr@purdue.edu](mailto:agrawalr@purdue.edu))  
Sean Garner ([GarnerSM@Corning.com](mailto:GarnerSM@Corning.com))