National Renewable Energy Laboratory
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Metastable Effects in Polycrystalline Thin Film Cells and Correlations with Performance and Durability

PV Module Reliability Workshop

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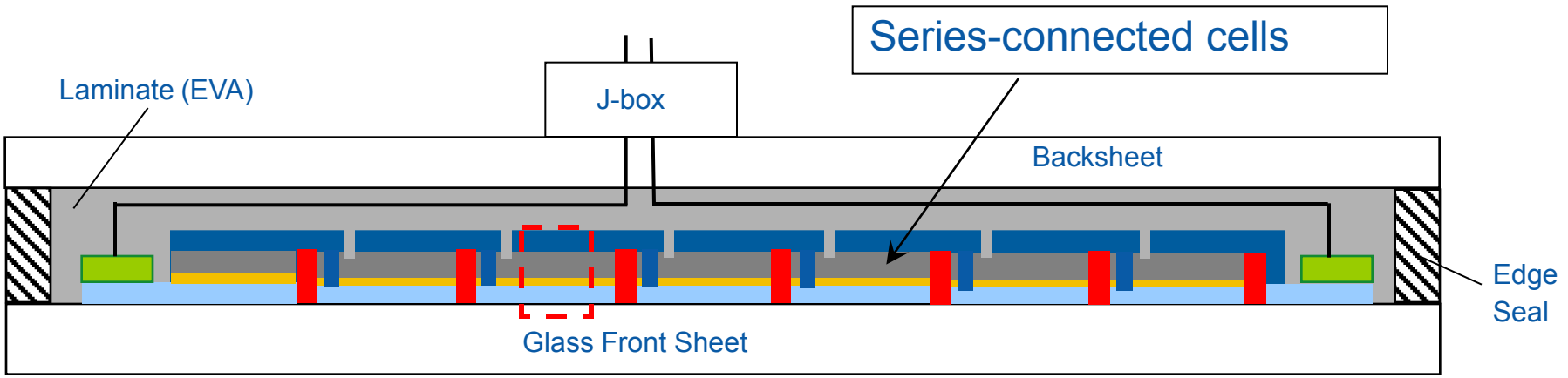
Industry Collaborations

This presentation does not contain any proprietary or confidential information.

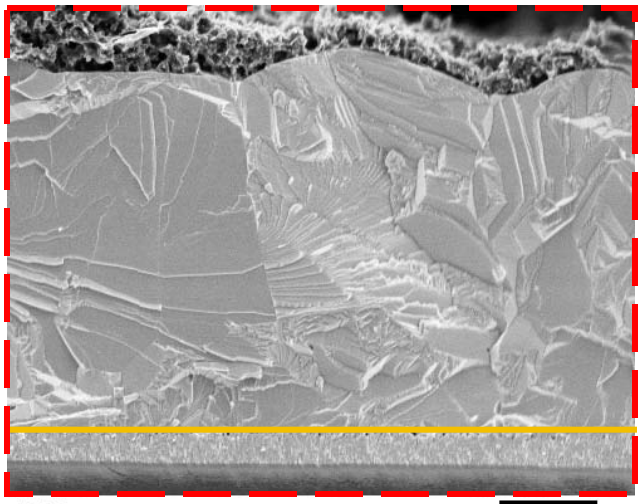
Cell durability fundamental to module durability

Systems

Modules



Cell durability is a function of cell fabrication



light

back contact

back contact

p-layer

n-layer

TCO

glass

metallization (ZnTe, metals, dag-pastes)

Cu-doping

back contact Surface Prep (acid etch, dry etch)

$CdCl_2$ (soln, vapor)

CdTe (CSS)

CdS (CSS, sputter, CBD)

650 ºC – CdS+He anneal

Zn_xSnO_x (ZTO, sputter)

650 ºC – CdS+He anneal

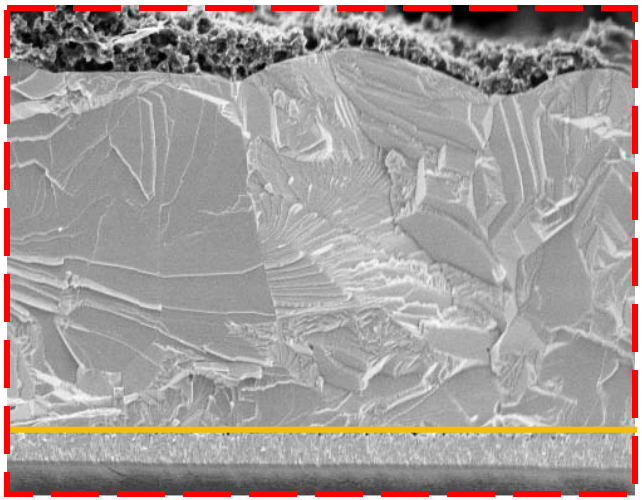
Cd_2SnO_4 (CTO, sputter)

i-SnO_2 (MOCVD)

F-doped n-SnO_2 (MOCVD)

Glass Superstrate (borosilicate vs sodalime)

Past Cell Durability Studies



light

back contact

back contact

p-layer

n-layer

TCO

"**Pre-contact Surface Chemistry Affects on CdS/CdTe Solar Cell Performance and Stability**", Albin, et al., 28th IEEE PVSC, 583-586 (**2000**)

"**Stability study of CdS/CdTe solar cells made with Ag and Ni back-contacts**", Demtsu, et al., Sol. Energy Mat. & Solar Cells, 90, 2934-2943 (**2006**)

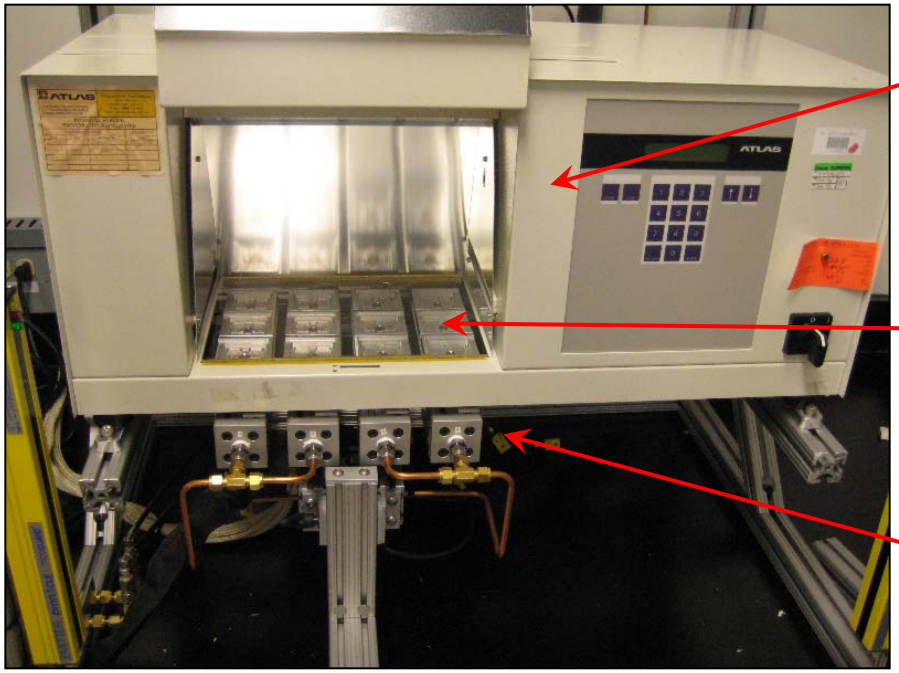
"**Film thickness and chemical processing effects on the stability of cadmium telluride solar cells**", Albin et al., Thin Solid Films, 2659-2668 (**2006**)

"**Accelerated Stress Testing and Diagnostic Analysis of Degradation in CdTe Solar Cells**", Albin, in Reliability of Photovoltaic Cells, Modules, Components, and Systems ed. N. Dhere, SPIE Proceedings Vol. 7048 (**2008**)

"**Degradation and Capacitance-Voltage Hysteresis in CdTe Devices**", Albin et al., , in Reliability of Photovoltaic Cells, Modules, Components, and Systems II ed. N. Dhere, SPIE Proceedings Vol. 7412 (**2009**)

"**Striving for a standard protocol for preconditioning or stabilization of polycrystalline thin film photovoltaic modules**", del Cueto et al., , in Reliability of Photovoltaic Cells, Modules, Components, and Systems II ed. N. Dhere, SPIE Proceedings Vol. 7412 (**2009**)

Cell Accelerated Lifetime Testing (ALT)



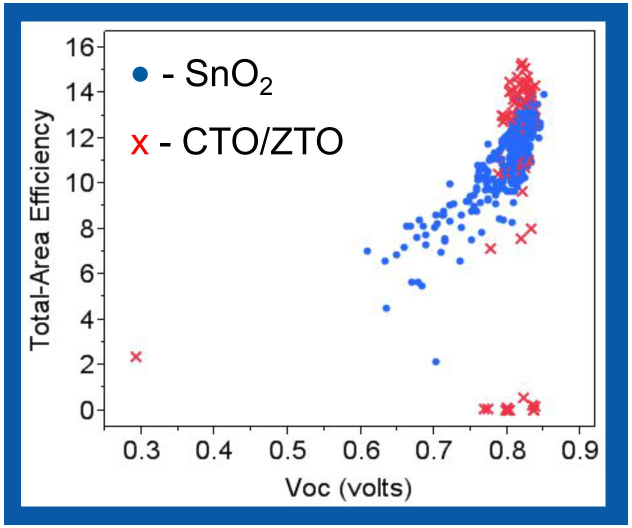
Atlas Suntest CPS solar simulator
- Solar-matched spectrum
- 1500 hrs continuous
- V_{oc} bias

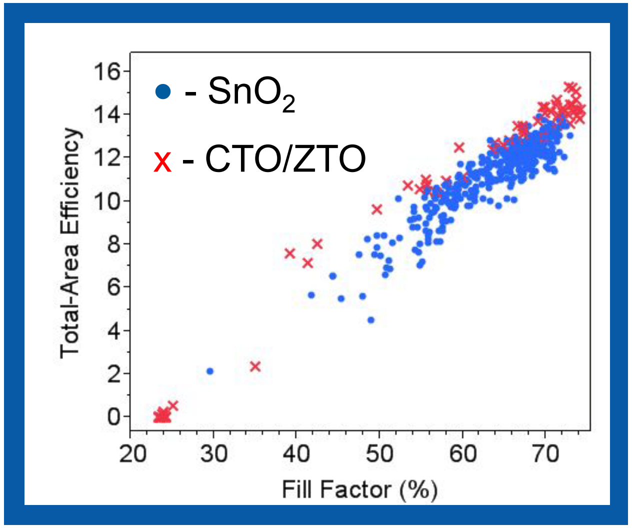
Aluminum-milled cell holders
- Cells oriented TCO up
- No Shunting
- Good thermal uniformity

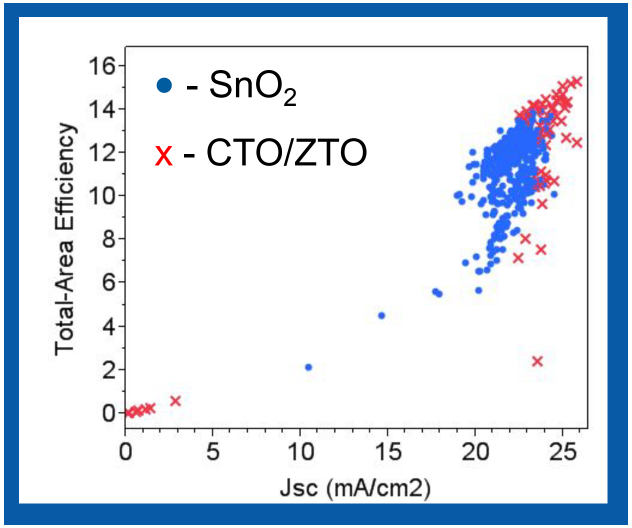
Independent heating/cooling zones
- T_{sample} controlled to ±1 ºC
- Irradiance can affect T_{sample}

Experimental Procedure:
- Make initial, t=0 measurement
- Expose cells for some t
- Remove cells, store in the dark (12-24 hrs)
- Measure cells (J-V, **C-V**, Q-E, etc.)
- Repeat

SPIE 2009 Study –Performance of CTO/ZTO vs $nSnO_2/iSnO_2$





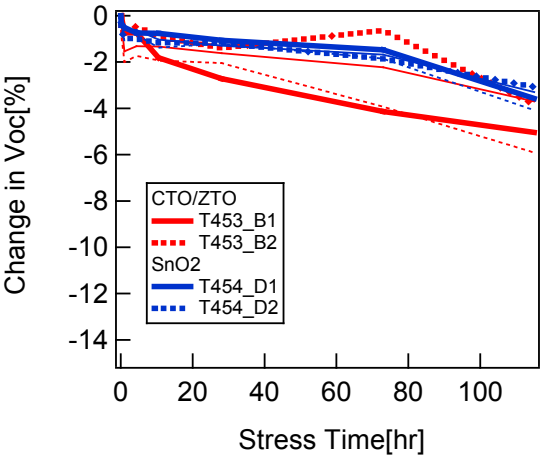


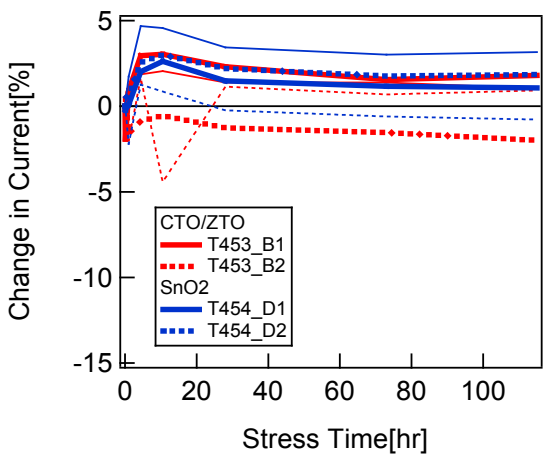
No difference in V_{oc}

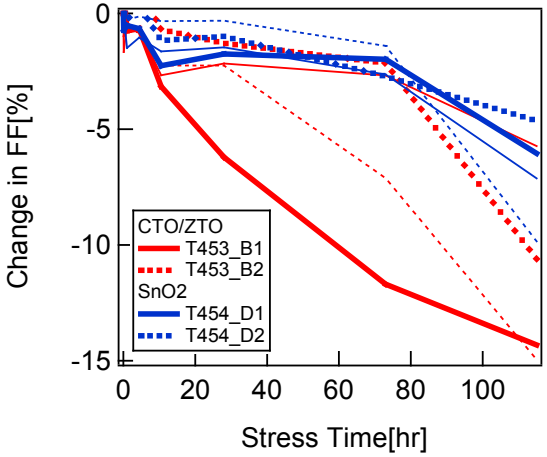
~1.5 mA/cm^2 increase in J_{sc}

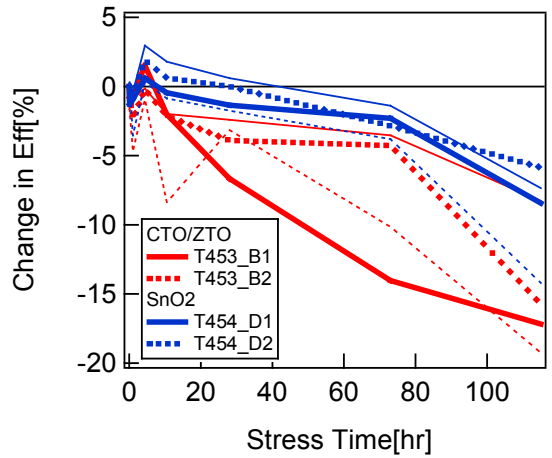
FF increases about 1 to 1.5 % pts.

SPIE 2009 Study –Durability of CTO/ZTO vs $nSnO_2/iSnO_2$









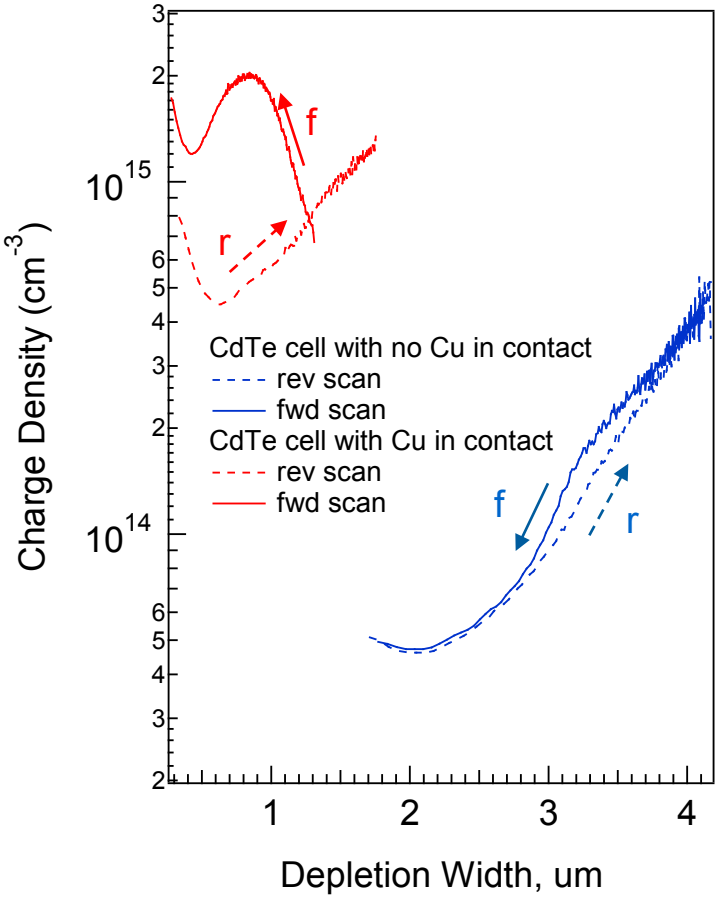
Cells fabricated identically except for TCO

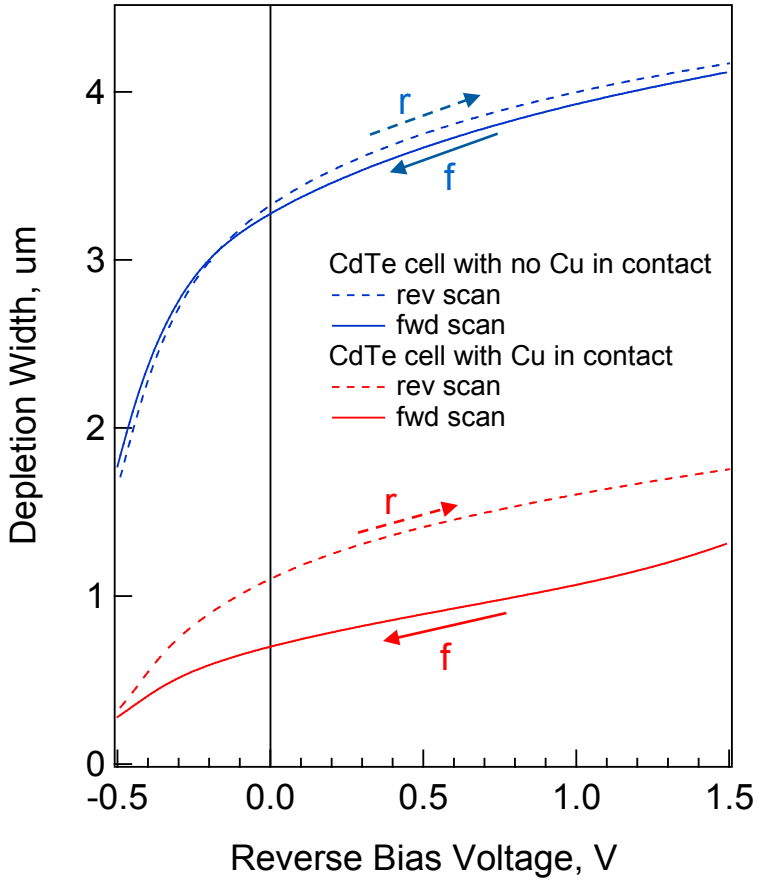
(Cu,Hg) doped BC	(Cu,Hg) doped BC
CdTe	CdTe
CdS	CdS
$ZnSn_xO_y$	**$i\text{-}SnO_2$**
Cd_2SnO_4	**$n\text{-}SnO_2$**
glass	glass

Stressed identically (100 ºC, V_{oc}, 1-Sun)

Differences in degradation due to different TCO layers

C-V hysteresis (metastability) during ALT

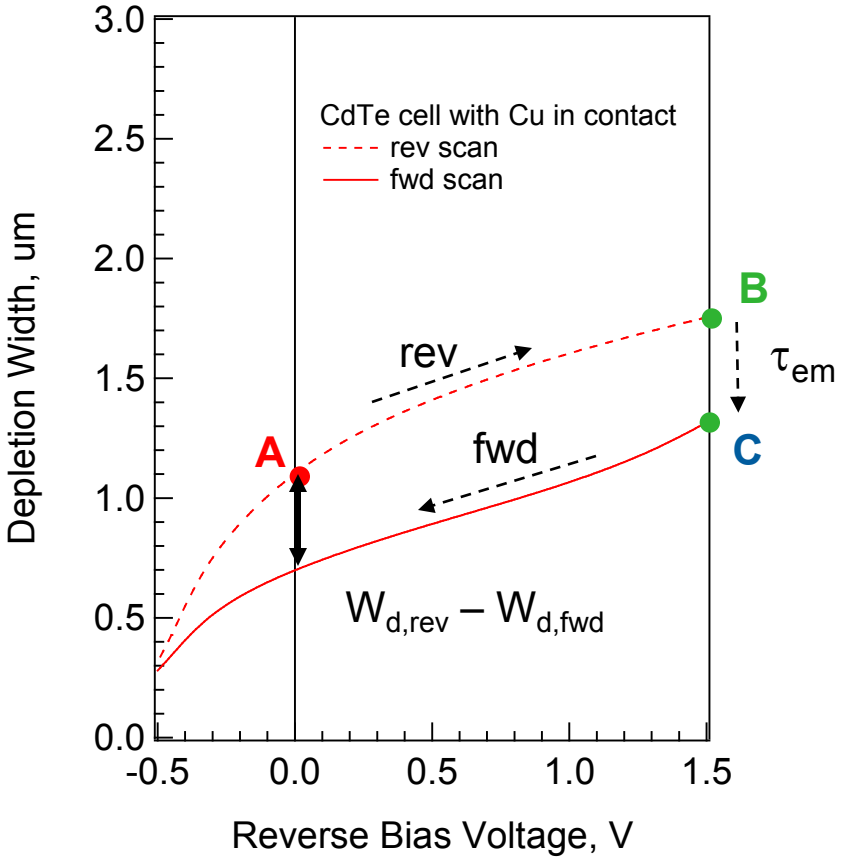


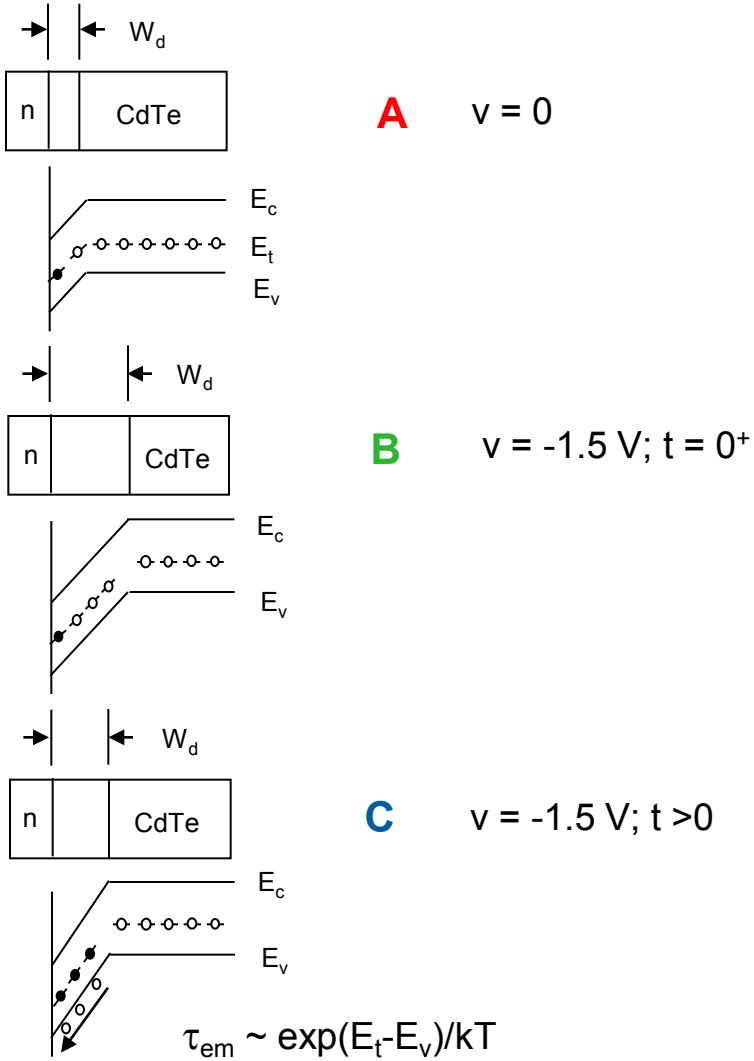


"rev scan" → +0.5 V to -1.5 V

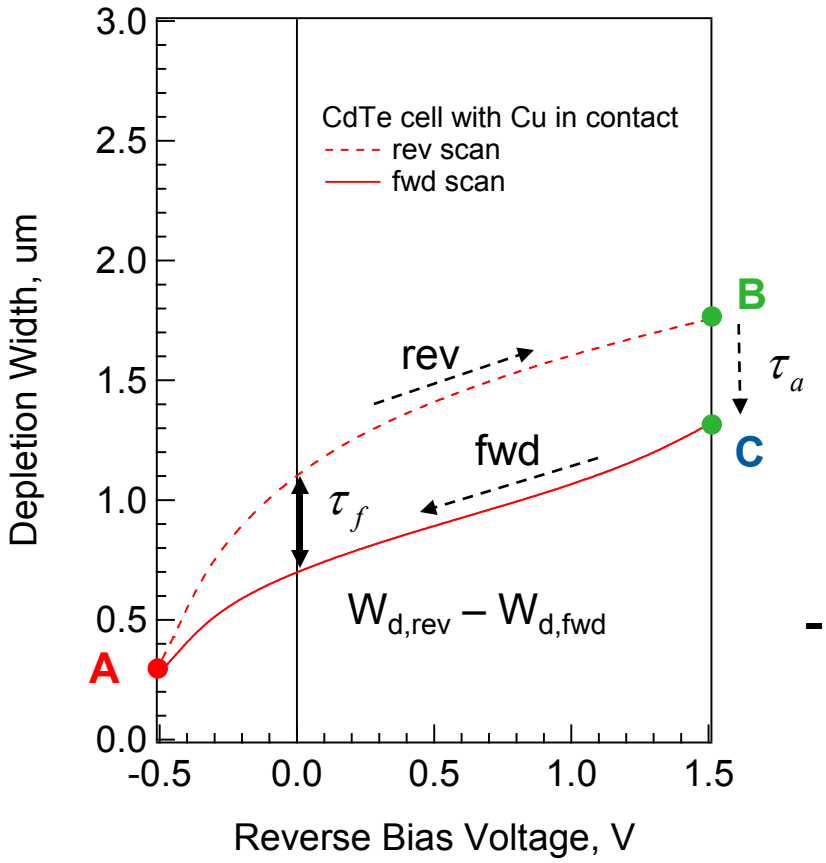
"fwd scan" → -1.5 V to +0.5 V

C-V hysteresis (electronic processes) during ALT





C-V hysteresis (ionic processes) during ALT



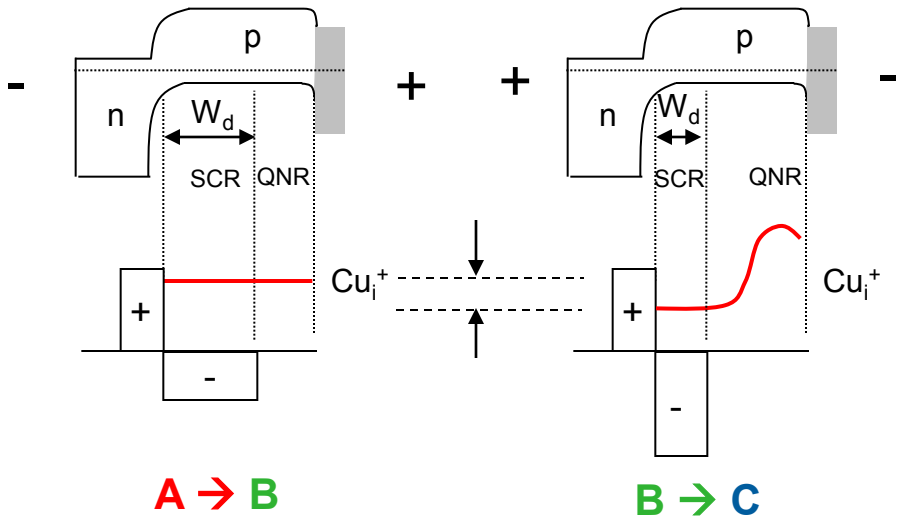
Perform "rev" scan

- *Measure SCR with Cu_i^+ screening N_a^-*

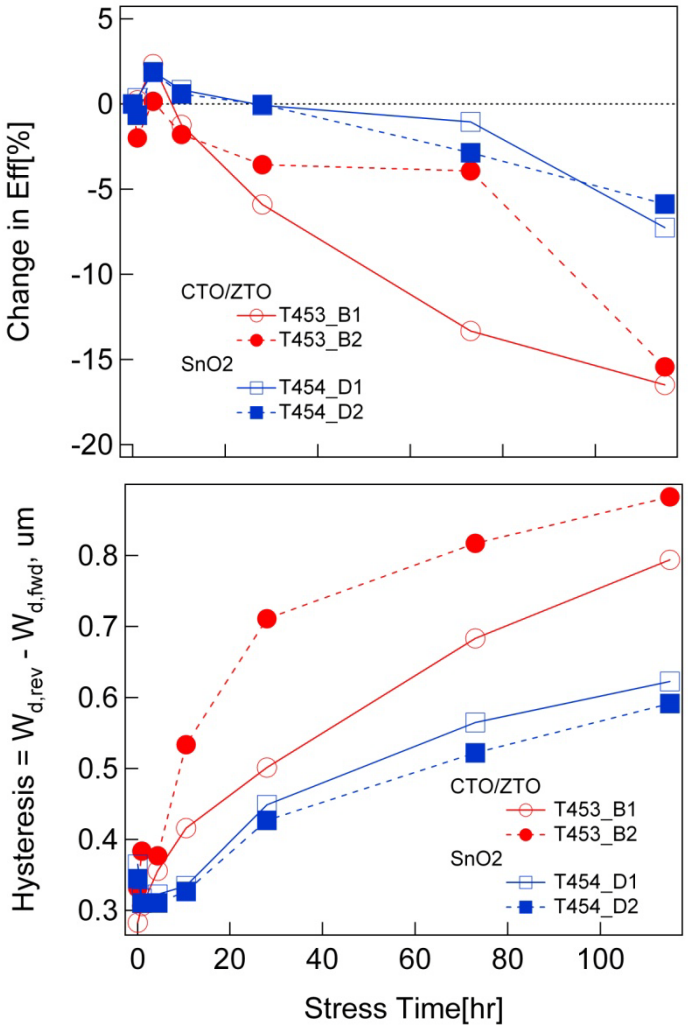
Hold cell at rev-bias for 5m (τ_a)

Perform "fwd" scan

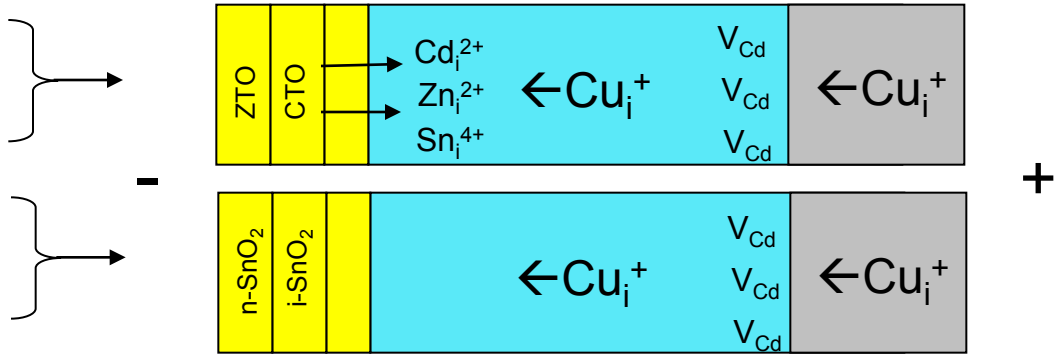
- *Measure SCR with Cu_i^+ removed from SCR*



CV-hysteresis correlates with performance during stress test

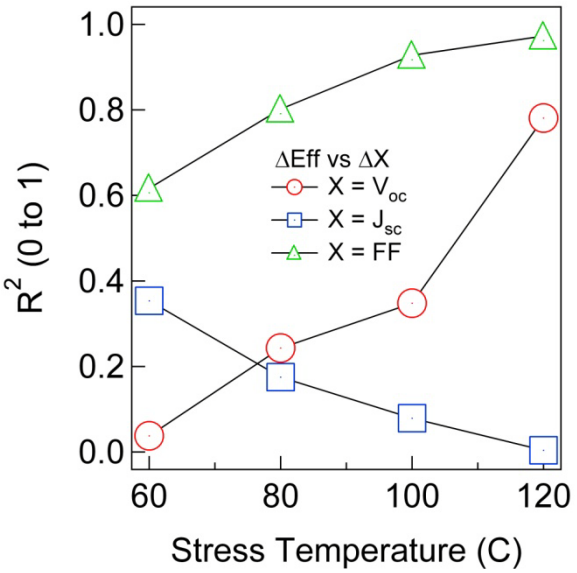


- CdTe cells grown on CTO/ZTO transparent conducting oxides *degrade faster*
- Magnitude of degradation proportional to hysteresis
- For all cells, increasing hysteresis partly due to continuous diffusion of Cu from the back contact.

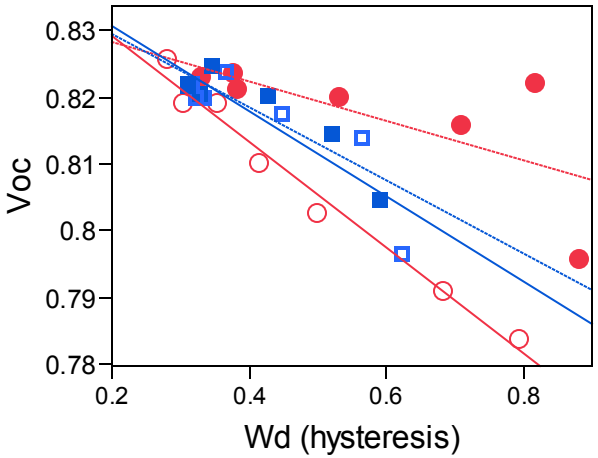


- Additional hysteresis indicative of "decomposition" of the CTO/ZTO layers

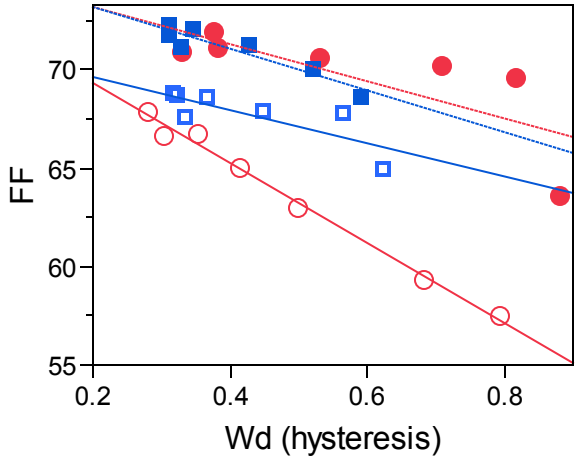
CV-hysteresis correlates with performance during stress test



•At 100 ºC; cell stability is determined by changes in FF and V_{oc} (SPIE-2008)

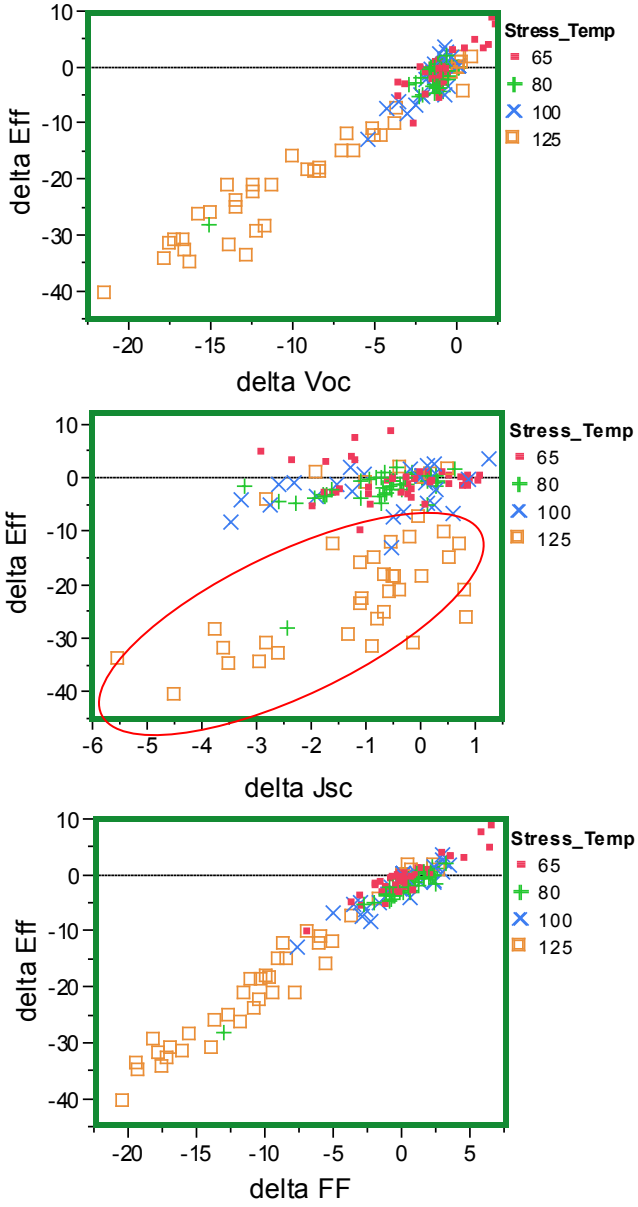


0.46 < R^2 < 0.98



0.58 < R^2 < 0.99

C-V hysteresis in industrial CdTe cells and mini-modules



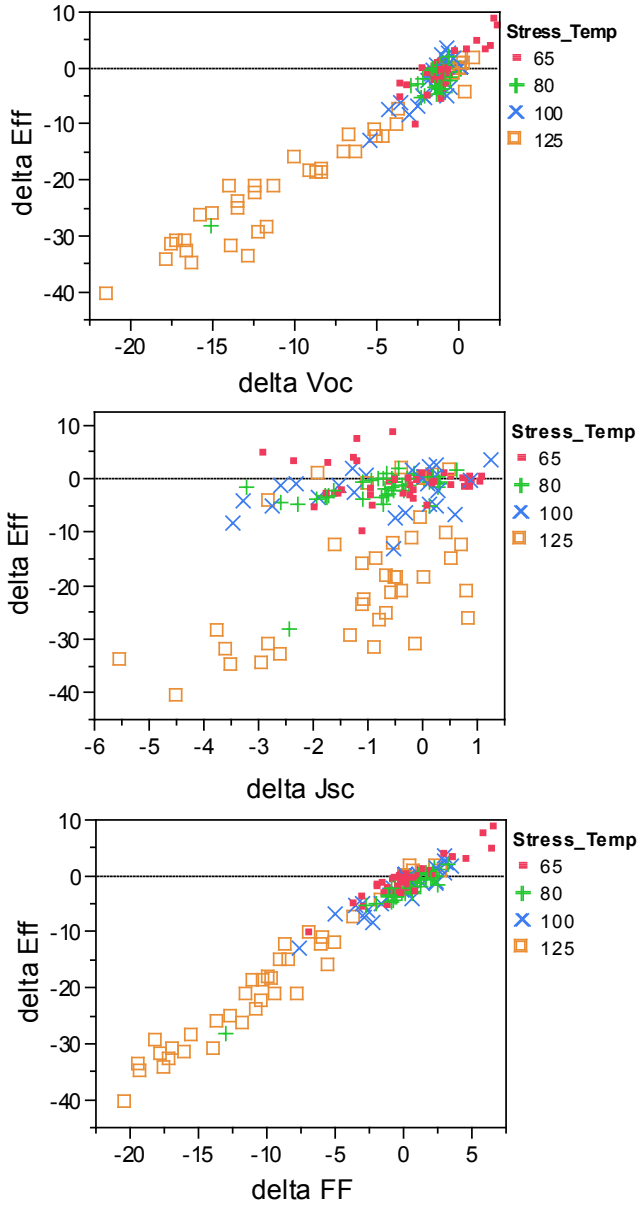
- Cells "cut" from mini-modules and full-size modules
  - ALT performed at 65, 80, 100, and 125 ºC
  - 1-sun illumination and V_{oc} bias
  - Correlate ΔEff vs ΔV_{oc}, ΔJ_{sc}, and ΔFF

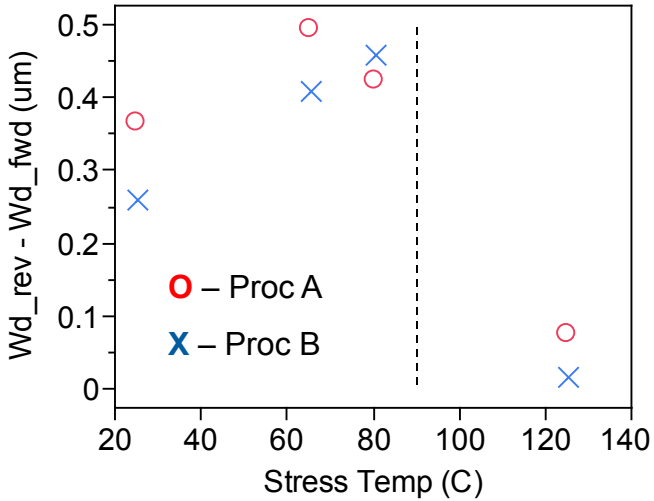
- Strong correlations between ΔEff and (V_{oc} , FF)

- Cell and mini-module reliability good at 65-80 ºC

- Higher stress temperatures (125 ºC) see "outliers" in Eff vs J_{sc} curve not associated with series resistance

C-V hysteresis in industrial CdTe cells and mini-modules

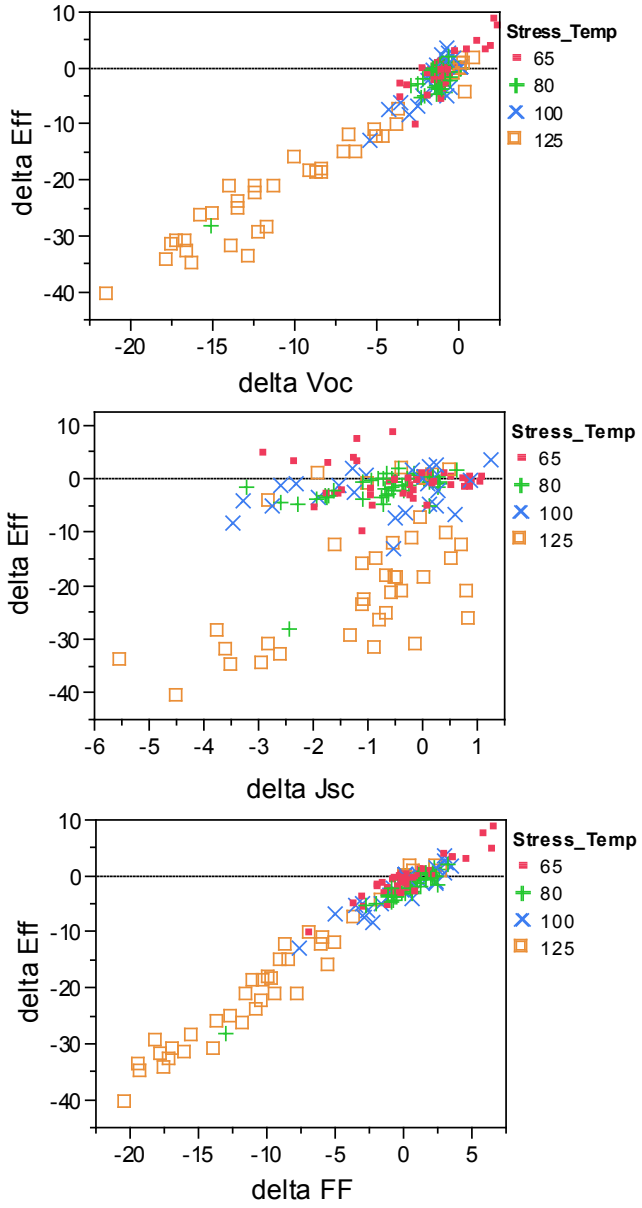


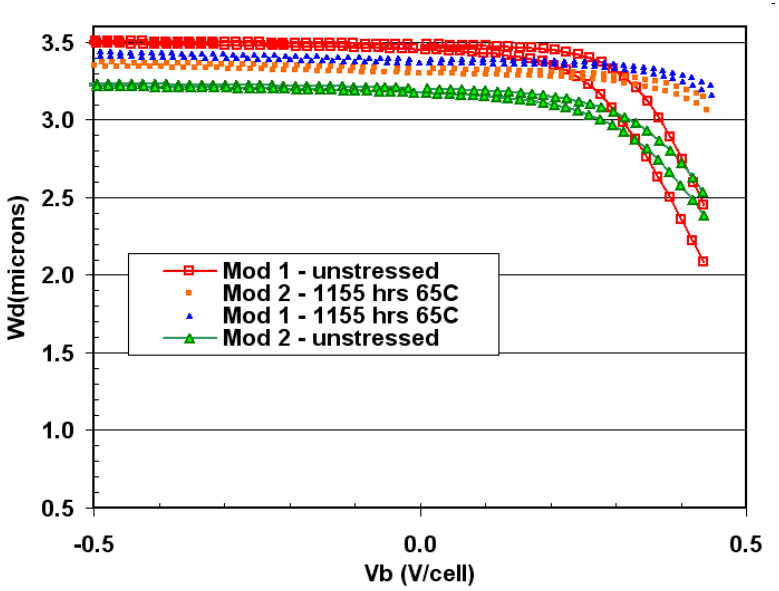


At lower stress temperatures see increasing hysteresis but begins to decrease at longer stress times

At higher stress temperatures (and longer times) see decreasing hysteresis

C-V hysteresis in industrial CdTe cells and mini-modules





- Indoor ALT of series-connected mini-modules (unencapsulated)
- After 1155 hrs at 65 ºC observe a decrease in hysteresis
- Also observed in individual “cells”

Conclusions

- NREL CTO/ZTO cells are superior to SnO_2-based cells in initial performance but have some fundamental durability problems
- C-V *hysteresis* has been observed to increase with stress in cells using “infinite” sources of dopant (Cu).
- Additional *hysteresis* in CTO/ZTO cells strongly suggests a “decomposition” of the CTO/ZTO layers
- C-V hysteresis also observed to increase in industrial cells. Observe decreasing hysteresis at longer stress times and higher temperatures.
- C-V measurements easily implemented during ALTs as a non-destructive technique to better identify degradation mechanisms in cells and modules

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