Stability of CdTe Cells with Different Device Structures

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NREL Photovoltaic Module Reliability Workshop
February 26, 2014

with former students: Jason Hiltner, Alex Pudov, Sam Demtsu, and Caroline Corwine

and current students John Raguse and Russell Geisthardt, and research associates Jennifer Drayton and Tyler McGoffin

Funding from DOE F-PACE program

Cell-Level Stability Testing

Motivation for cell-level CdTe stability testing:

- Possible intrinsic issues with CdTe cells
- Additional issues can arise with different device structures
- Device analysis generally assumes good stability; flawed otherwise

Multiple stress parameters important:

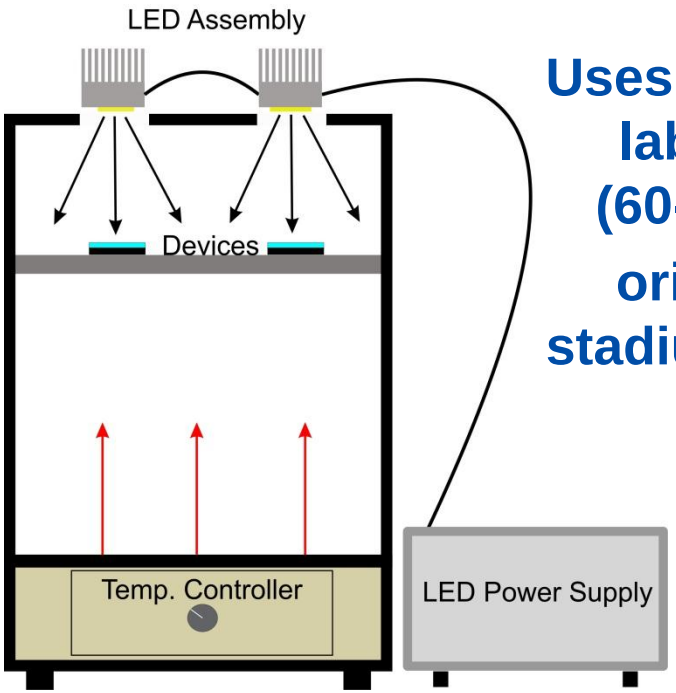
- Temperature
- Voltage bias
- Illumination level
- (Humidity)

Multiple tracking measurements important:

- Average cell properties: J-V, C-V, (QE, J-V-T)
- Cell uniformity: LBIC, EL

Focus on plausible physical mechanisms

Accelerated Life Testing

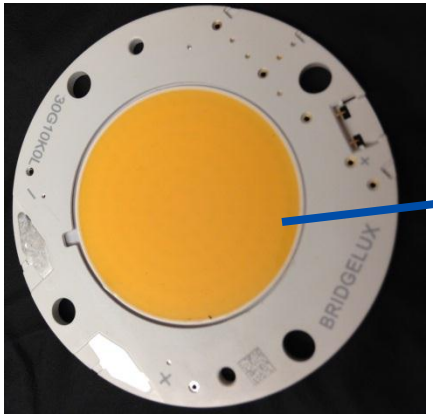


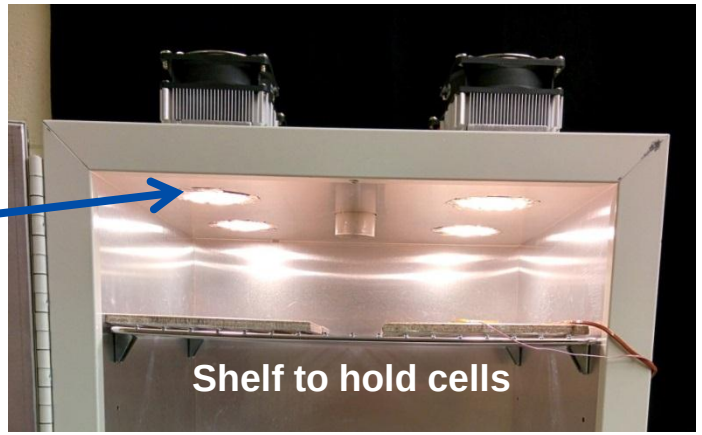
John Raguse, Jennifer Drayton, and Russell Geisthardt

Uses compact lab oven (60-100°C)

originally stadium lights

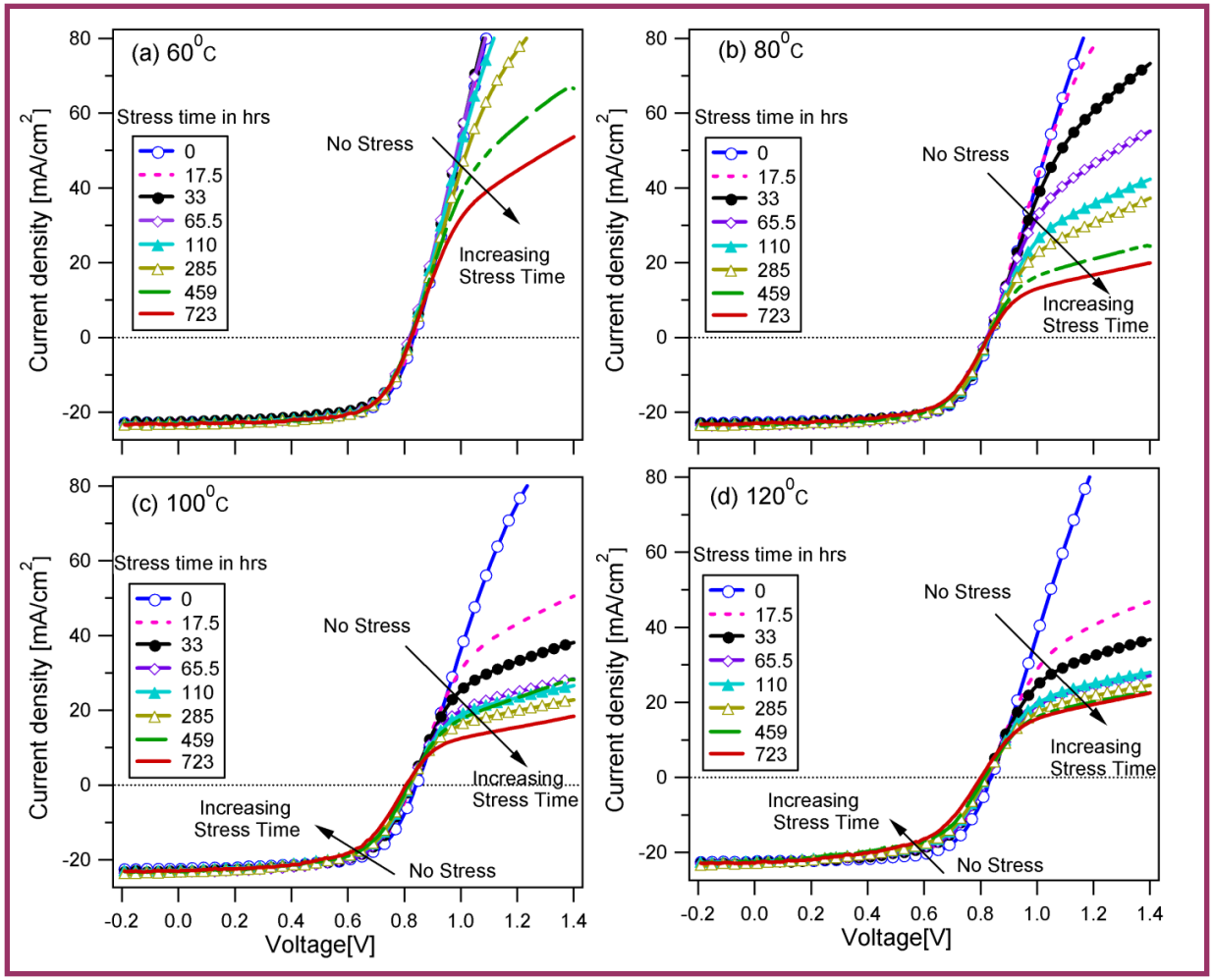
LED arrays for illumination (3 cm diam; 0-2 suns)





Changes in CdTe Current-Voltage

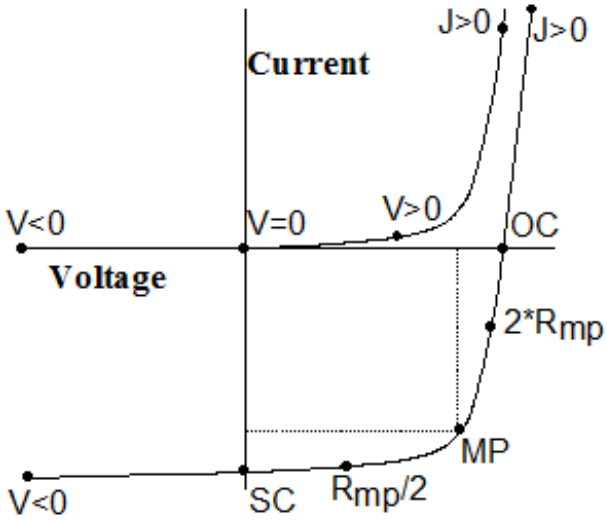
Change seen earlier in first quadrant, later in power quadrant. Increasingly greater at higher temperatures.



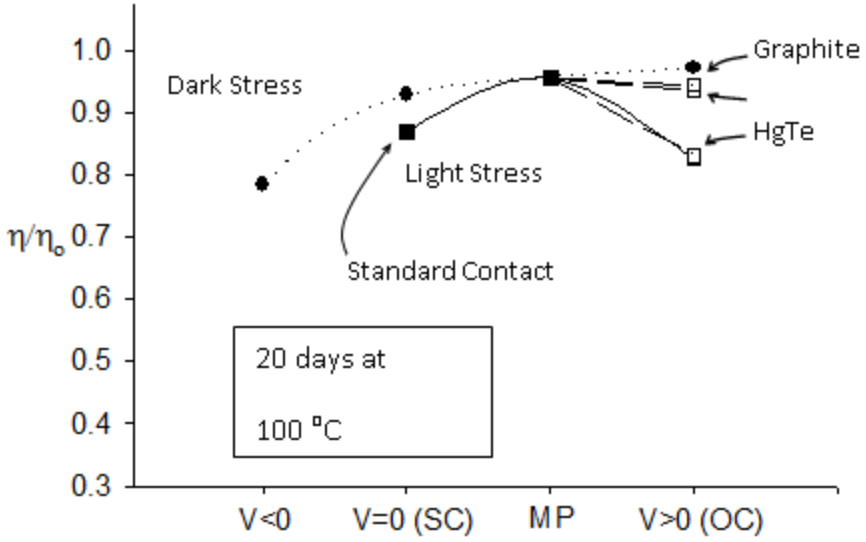
From Samuel Demtsu

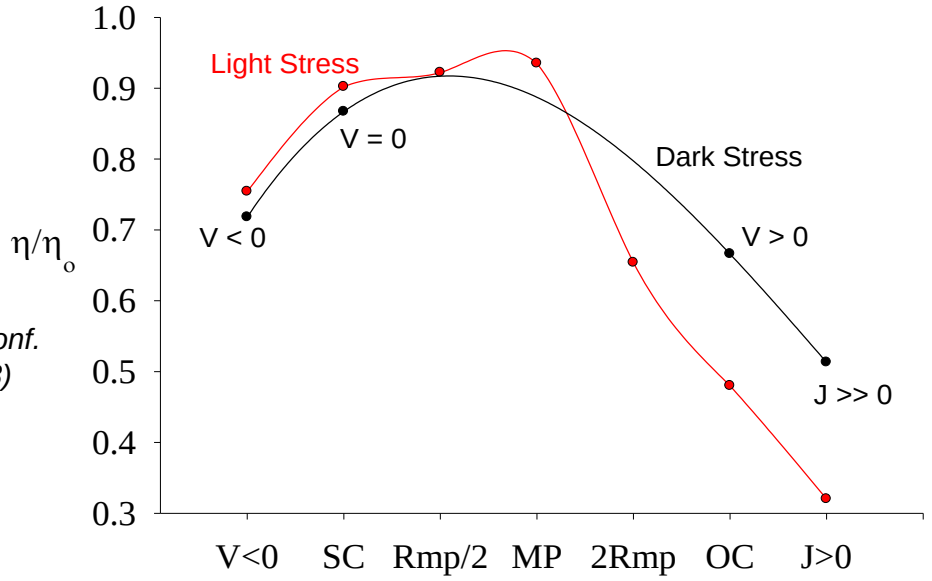
Voltage and Illumination Dependence

Bias voltage during stress seemed to be the larger factor, but contacting also played a role



*Hiltner and Sites, AIP Conf. Series **462**, 170 (1998)*





Cells from NREL and Solar Cells, Inc

Long-Term Expectations

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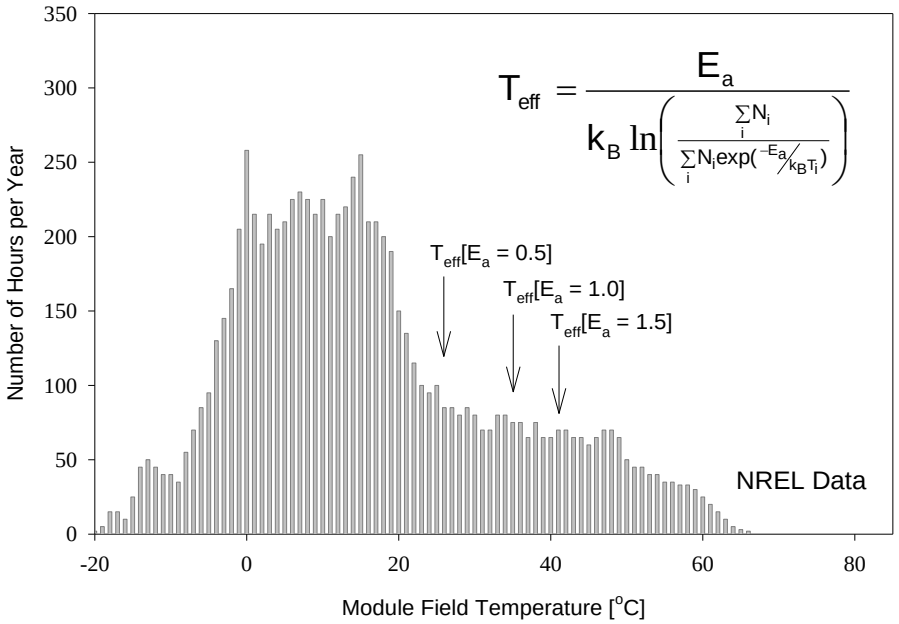
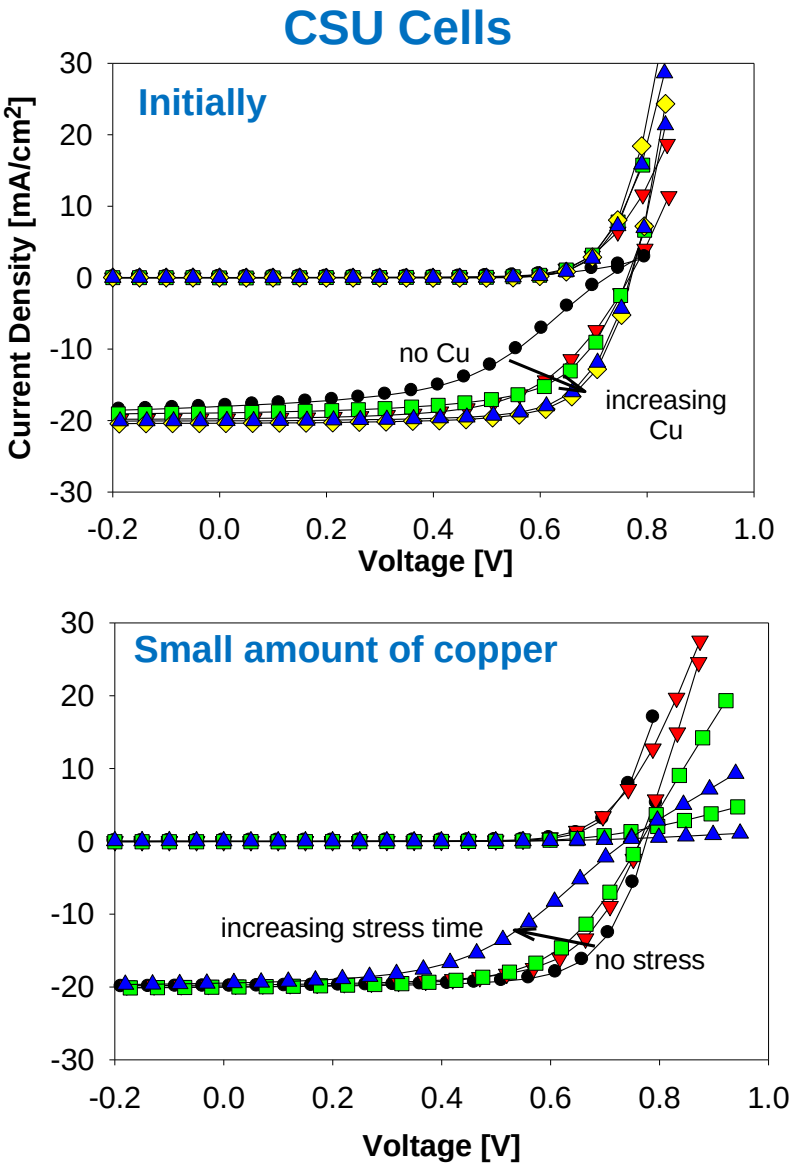
Define Acceleration Factor $a = \exp(E_a/kT_{eff} - E_a/kT_{cell})$ where an activation energy E_a (typically ~1 eV) can be deduced from rate of change at different temperatures and T_{eff} from a histogram of daylight module temperatures (and an estimate of E_a)



For CdTe with T_{cell} = 85°C and typical field temperatures, a appears to be in the range of 100-1000

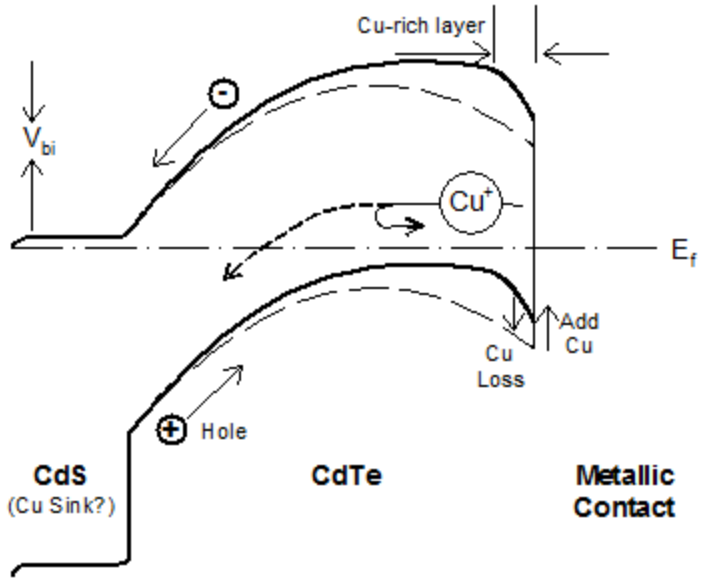
Copper Model



Copper reduces the CdTe back-contact barrier, but can diffuse away.

Positive ions diffuse faster when field is reduced at V_{OC} and above.

Small amount of copper may not be sufficient, and may diffuse from back.

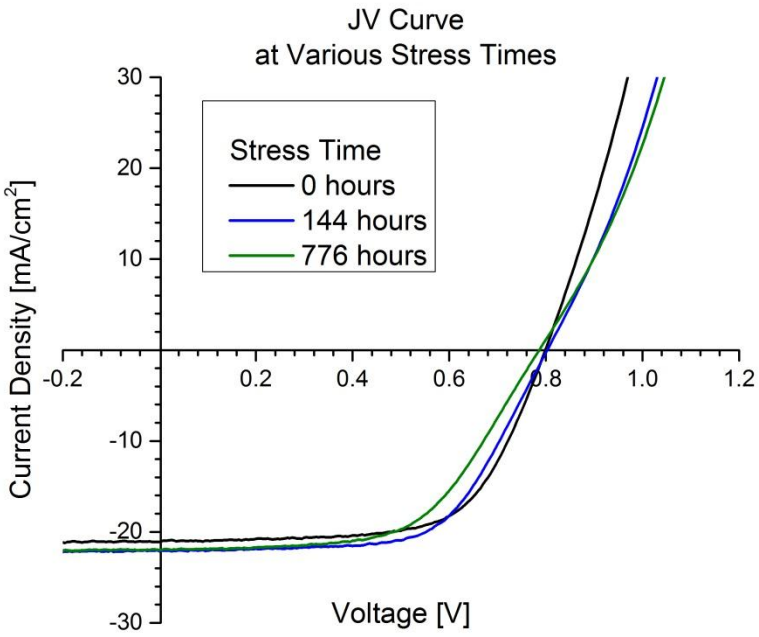


*Caroline Corwine et al, SOLMAT **82**, 481 (2004)*

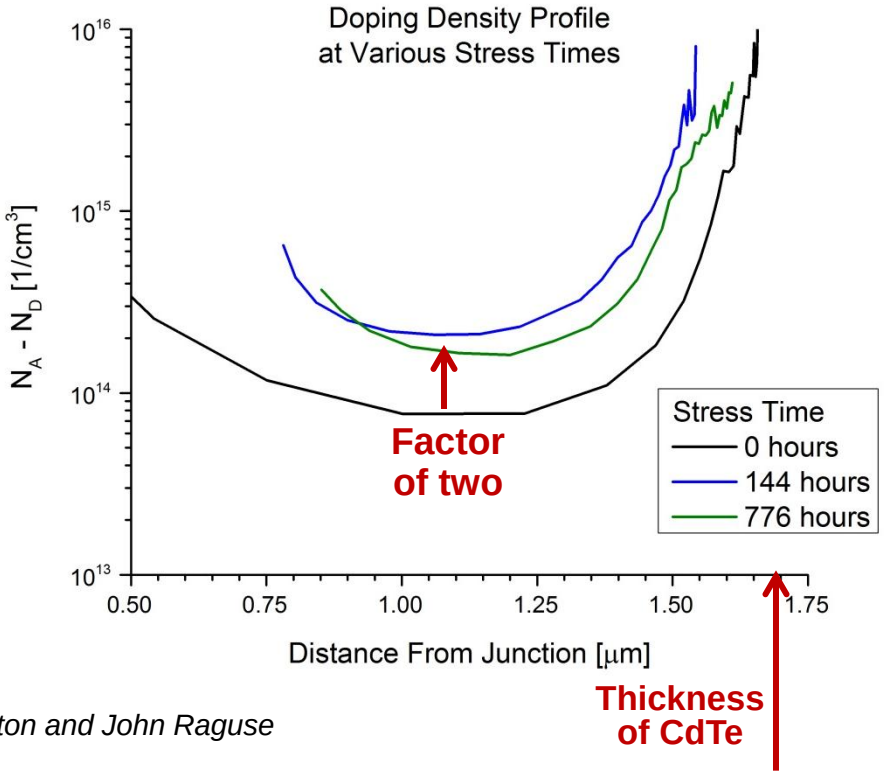
Effect on Capacitance

Copper diffusion appears to also increase carrier density

CSU CdTe cells



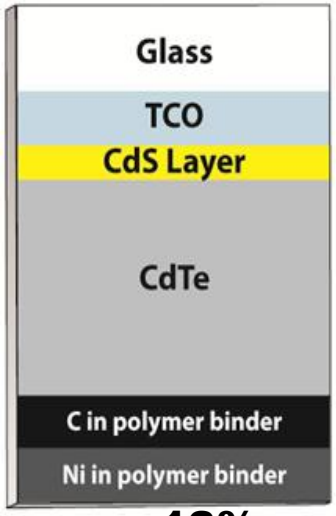
Hole density is derived from C-V



Jennifer Drayton and John Raguse

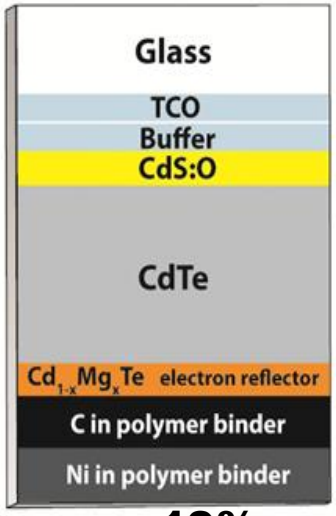
Alternative CdTe Structures

Standard Baseline



η = 13%

Transparent Window and Electron Reflector

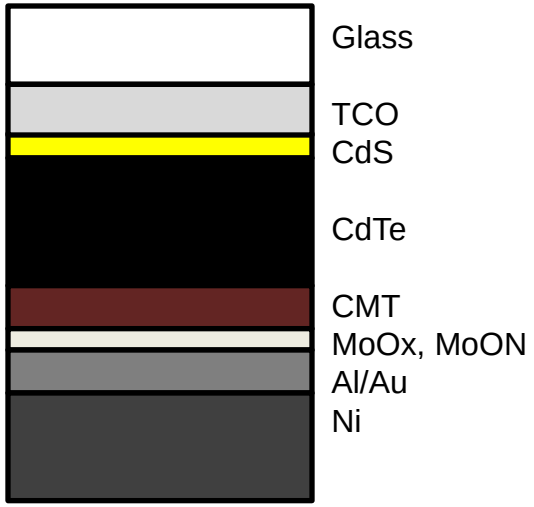


$\eta \approx 19\%$

Target

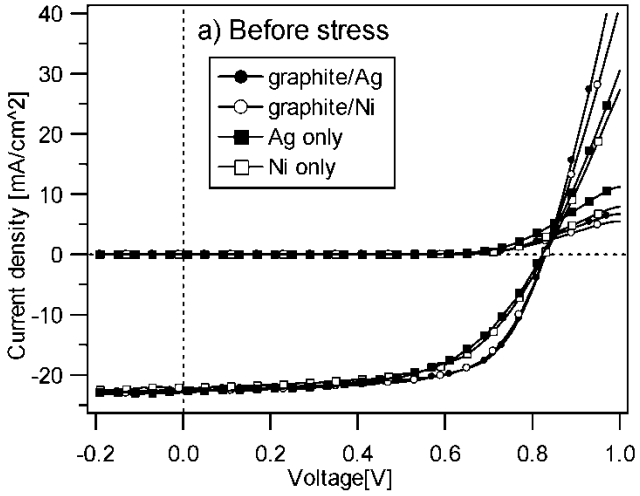
16.2% achieved

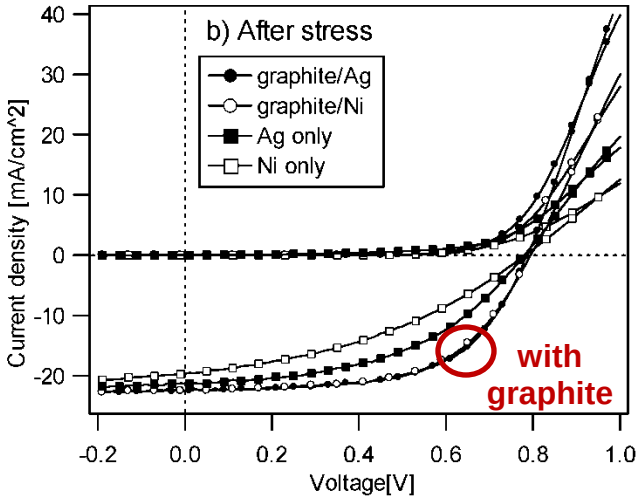
Transparent Back Contact

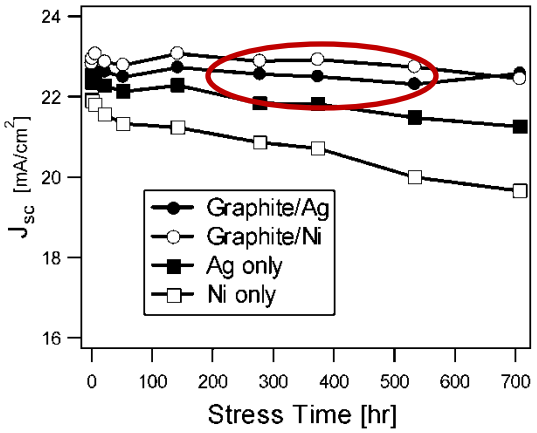


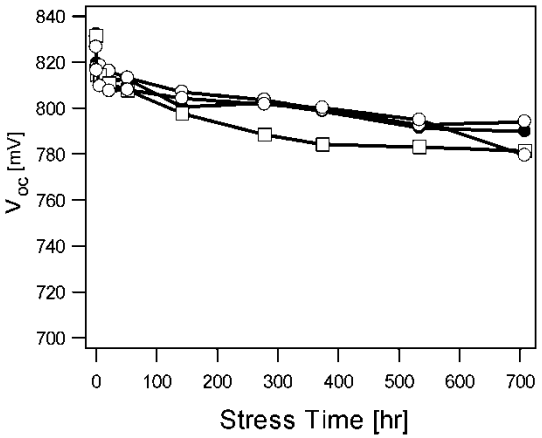
Studies in progress

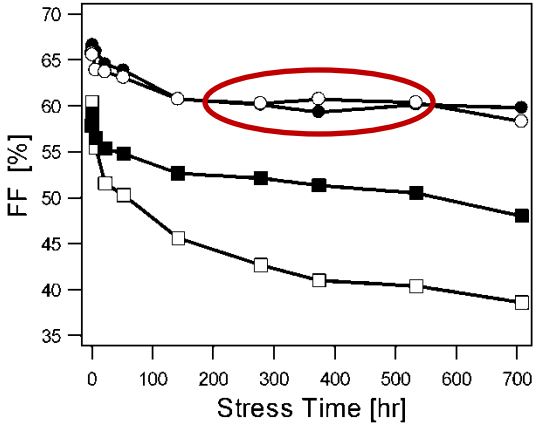
Varying the Back Contact

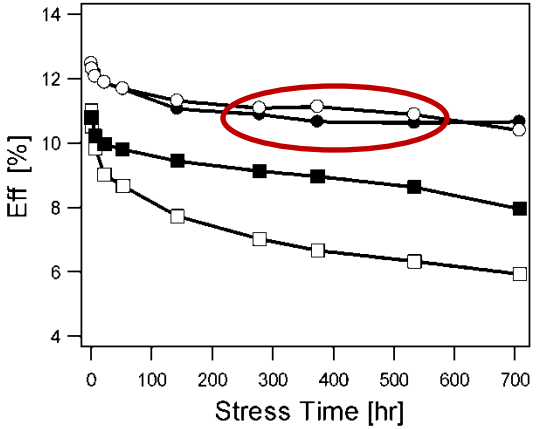








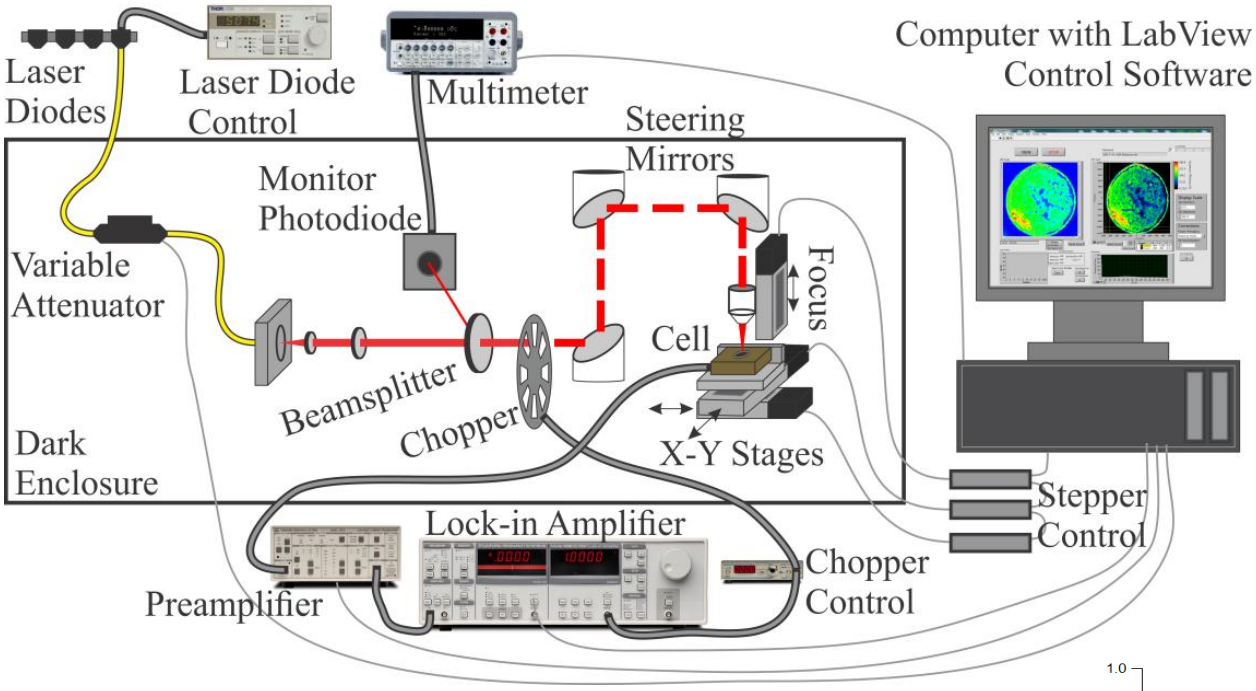




*Demtsu, Albin, Pankov, and Davies, SOLMAT **90**, 2934 (2006)*

Light-Beam-Induced Current

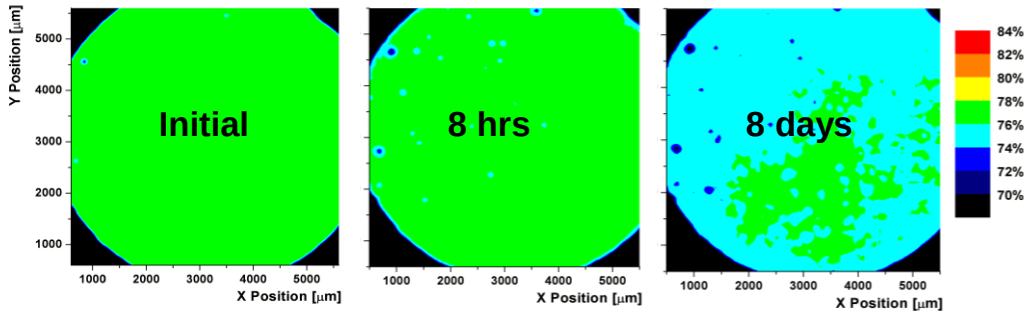
Steps through 10,000 points in 10 min

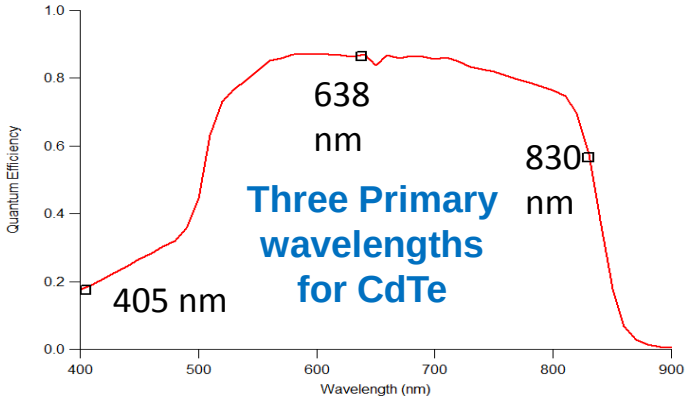


Resolution down to 1 μm at 1 sun intensity

Built by Jason Hiltner

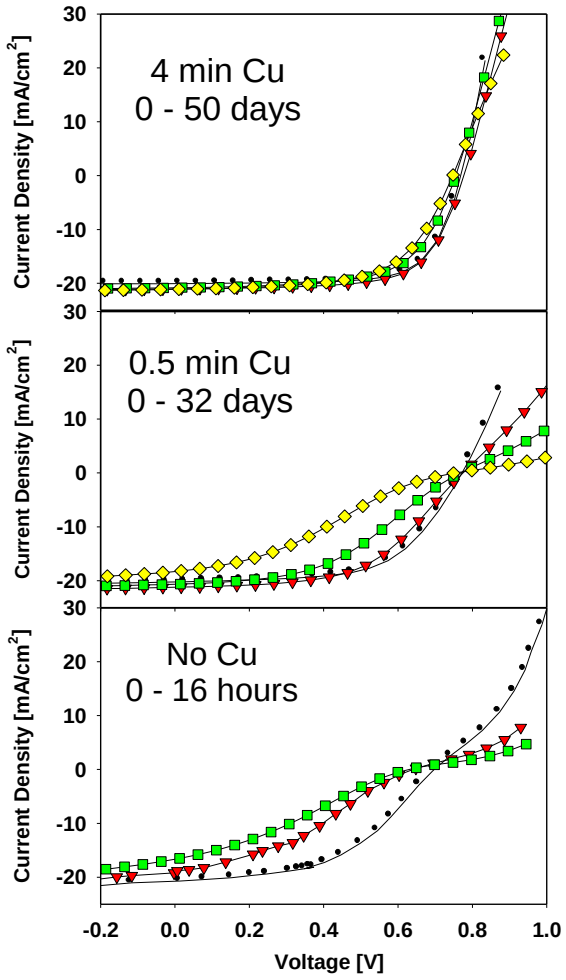
Updated by Tim Nagle and Russell Geisthardt



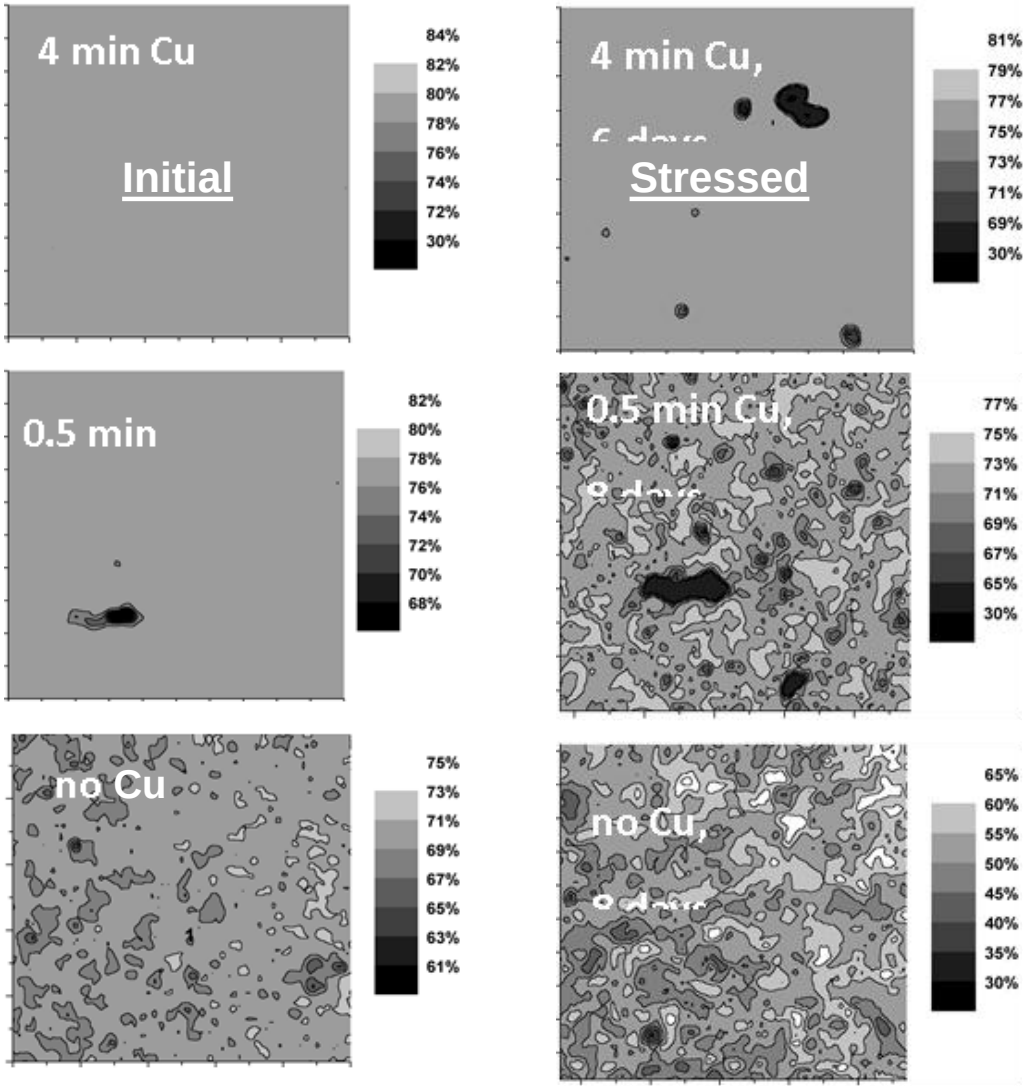


Different Amounts of Copper

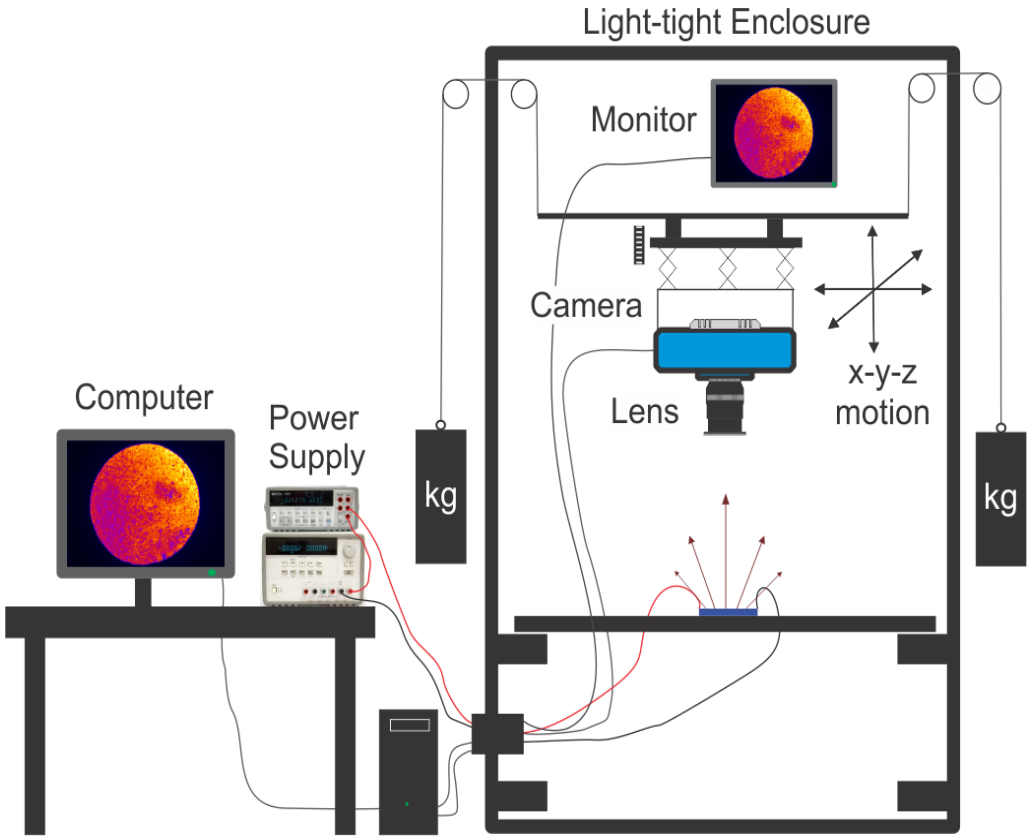
100°C, illuminated, short circuit (CSU cells)



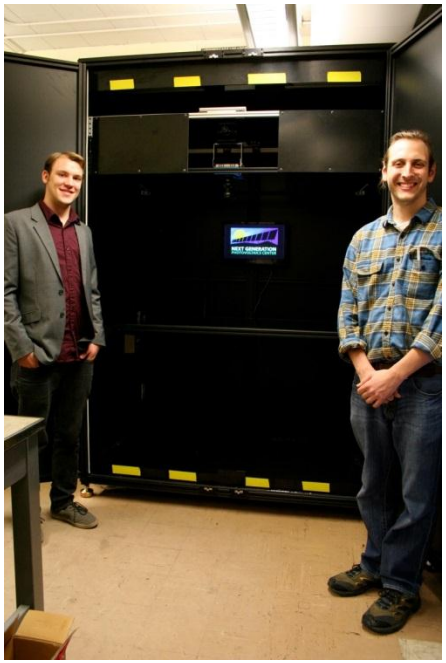
A. Pudov et al, PVSC-29 (2002)

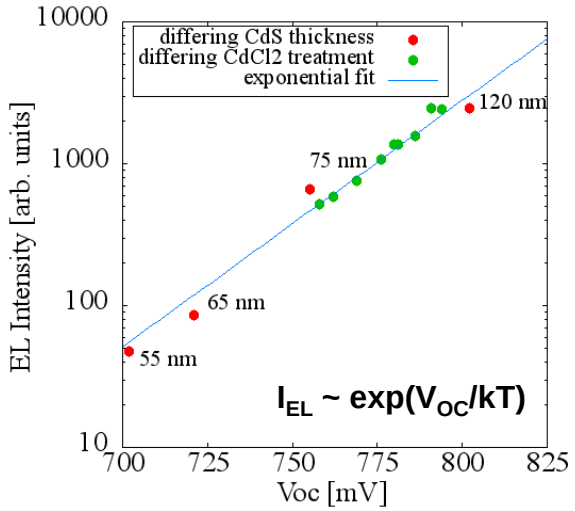


Electroluminescence (EL)



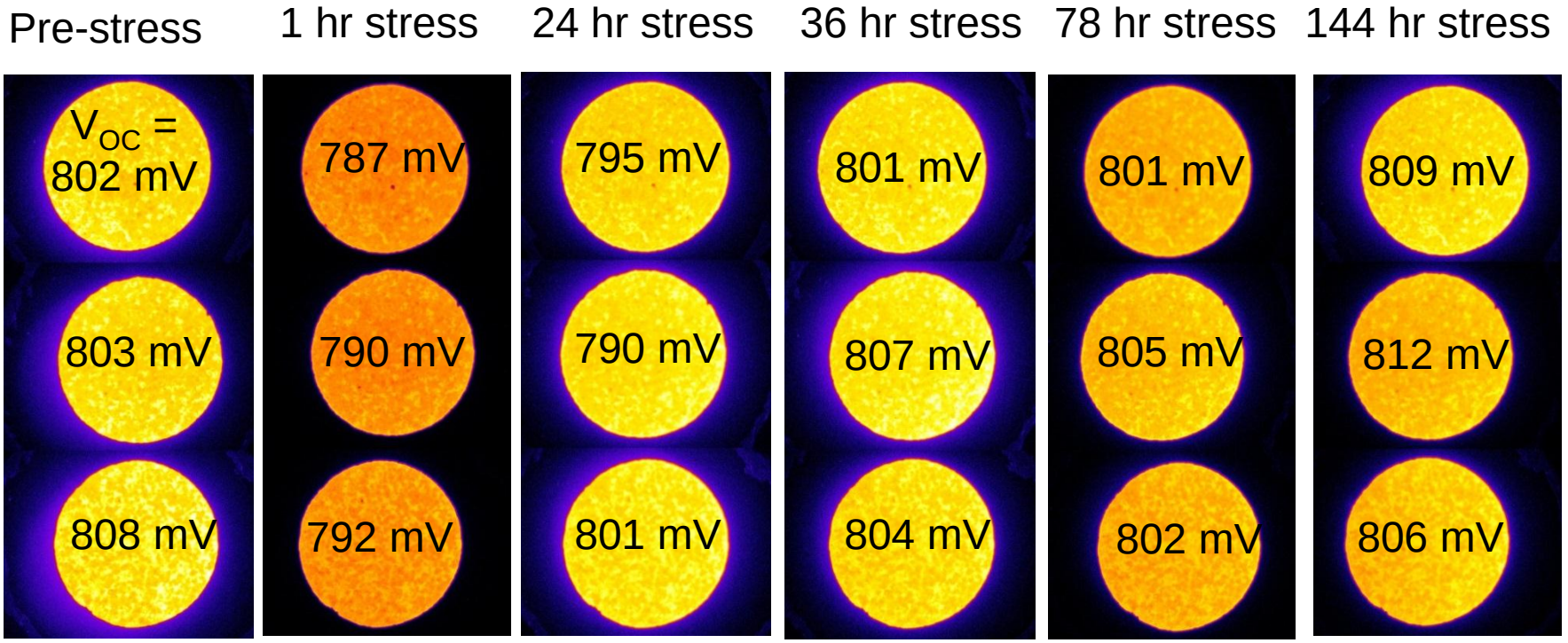
John Raguse and Tyler McGoffin





EL and Voltage of Stressed CdTe Cells

EL tracks voltage; gives confidence to both



John Raguse and Jennifer Drayton

- Devices are standard CSU cell recipe
- Devices stressed at 65°C, at V_{OC} under nominal 1 sun illumination
- Decline and recovery appears real. Two effects from copper diffusion?

Summary

(1) Cell-level CdTe stability is generally good, but needs to be tested with new device structures.

(2) Copper used with back contact is responsible for at least some of the change.

(3) A mix of tracking measurements, including uniformity, is highly desirable.

(4) There can be small stability issues that have little effect on performance, but can compromise analysis and could be precursor to later trouble.