Stress Induced Degradation Modes in CIGSS Minimodules

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Experimental Objectives

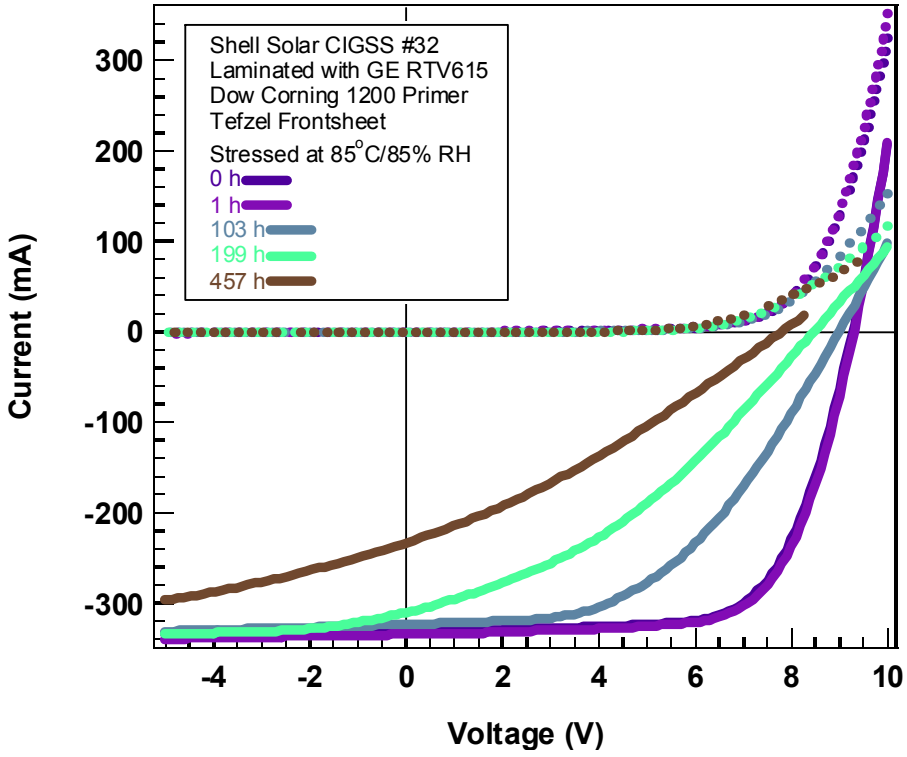
- Compare the performance of modules exposed to high temperature and humidity.
- Determine the effects of different encapsulants on long term stability of CIGSS modules.
- Analyze failure modes to determine areas in need of improvement.

Experimental Setup

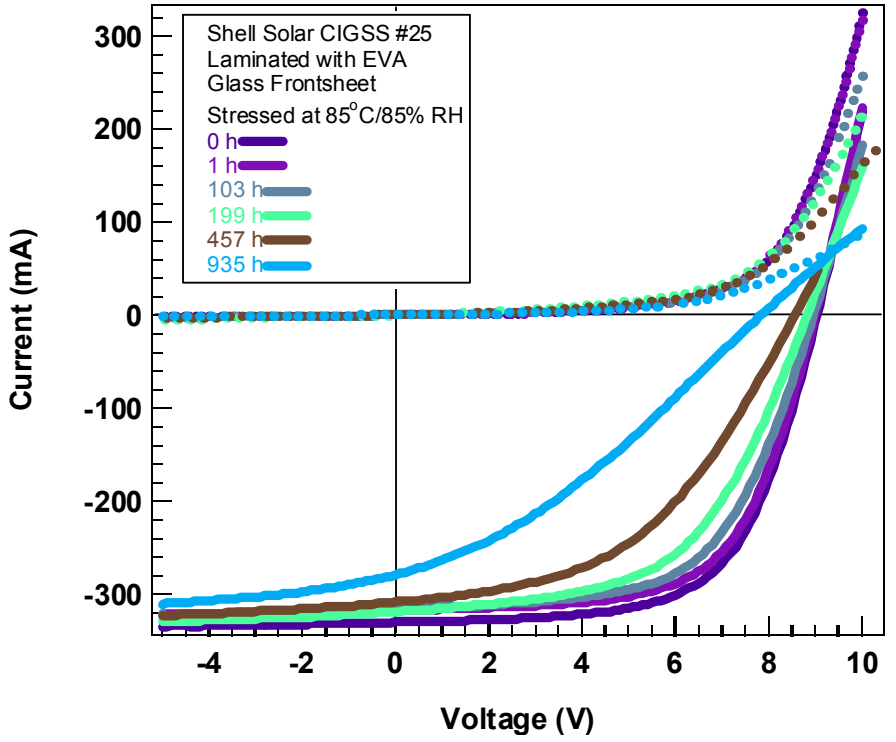
- Systematically changed:
  - (1) Encapsulant (EVA or GE RTV615 silicone)
  - (2) Front-sheet (Glass or Tefzel)
- Samples exposed to:
  - (1) 85C/85% RH in air.
  - (2) 85C/0% RH in air. (Dew point ~ -40C)
- Used 4 or 5 replicates. $4*2^3+2=34$ samples.
- Initial average cell parameters:
  - Voc=0.538 V
  - Jsc=32.8 mA/cm2
  - FF=65.7%
  - η=11.59%

Stress at 85°C and 85% RH Causes Rapid Degradation

Silicone with Tefzel Front-Sheet



EVA with Glass Front-Sheet

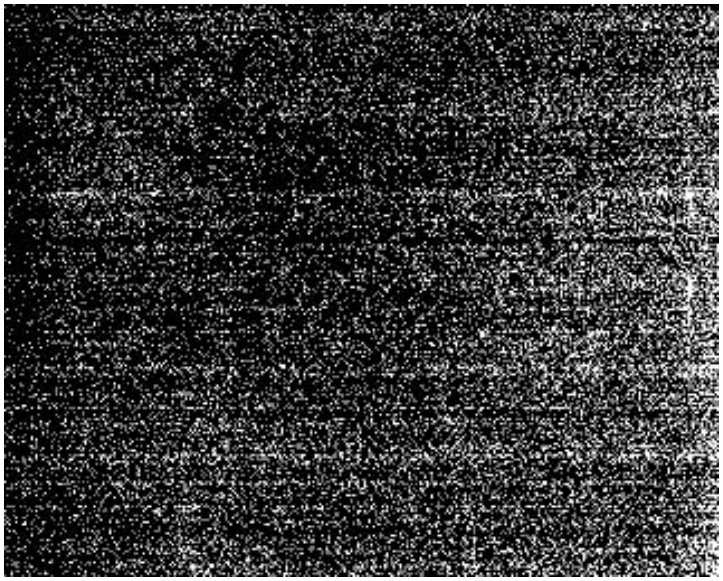


Glass Slows down the degradation but does not prevent it.

Infrared Images Shows a Striped Pattern

Silicone encapsulant with a Tefzel Front-Sheet. Module #32

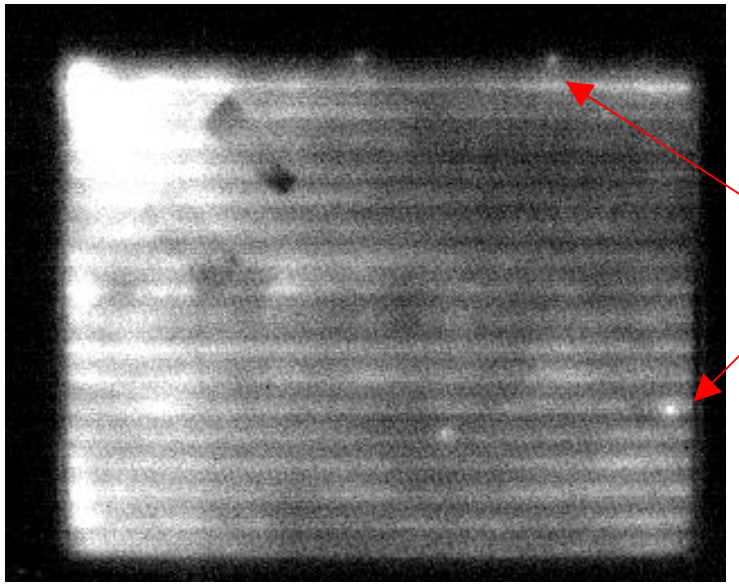
457 h of 85 ºC and 85% RH



-0.24 mA, -9.6 V

Reverse Bias

No Signs of Shunts



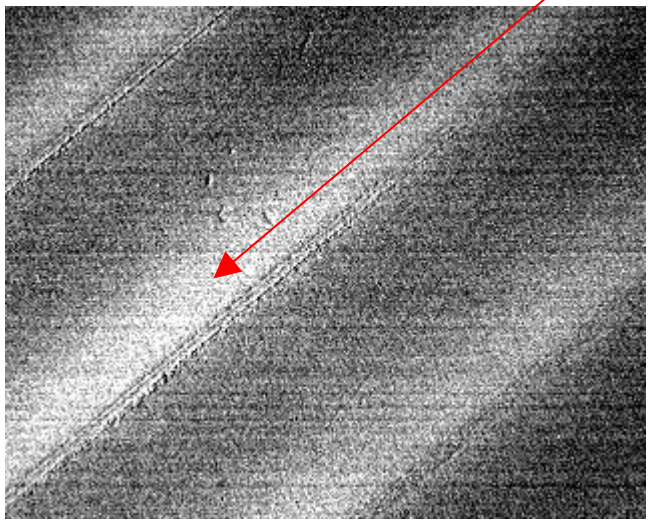
Weak Diodes

(i.e. small area with low V_{oc})

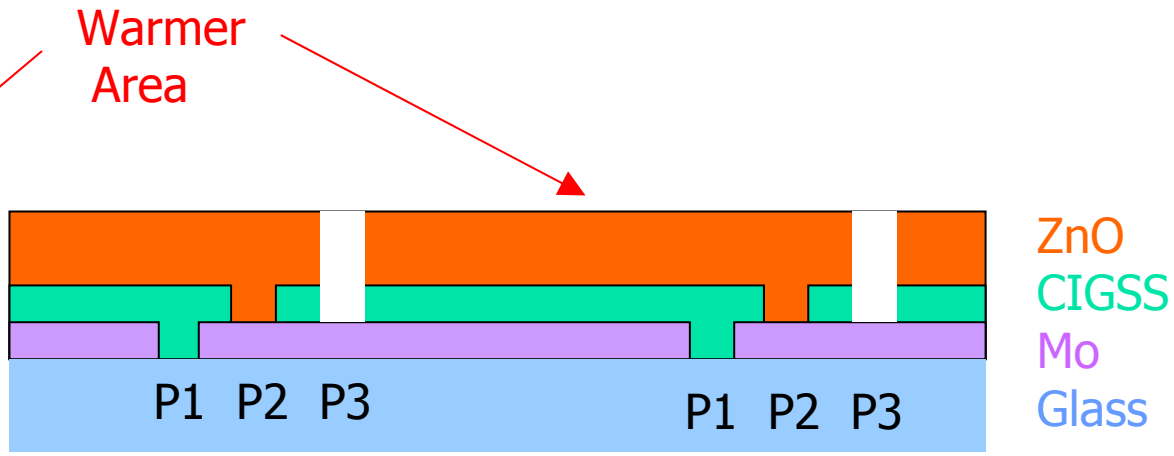
+81 mA, 9.6 V

Forward Bias

IR Heat Pattern Indicates High Resistance ZnO



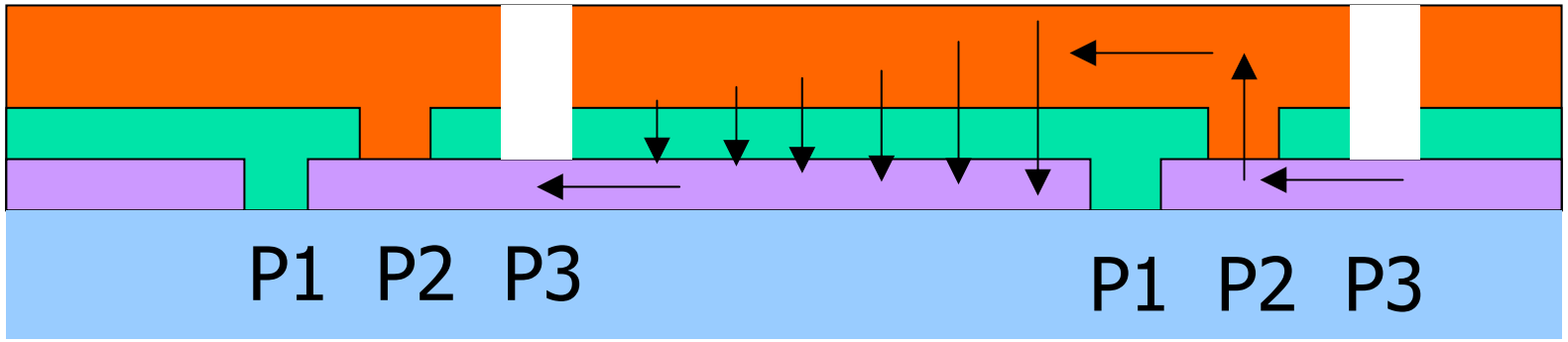
IR image of module under forward bias of 9.6V and 81 mA.



Schematic representation of CIGSS cell interconnection scheme

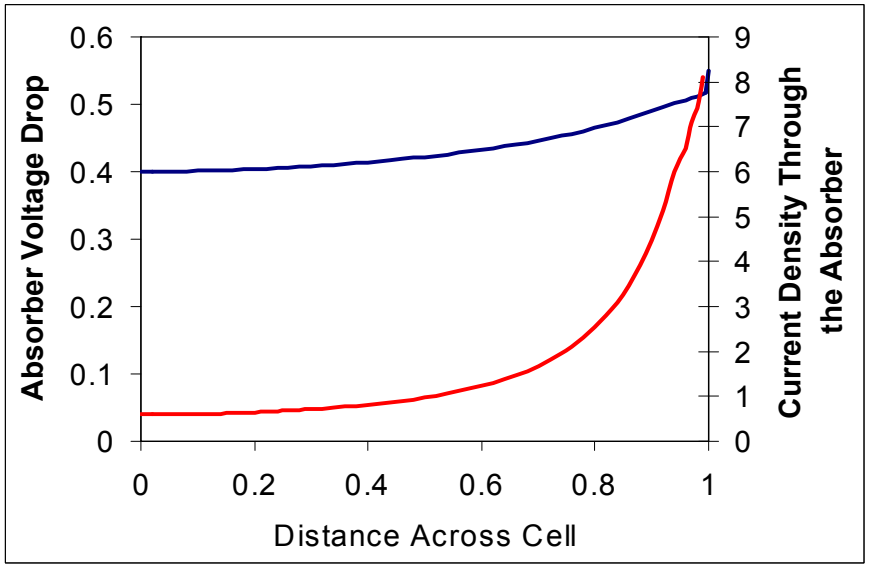
Heating not symmetric around the scribe and therefore is not due to resistance in interconnection scribes.

Heating Caused Principally by Recombination Current



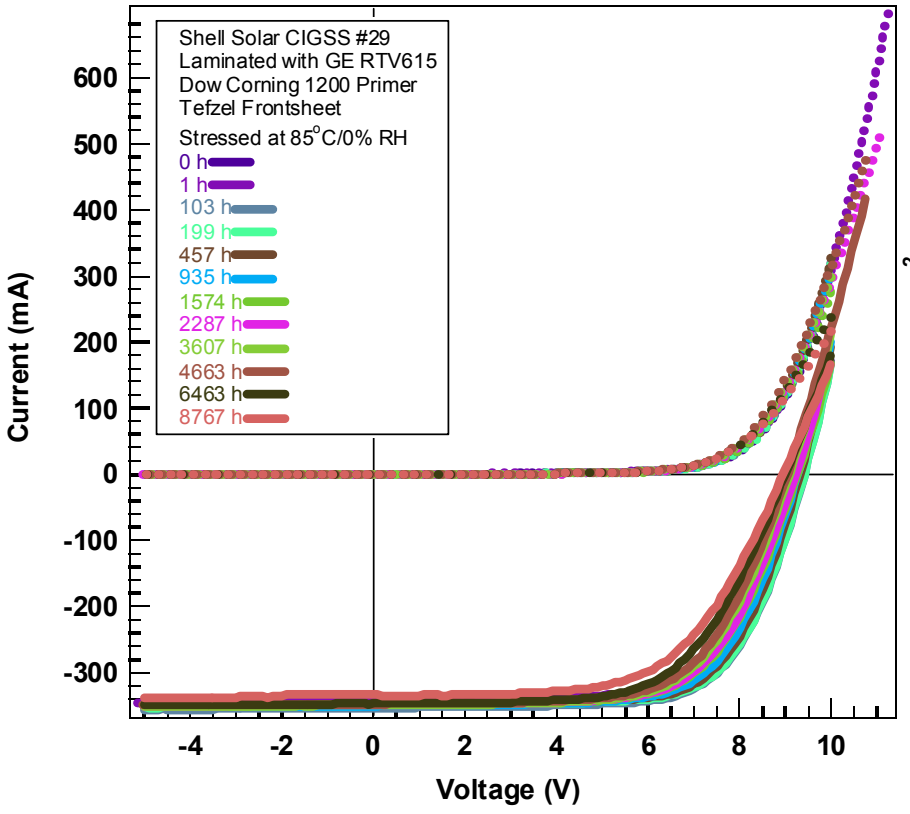
ZnO
CIGSS
Mo
Glass

$$j = j_o\left[\exp^{\left(\frac{qV}{nkT}\right)} - 1\right]$$

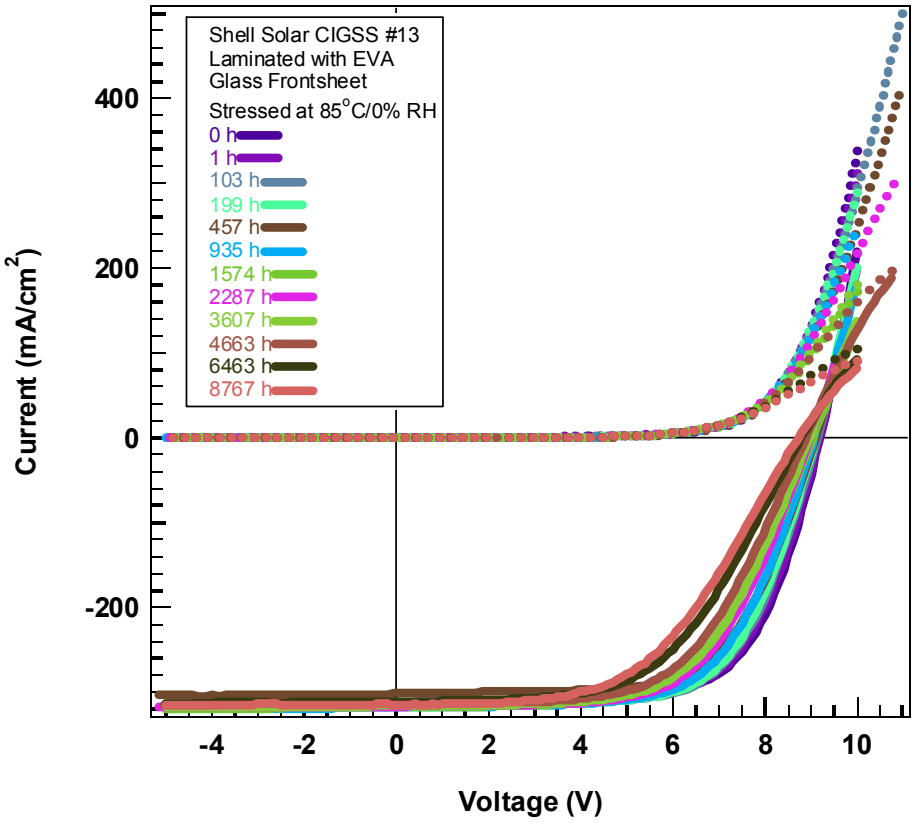


85°C and 0% RH Exposure Causes V_{oc} and FF Losses

Silcone



EVA



Silicone encapsulated cells performed better. They had better fill factors and less roll over.

An Analysis of Variance Indicates Statistical Significance

Treatment	ΔV_{oc}		ΔJ_{sc}		ΔFF		Δ Efficiency	
	F Ratio	Probability	F Ratio	Probability	F Ratio	Probability	F Ratio	Probability
Front-sheet	0.005	0.94	0.40	0.54	0.015	0.91	0.16	0.70
Encapsulant	0.55	0.47	0.080	0.78	13.5	**0.0036**	6.66	**0.026**
Encapsulant*Front-Sheet	0.14	0.72	1.15	0.3	0.52	0.49	0.36	0.56

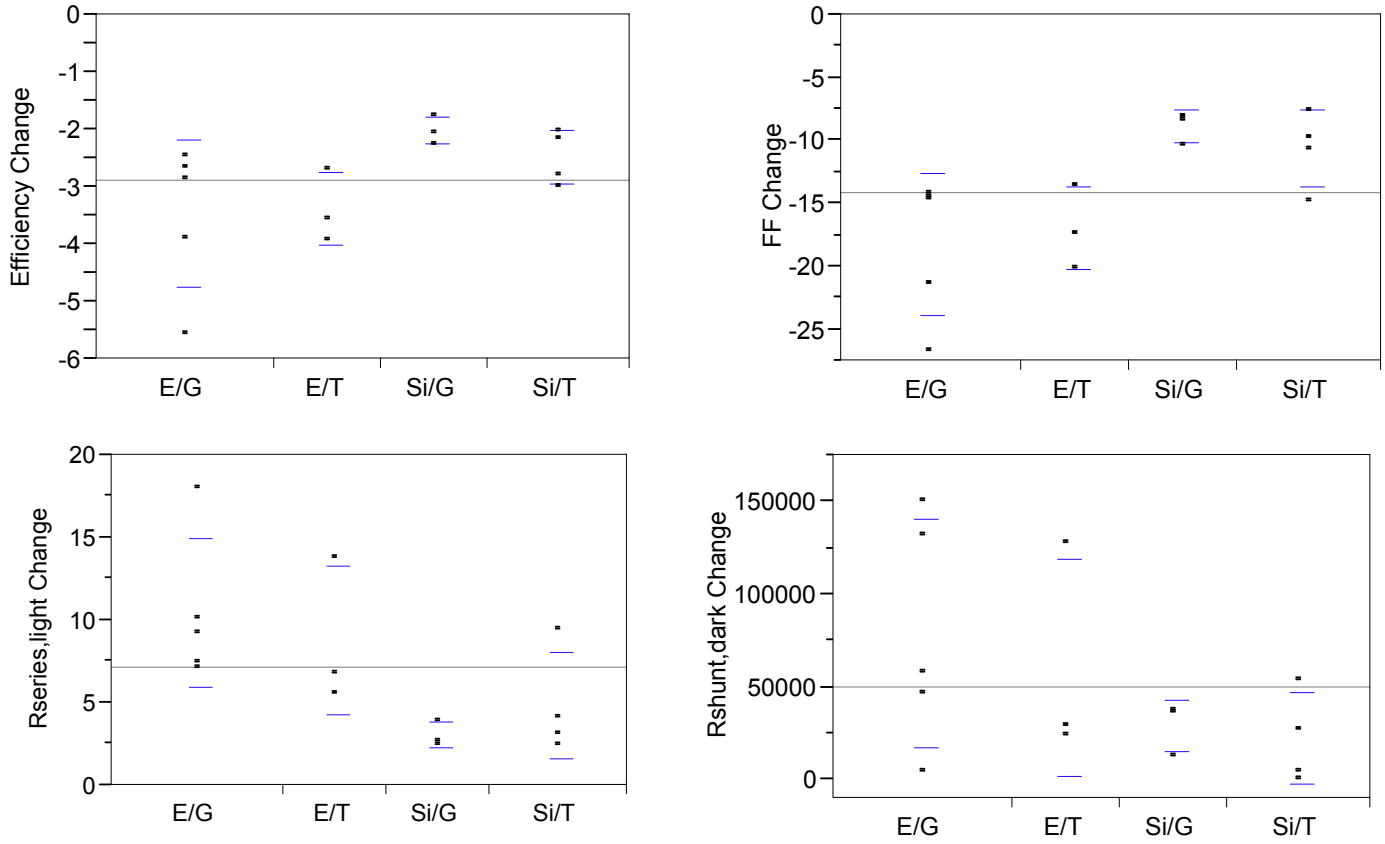
Treatment	$\Delta R_{sh,light}$		$\Delta R_{s,light}$		$\Delta R_{sh,dark}$	
	F Ratio	Probability	F Ratio	Probability	F Ratio	Probability
Front-sheet	1.6	0.23	0.0012	0.97	0.27	0.62
Encapsulant	0.19	0.67	8.3	**0.0149**	3.16	*0.10*
Encapsulant*Front-Sheet	0.0021	0.96	0.77	0.40	0.047	0.83

Resistances determined from inverse slope.

Two factor ANOVA for samples exposed to 8767 h of 85ºC and 0% RH.
"F ratio" is the ratio of the uncertainty between treatments to the sample set uncertainty.
"Probability" is the chance of getting this F ratio if the two treatments were actually equivalent.
"Encapsulant*Front-sheet" indicates the probability that interactions between treatments significantly affect the results.

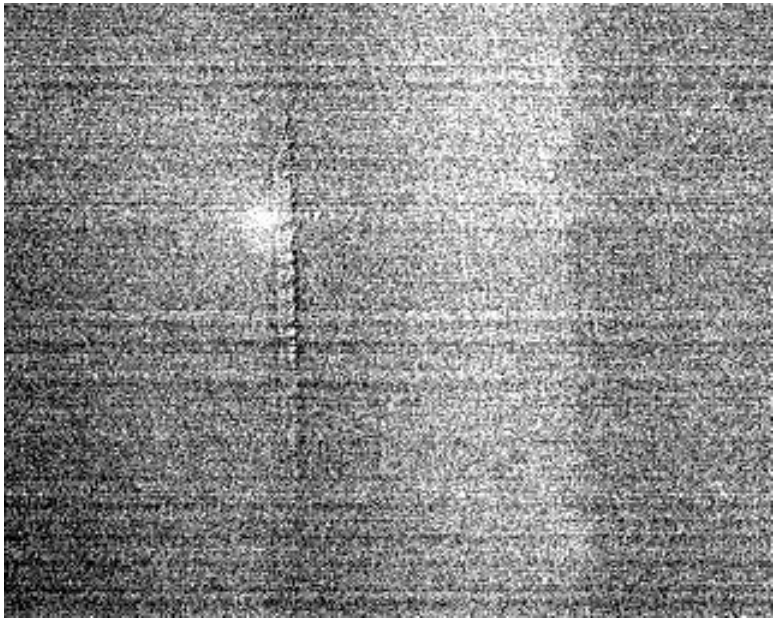
Silicone Encapsulated Cell Have Lower FF and "R_s" Losses

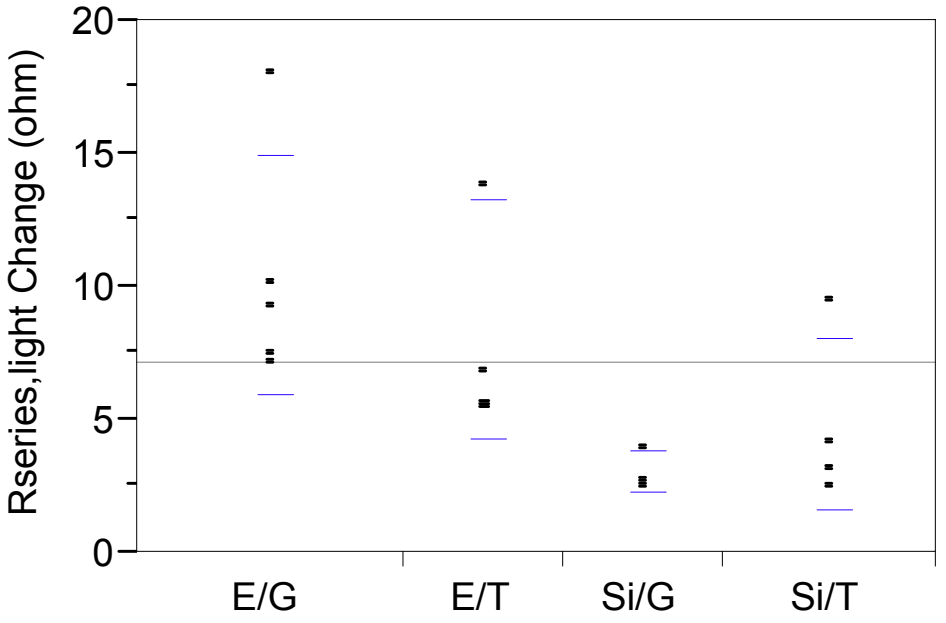
8767 hours of 85ºC and 0% RH



Resistances were inferred from the inverse slope.
The horizontal lines for each data set correspond to the 95% confidence interval for the magnitude of the changes.
The large horizontal line spanning the plots is the grand mean for the data set.

At 8767 h 85C and 0% RH ZnO Resistance Has Increased

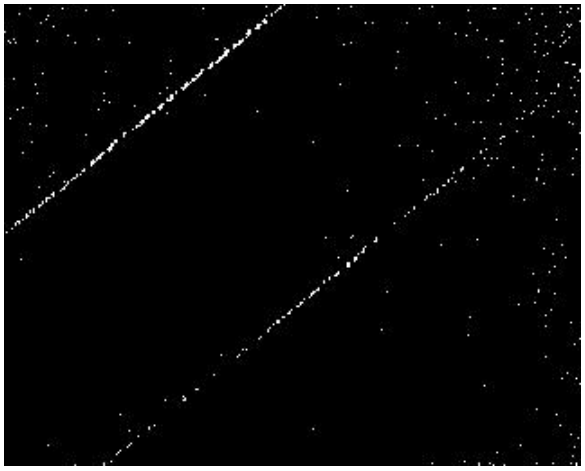




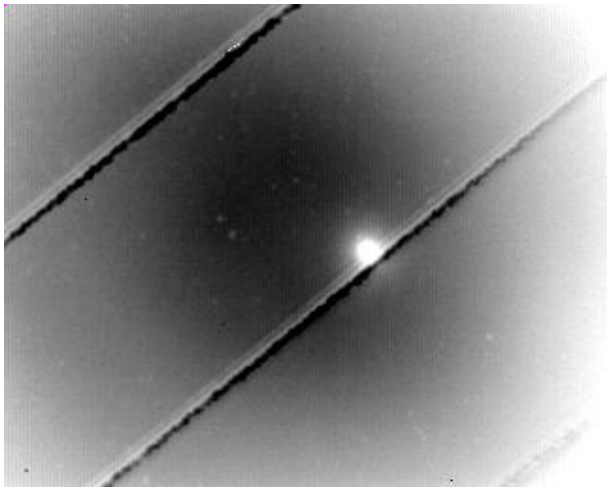
Forward Bias Module #15
9.5 V, 31 mA, 15 s
8767 h 85°C and 0% RH
EVA/Tefzel

IR Images Distinguish Weak Diodes from Shunts

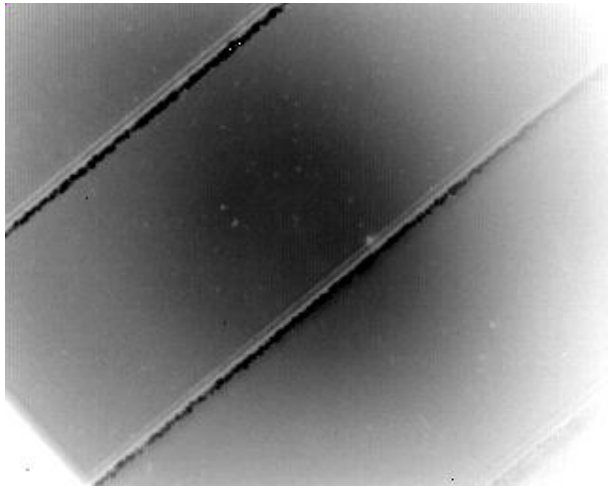
Silicone/Tefzel after 2290 h 85ºC and 0% RH. #29



5 s Reverse Bias
9.3 V 0.53 mA



5 s forward Bias
9.3 V 153 mA

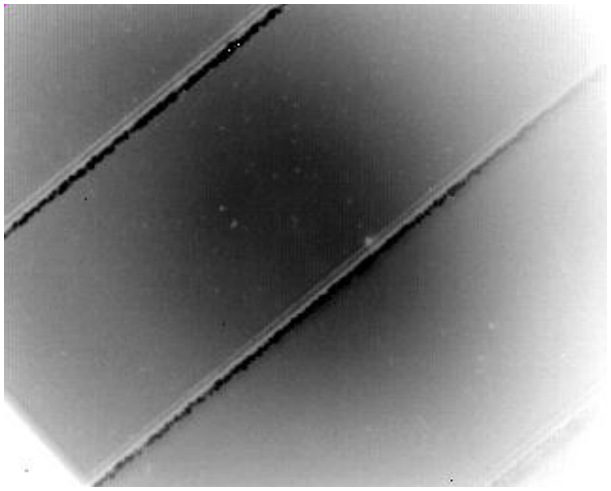


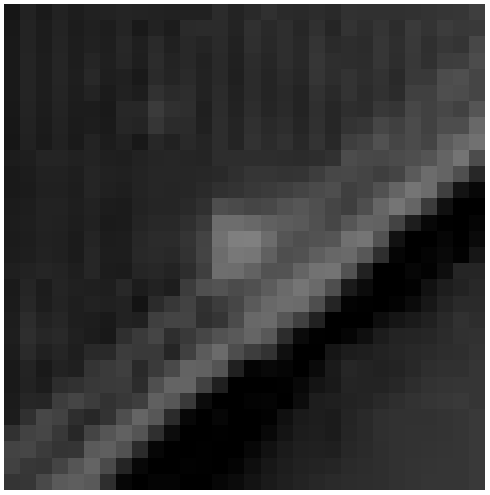
Flashlight
Illumination

IR images are made by subtracting image values before and after application of voltage.

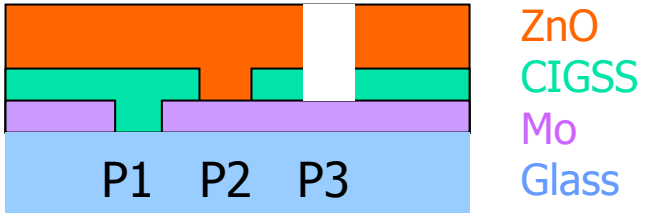
Many Weak Diodes Are Located on the P1 scribe

Flashlight Illumination



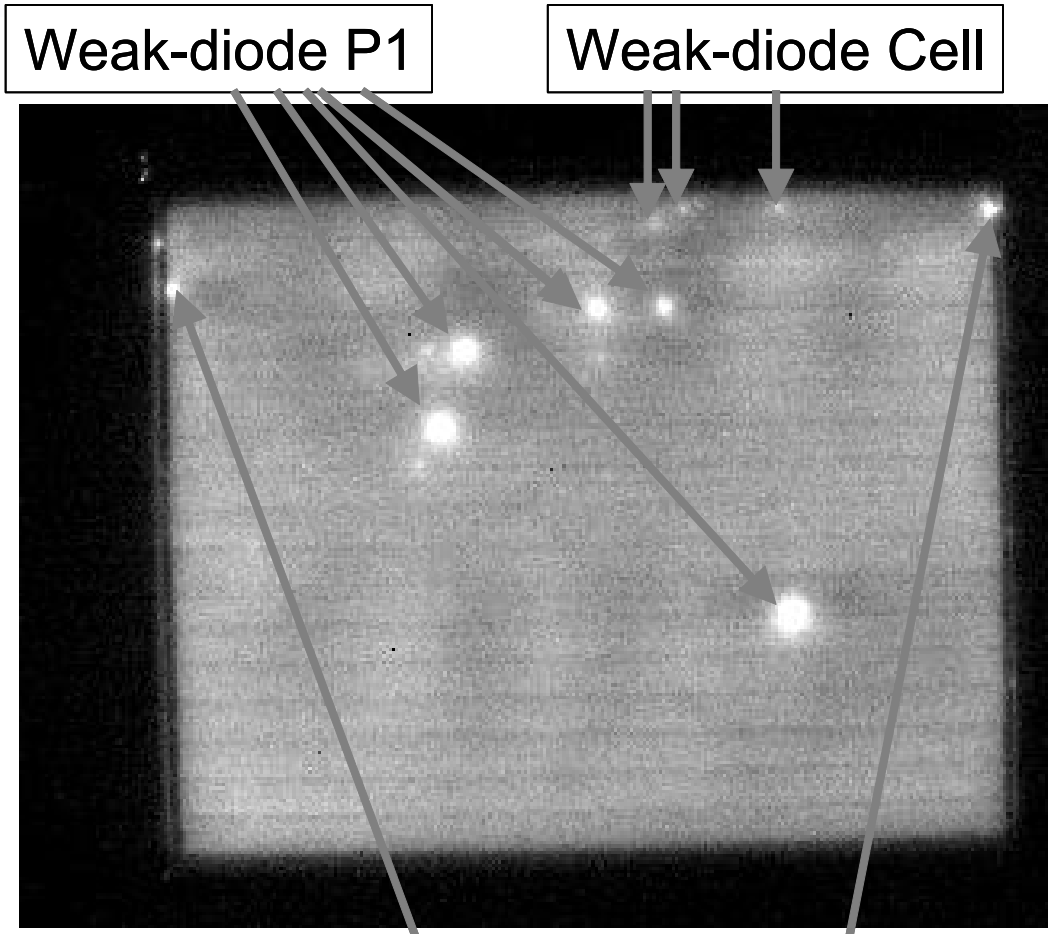


The flashlight illuminated the side of the cell just outside the image to ensure that we were not just seeing a reflection.



Silicone/Tefzel after 2290 h 85ºC and 0% RH. #29

Weak Diodes Principally Located at P1 Scribes or Cell Edge



Silicone/Tefzel
after 2290 h
85ºC and 0% RH.

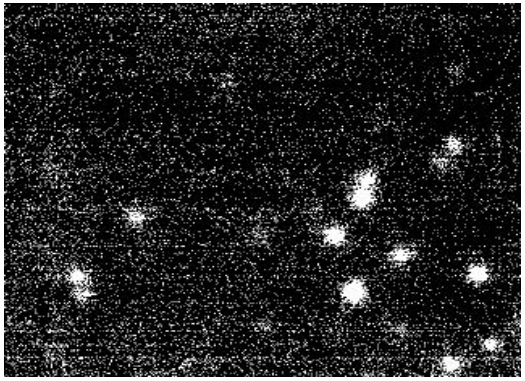
9.3V and 153 mA
Applied for 20 s

Module #29

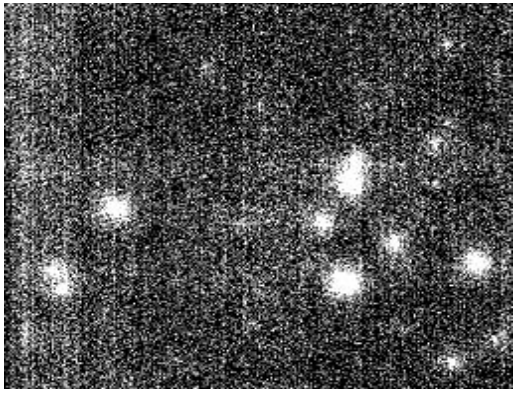
The Number of Weak Diodes Barely Changed

Module #30, Silicone/Tefzel at 85°C/0% RH

Reverse Bias



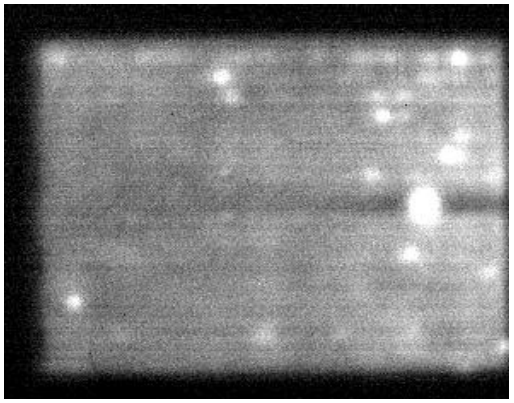
2 mA, -9.6V
20s
2290 h Exposure



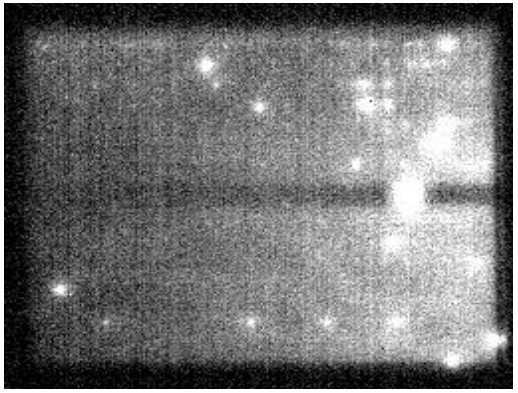
2.3 mA, -9.5V
20s
8770 h Exposure

Shunts

Forward Bias



90 mA, 9.6 V
20s
2290 h Exposure

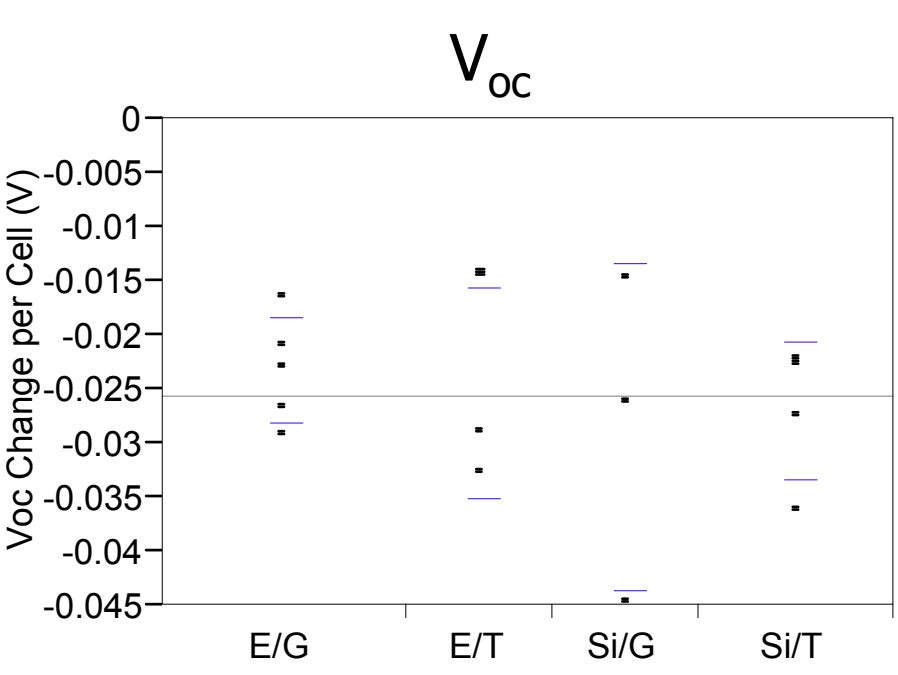


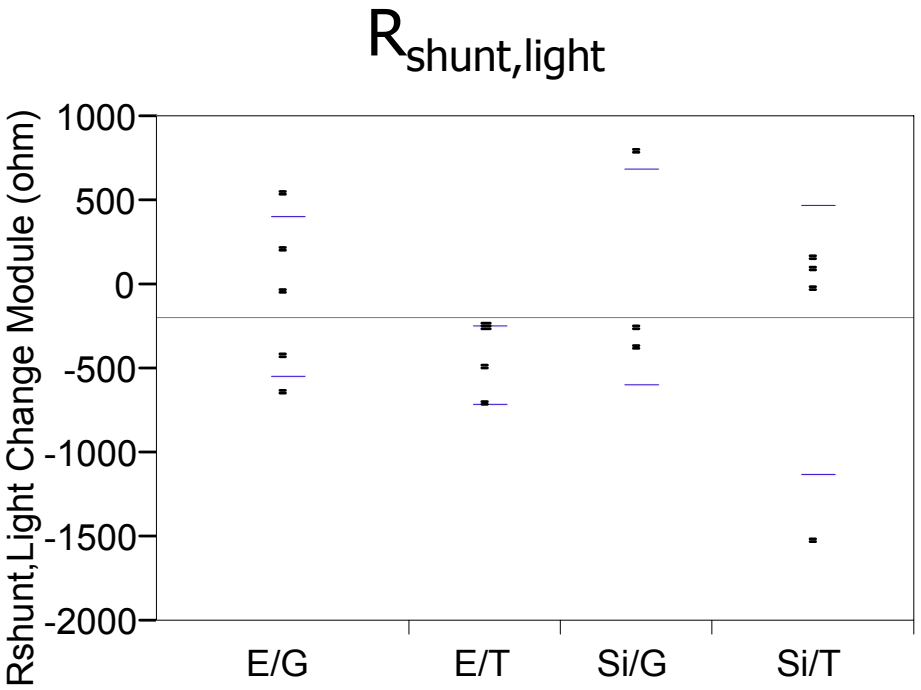
50 mA, 9.5 V
20s
8770 h Exposure

Shunts and Weak Diodes

Diodes are Weaker but Shunting is Unchanged

8770 h exposure to 85°C and 0% RH





Similar change in V_{oc} across all sample sets. No statistically significant change in Shunts.

Conclusions

- Exposure to 85°C and 85% RH for 457 h or 935 h:
  - Large increases in ZnO resistance.
  - Some V_{oc} losses.
- Exposure to 85°C and 0% RH for 8767 h:
  - Small increases in ZnO resistance.
  - Some V_{oc} losses.
  - No shunting change.
  - Silicone encapsulated cells performed better than EVA.
  - EVA produced greater losses in FF and series resistance

Acknowledgements

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