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Failure Analysis to Identify Thermal Runaway of Bypass Diodes in Fielded Modules

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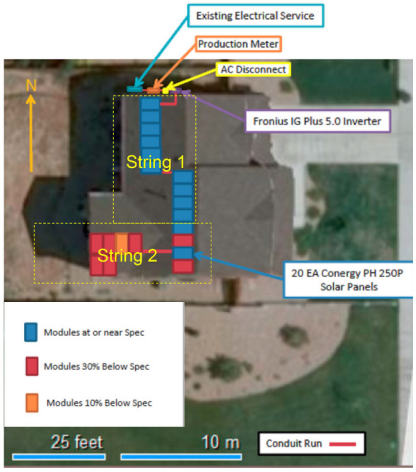
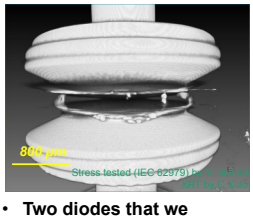
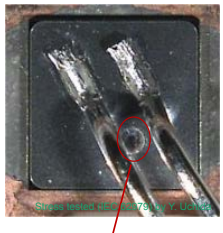
Background & Introduction



- Two 10 module strings, one of which has South and West facing modules. This string had many bypass diode failures (shunting) with module power loss as shown.
- Did these diodes fail by thermal runaway?
- IEC 62979 ed 1 (draft) "Photovoltaic module bypass diode thermal runaway test" was applied on unfailed diodes from these modules. No failure seen.
- We performed failure analysis on the field-failed bypass didoes to determine if the failures resemble thermal runaway, a lighting strike, electrostatic discharge, or other overheating?
- **Failure analysis of short-circuited diodes from fielded modules to show thermal runaway has not yet been demonstrated.**

Lab-stressed thermal runaway diodes





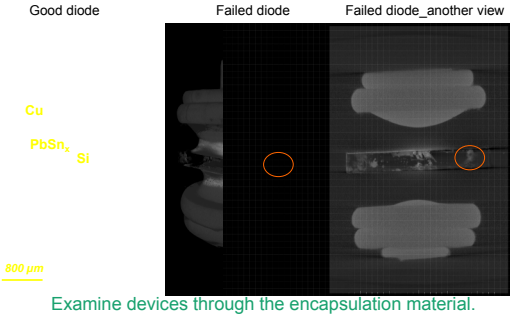
- Two diodes that we examined that failed by thermal runaway by the IEC 62979 (draft) test showed melted solder and migrated metal (Pb) on the diode edge faces (above). Etch back shows evidence of burns or residue on the chip face (right).

Experiment

1. ***Bypass diode recuperated from fielded modules in a rooftop installation to determine the failure mechanism***
2. ***X-ray tomography to identify shunt locations without breaking encapsulation***
3. ***Unencapsulate the package, use dark lock-in thermography to study the locations identified by X-ray tomography***
4. ***Aqua Regia etch the diode to expose silicon piece***
5. ***SEM/EDS and optical microscopy to image suspicious shunt locations***

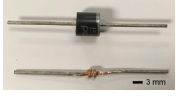
Results & Discussions

X-Ray Tomography

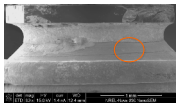


Examine devices through the encapsulation material. Obvious particles observed on silicon surface, similar to the lab-stressed diodes.

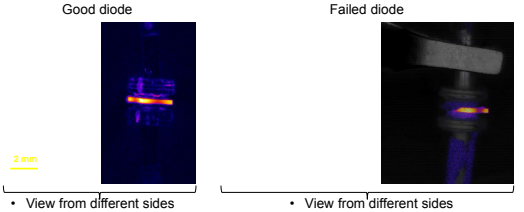
Mechanically remove the encapsulation to expose the semiconductor device.



SEM



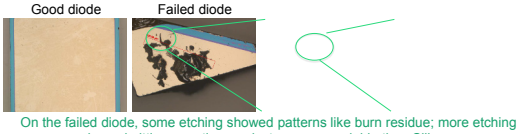
Thermal Imaging & Lock-In Thermography



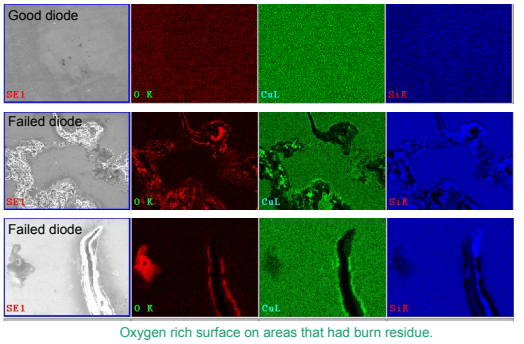
- View from different sides
- Uniform heating in forward bias

- View from different sides
- Nonuniform heating.

Optical images after acids etch away metal, do EDS

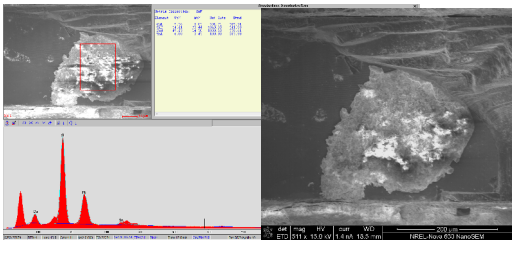


On the failed diode, some etching showed patterns like burn residue; more etching showed pitting, reaction product are more soluble than Silicon.



Oxygen rich surface on areas that had burn residue.

SEM Energy-Dispersive X-ray Spectroscopy (EDS)



- High resolution imaging to examine defects and identify materials.
- ***Obvious Pb-rich phase, appears to be melted solder.***

Conclusions

- **The field-failed diode showed similar characteristic of thermal runaway, specifically XRT evidence of migrated metal;**
- **1) Observed burn marks on silicon surface like those lab-stressed for thermal runaway;**
  2) Reaction products are more soluble than silicon, surface is oxygen rich.

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