Prediction of critical module hot spots caused by shunts in silicon solar cells using in-line thermography

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Background and Motivation:

One of the critical failure modes of photovoltaic modules installed in the field is damage of the module due to hot spots. The effects of hot spots in the field range from degradation of the module power to complete loss of module performance. Hot spots in modules can be classified into two main groups as cell related (shunts) and non-cell related (arcing). This work focuses on cell related hot spots and their detection using in-line thermography in a high-volume crystalline solar cell manufacturing environment.

Shunts in solar cells can lead to hot spots and are either process or material induced. Process induced shunts can be due to insufficient edge isolation or metallization edge paste. Material related shunts in cells can be due to carbon inclusions or impurities at grain boundaries when these are located near the PN-junction.

Shunts across the PN-junction of a solar cell lead to an increase of current at a given reverse bias. While the reverse-bias current can be measured during IV-curve testing, it is not a good predictor of hot spots as the shunt area determines the dissipated power and subsequent Joule heating[1]. Figure 1 shows the correlation of the reverse-bias current measured by an IV-curve tracer to the temperature of the hot spot for a large amount of sample cells. Many of potentially critical hot spots would not be caught by mere reverse-bias current sorting of cells. On the other hand, not every cell with a high reverse-bias current displays significant hot spot behavior.

To solve this problem, SolarWorld is implementing an in-line thermography system for production monitoring in their cell testers. The thermography system uses an IR camera to detect hot spots on cells while applying a reverse bias and measuring the resulting localized temperature. Due to the required high throughput of the cell testers, the thermography measurement has to be limited to less than one second. The thermal mass of the solar cell and the varying degree of the shunting make it difficult to correlate this short measurement to the equilibrium temperature of the shunt or even potential module damage.

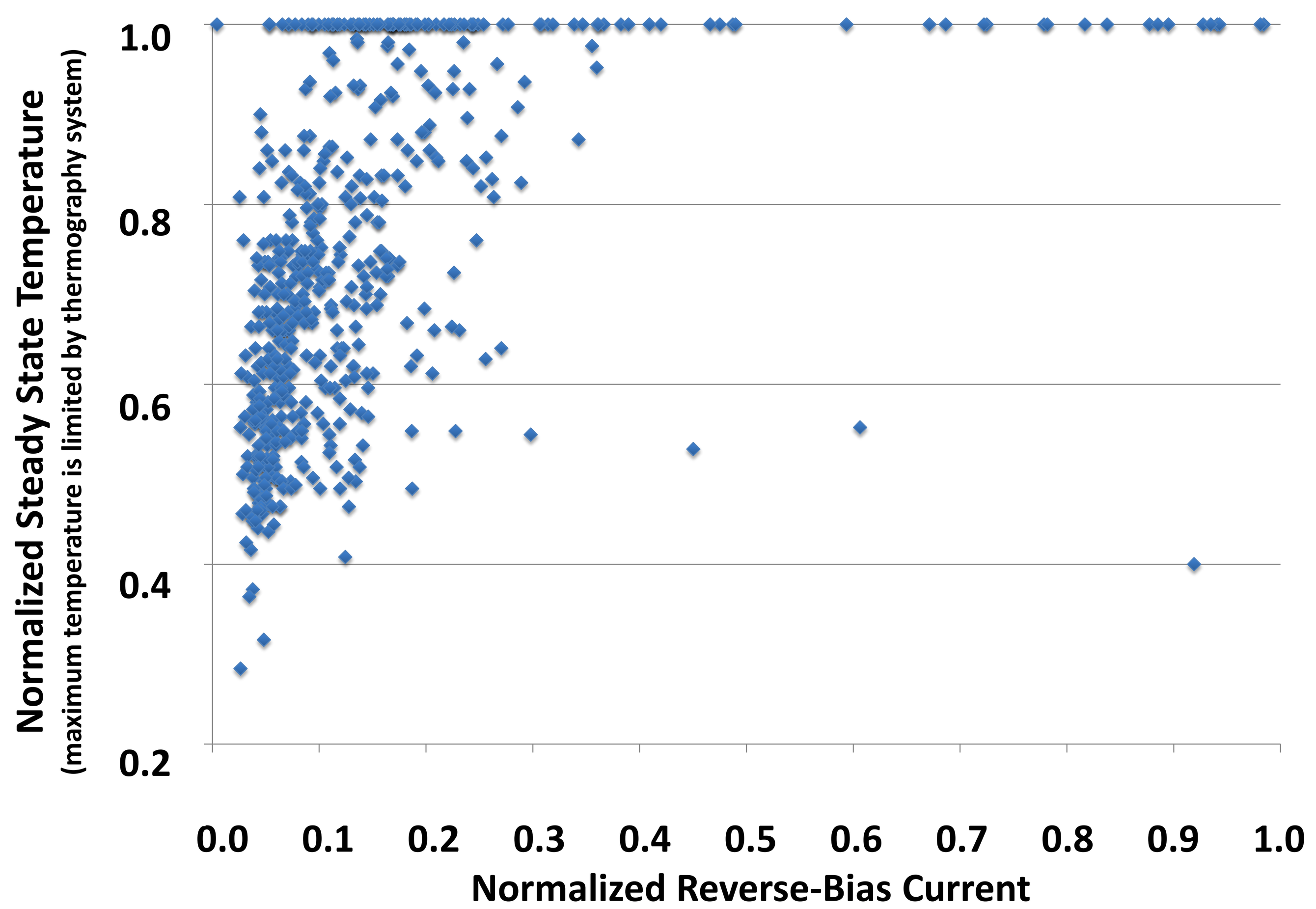

Fig. 1 – Correlation between reverse-bias current and steady state hot spot temperature

References:

[1] M. Kasemann *et al*, "Spatially resolved silicon solar cell characterization using infrared imaging methods," *Proc. 33rd IEEE PVSC*, San Diego, CA, 2008.

[2] F. Fertig, "Hot Spot Detection via IR Thermography in Crystalline Silicon Solar Cells", Masters Thesis, IPE, University of Stuttgart, 2009

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Methodology:

In order to correlate the in-line thermography measurements to the hot spot behavior of modules, the methodology shown in Figure 2 was established.

A test set of about 1,000 solar cells with hot spot signatures was sorted out at the cell tester and characterized on an off-line thermography system (Fig. 3). The hot spot temperatures of these cells were measured at steady state equilibrium. The samples were then grouped into temperature bins of 10 °C steps and cells from each group were interconnected and encapsulated into modules.

These modules were exposed to sun irradiation >800 W/m^2 under short circuit conditions and the steady state temperatures of the resulting hot spots of shaded cells were measured using an IR camera (Fig. 4, Fig. 5).

In addition to the IR camera temperature measurements, any optical defects like bubbling, delamination, or discoloration of the back sheet or EVA arising from the hot spot were recorded with respect to the hot spot temperature. Figure 6 shows an example of delamination on the front and the back side of a module caused by a significant hot spot which was created specifically for this experiment.

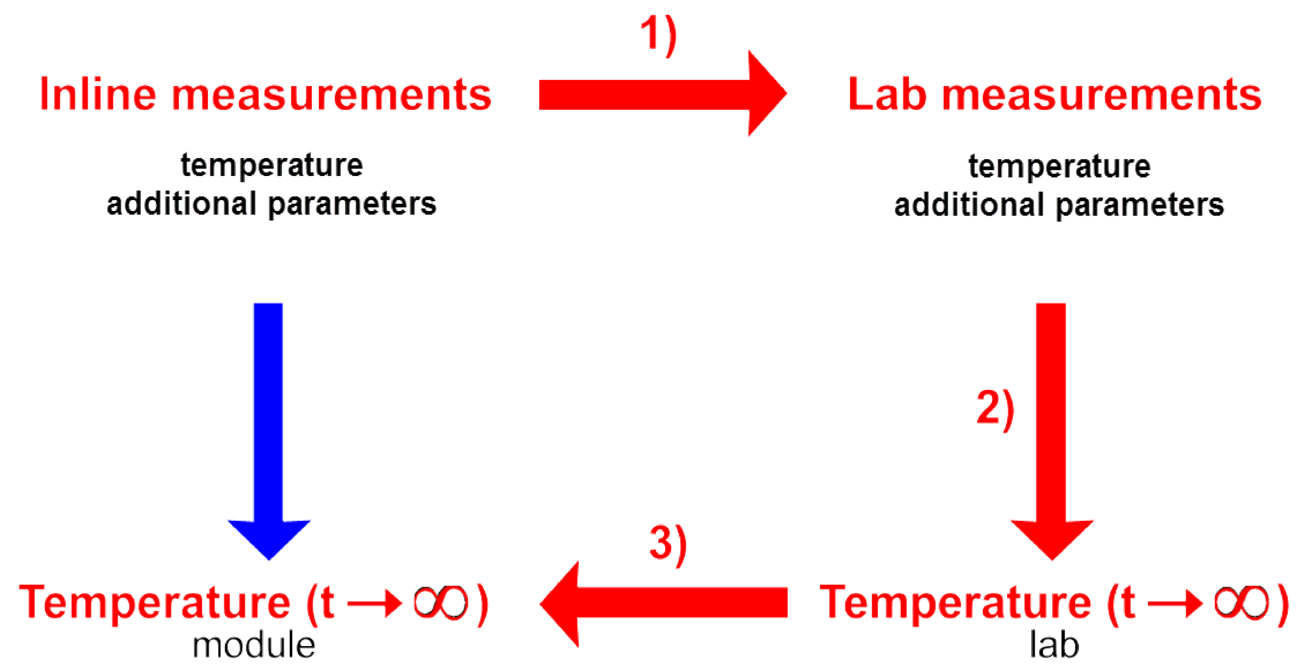

Fig. 2 – Methodology to correct in-line thermography measurements to module hot spot temperatures[2]

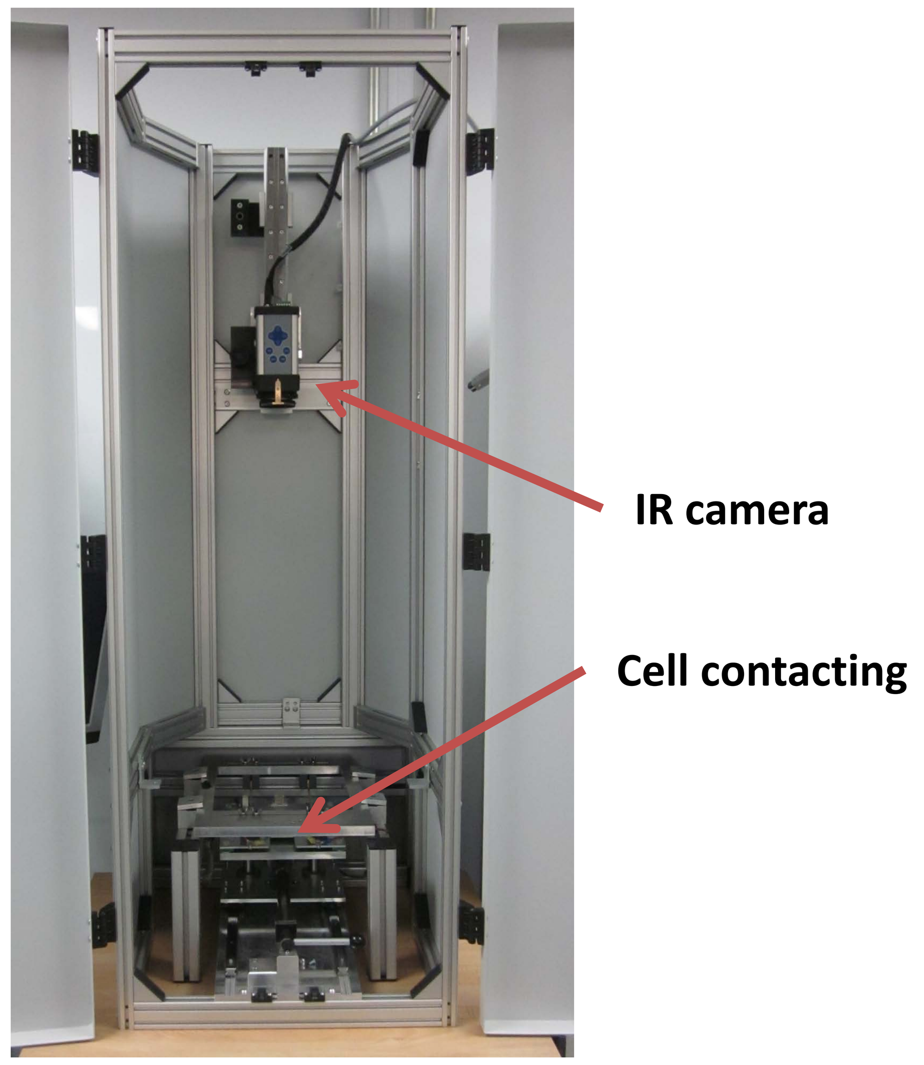

Fig. 3 – Off-line thermography measurement system

Results:

Based on these module test results, a relationship between maximum allowable hot spot temperature (as measured on solar cells with the off-line thermography system) and the potential for module damage was established. The temperature at which module damage can occur is dependent on the material properties of the encapsulants.

In the final step, multiple-regression algorithms were used to fit parameters from the in-line thermography measurement to the steady state measurements and establish cell sorting criteria.

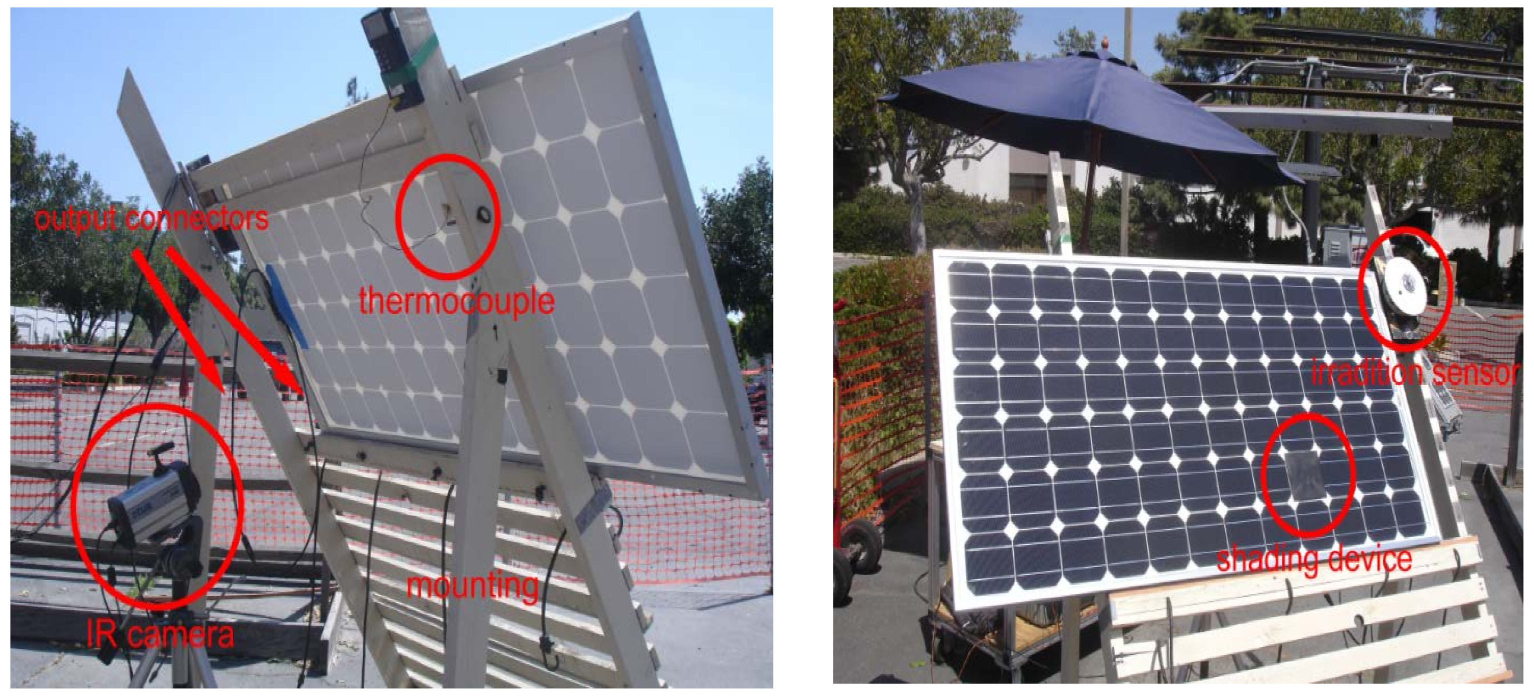

Fig. 4 – Set-up of outdoor hot spot measurements

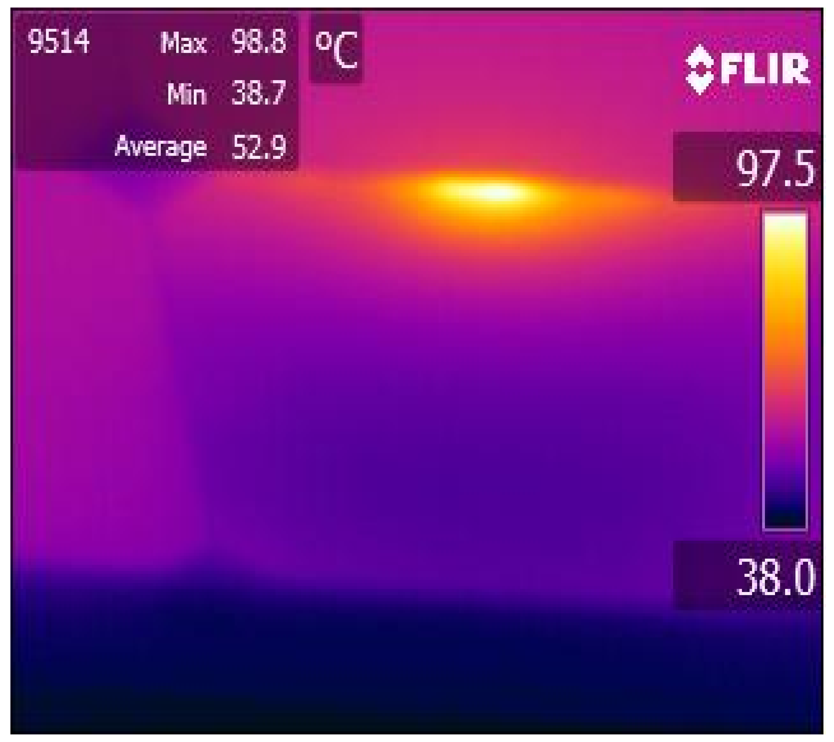

Fig. 5 – Example of a hot spot measured in a shaded cell using an IR camera

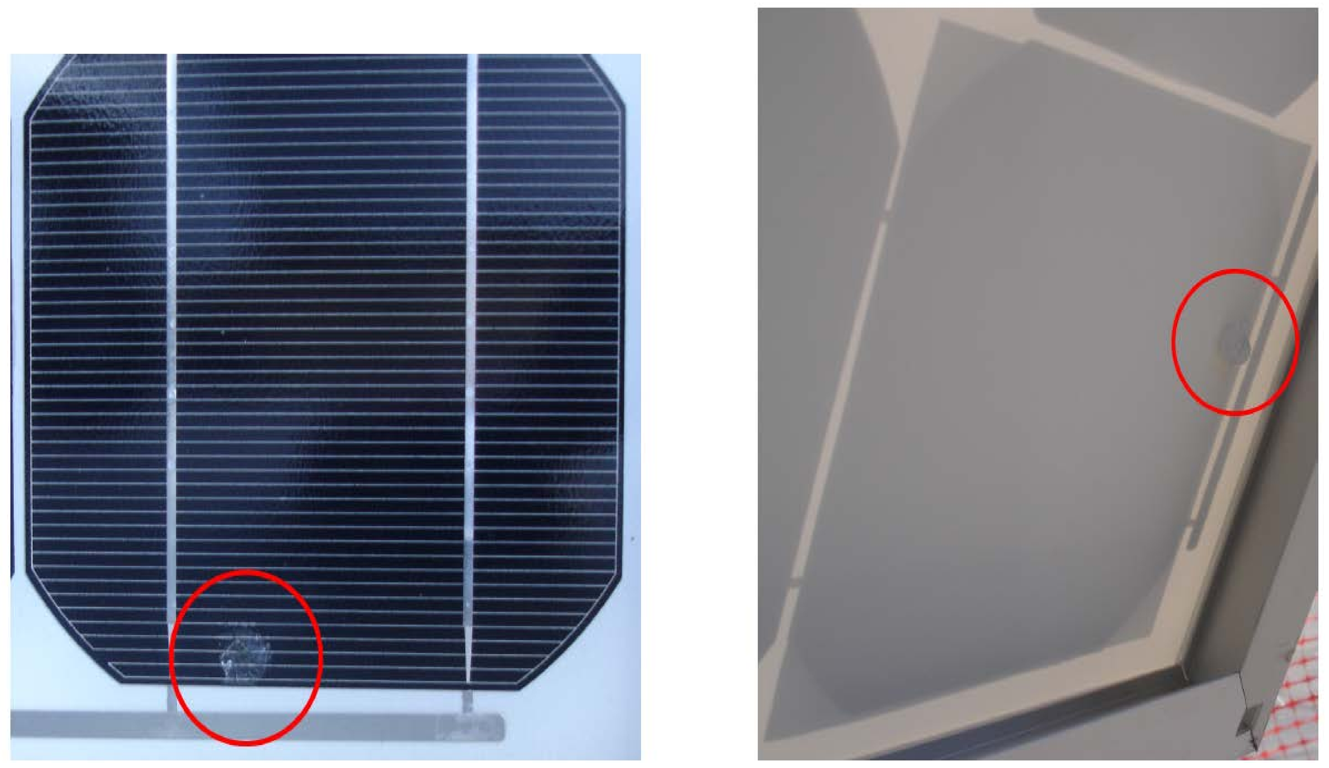

Fig. 6 – Example of delamination due to hot spot

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