Metal thin-film temperature sensor embedded in heat-sink for CPV cells characterization

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Metal Thin-Film Temperature Sensor Embedded In Heat-Sink For CPV Cells Characterization

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Abstract. The efficiency of a photovoltaic cell is dependent on its temperature, for this reason an accurate measurement of this parameter is important to fully characterize the device and to optimize its performance. For CPV applications a significant heat flux is needed to remove excess heat from the cell towards a heat sink, making it difficult to derive the cell temperature. In fact, measurements performed directly between the cell and the heat-sink, by use of commercial bulk sensors, would produce a significant disturbance in the heat flow; on the other hand, a measurement performed out of the cell / heat sink axis would be subject to large uncertainties, due to the high radial temperature gradient. We approached the problem of accurate temperature monitoring of PV cells by fabricating a metal thin-film thermometer directly on the heat sink. The measure is thus very accurate while the sensor thinness ensures minimal disturbance to the heat flow.

Keywords: HCPV, multi-junction cell, temperature, thin-film sensor, heat sink.
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INTRODUCTION

High Concentration PhotoVoltaic (HCPV) modules are usually based on high efficiency multi-junction photovoltaic cells. These cells are subject to very intense solar irradiation and must dissipate the produced heat by means of a proper heat sink. The cell temperature affects the conversion efficiency [1][2], so it is a key parameter to characterize and optimize the HCPV system. Moreover, it is imperative that the cell is always maintained within a safety temperature to avoid permanent damage or shortening its life.

Methods have been proposed to estimate the cell temperature from the open circuit voltage, or the maximum power voltage of the cell [3], thus enabling direct on-field measurements. These methods require an accurate calibration to correlate the involved parameters with the cell temperature in a calibration session. Unfortunately an in-situ measurement of the temperature of the cell under irradiation is difficult because of the lack of an immediate physical access to the cell itself, since one side is irradiated and the other is attached to the heat sink.

Usually the temperature is obtained from measurements performed in a different location through the knowledge of the relative thermal resistance and heat transfer dynamics, which are quite difficult to model accurately. Also the calculations are rather inaccurate because of the high heat flux and the corresponding high thermal gradients involved.

An alternative approach consists in using flash solar simulators that use very short light pulses allowing to perform the electrical measurements without appreciably affecting the temperature of the cell [3]. Anyway this solution requires specific and very high cost equipment and only applies to laboratory testing.

In our initial effort to characterize the HCPV module we developed in the framework of the FAE “Fotovoltaico ad Alta Efficienza” research project [4], we sacrificed a small portion of the cell active surface placing a temperature sensor on one of its corner. To avoid this undesirable intrusion, we successively developed a process to fabricate a thin-film sensor directly on the heat sink surface, right under the cell (FIGURE 1). A sensor placed between the cell and the heat sink allows an accurate reading, but using a bulk commercial sensor would interfere with the heat transport. Embedding the sensor in the heat sink adds only a few microns thick layer of insulating material and only a thermal grease interface separates the sensor from the cell. The measure can thus be accurate while the perturbation to the heat flow would be negligible, or anyway easy to model if a higher accuracy is needed.

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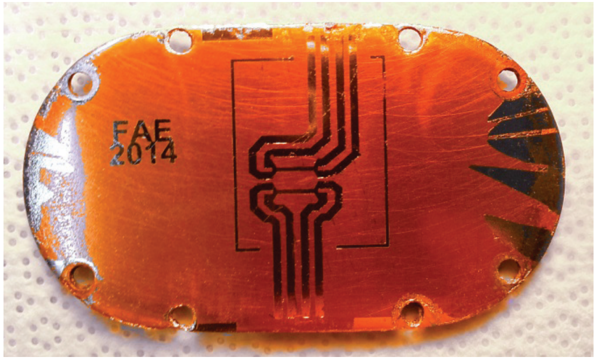

FIGURE 1. Two thin-film temperature sensors deposited on a copper heat sink. The sensors are the two small titanium strips; each one of them is connected to four electrical tracks to make 4-wire resistive measurements.

THIN-FILM TEMPERATURE SENSOR FABRICATION

The sensor is a resistance temperature detector. It consists of a 40 nm thick strip of titanium sandwiched between two insulating layers, that prevent the sensor to be short-circuited from the conductive copper heat sink and protect it mechanically. The temperature is proportional to the electrical resistance of the sensor, which is measured with a four wires configuration in order to bypass the resistance of the electrical tracks coming from the sensor. The fabrication of the sensor comprises the following steps:

1. heat sink surface preparation: lapping and polishing;
2. 1th dielectric layer deposition;
3. sensor and electrical tracks deposition and patterning;
4. 2th dielectric layer deposition.

Step 1 is critical if a thin insulating layer is to be used. In particular, it is difficult to polish copper obtaining a defect free surface because of its low hardness. A combination of mechanical polishing and electro-polishing is employed to produce a smooth surface free from tips or defects that could shorten the sensor. A solvent based resin is used for both the dielectric layers; it is deposited by spin-coating, producing a uniform 2.5 μm thick film that can compensate for small surface defects. It is then hardened by baking at 230 °C for several hours and it can withstand safely the maximum allowed temperature of the cells we operated with of about 130 °C. The sensor and the electrical tracks and contacts are deposited with an electron-beam vapour deposition system and patterned with a standard lift-off process.

Another version of the thin film sensor has been embedded with a similar process in a copper/beryllium disk that can be used as a very low thermal resistance thermometer (FIGURE 2). In this case 500 nm thick layers of Spin-On Glass (SOG) have been used in place of the organic resin, allowing operation up to 400 °C and offering an even lower thermal resistance because of the reduced thickness. The use of thin layers of SOG is permitted by the higher surface quality of polished Cu/Be compared to polished copper.

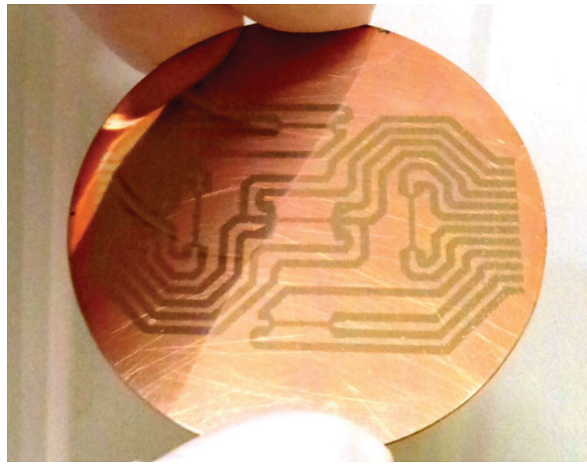

FIGURE 2. Five temperature sensors deposited on a Cu/Be disk. The surface quality is higher than that of polished copper: the roughness is lower and residual scratches, visible in the figure thanks to the grazing light, are of far less entity.

Calibration

The sensors shown in FIGURE 1 were calibrated coupling a PT100 sensor to the heat sink, shielding the bundle with metal foil to avoid non uniform convective or irradiative heat transfer, and slowly heating it in a oven. The resistance vs. temperature curve follows the expected trend as is showed in FIGURE 3.

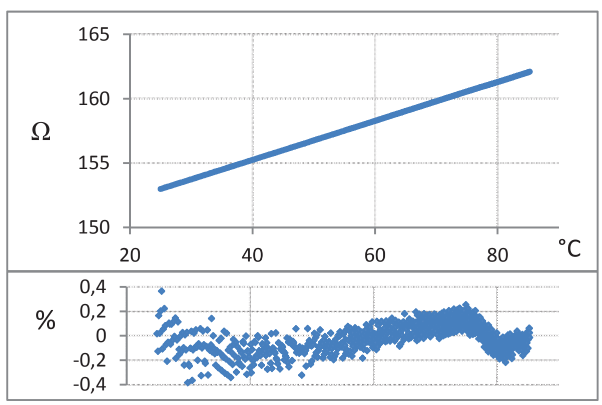

FIGURE 3. Resistance versus temperature for one of the sensors shown in FIGURE 1. Residuals from linear regression are shown in percent.

CONCLUSIONS AND FURTHER DEVELOPMENT

The possibility to embed temperature sensors in heat sinks with the method described offers a solution for accurate, unobtrusive measurements of photovoltaic HCPV cells temperature. The process described could also be used to fabricate sensor arrays to study the heat flux distribution toward the heat sink. Moreover the fabrication of very low thermal resistance thermometers built as a thin film sensor on Cu/Be substrates allows temperature measurements where the sensor, for whatever reason, cannot be directly deposited on a heat sink, or in any other application where a strong heat flux would make an higher resistance thermometer not acceptable.

We are currently developing the processes to deposit a temperature sensor directly on the back of a photovoltaic cell, using a technique similar to what has been described, to address the temperature measurement problems of cells that use cooling methods that don't rely on direct contact between the cell and a metallic heat sink.

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