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Application of infrared thermography to the characterization of multicristalline silicon solar cells

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Abstract

In this study, infrared thermography is used to detect defects in large area (100 cm^2) multicrystalline silicon solar cells. Hot spot observed in biased solar cells are correlated to a critical processing step which needs to be improved. Usually these shunts are due to short circuit of the junction which leads to a local heating. By this way infrared thermography appears as a very useful tool to improve solar cell fabrication and efficiency.

1. Introduction

Photovoltaic industry needs non destructive techniques permitting the mapping and detection of defects in large area solar cells (100 cm^2). LBIC (Light Beam Induced Current) is a very useful method which gives photocurrent cartography. DPCT (Dynamic Precision Contact Thermography) [1] permits to visualize thermal distribution at the surface of a biased solar cell but it necessitates contact between the cell and a thermal sensor and it is long. In contrary, Infrared Thermography (IRT) allows the mapping of temperature without contact and with a shorter delay than DPCT.

In this study we use infrared thermography in order to test the reliability of different technological steps of the elaboration of 100 cm^2 industrial multicrystalline silicon solar cells. The results allow to concentrate on critical steps and to improve the number of photovoltaic devices with good efficiency.

First, we will present the experimental setup and describe the solar cells. Then we will discuss the results and the improvement performed owing to infrared experiments.

2. Experimental

2.1. Infrared camera

The infrared scanner is an AGEMA 880 SW with an InSb monodetector (wavelength range : 3-5 μm). A 12° lens with a 5 mm extension ring provides a field of view of 10 cm x 10 cm at the distance of 0.66 m. The image repetition frequency of the camera is 25 Hz.

2.2. Photovoltaic cells description

Solar cells analysed are 100 cm^2 industrial multicrystalline silicon solar cells (average grain area : 1 cm^2) with submicronic junction ($x_j < 0.3$ μm). The structure of such solar cell is presented in figure 1. The basic component is a n^+p junction realized by $POCl_3$ diffusion on the whole surface of the silicon. The wafer is then etched at the edges in order to avoid any short circuit between front and back surface of the solar cell. The surface of the cell is texturised (it has been submitted to a NaOH chemical attack giving to the surface a pyramidal aspect and improving photons absorption). A SiO_2 layer is grown for surface passivation and TiO_2 is deposited as antireflection coating. Front and rear grid metallisations are screen printed and annealed at the end of the process. Emitter thickness is 0.3 μm and solar cell thickness is 200 μm. Short circuit current is about 3A and open circuit voltage about

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0.6V. During the measurements, the cell is in dark conditions and biased either in forward or in reverse polarization.

2.3. Measurements description

For the measurements, we are using averaging and subtraction of image of the cell not biased and of the cell polarized under stable DC conditions [2,3,4,5]. This permits to attenuate constrast due to emissivity differences between grains, particularly important in multicrystalline cells (between 0.5 and 0.8 [6]). Another way to proceed is to bias the cell with a periodical pulse and to synchronize the acquisition time with the pulse. In order to measure the transmission coefficient of the solar cell, we have used a spectrophotometer working in the spectral range : 2.6 μm to 16 μm. For the solar cell, the transmission was equal to zero for the whole spectral range probably because of contacts, antireflection coating and texturisation. For the emissivity, we use an average value of 0.66, determined by measurements of the luminance emitted by the solar cell heated at different known temperatures. Another way to proceed is to cover the cell with a blackened plastic foil [7].

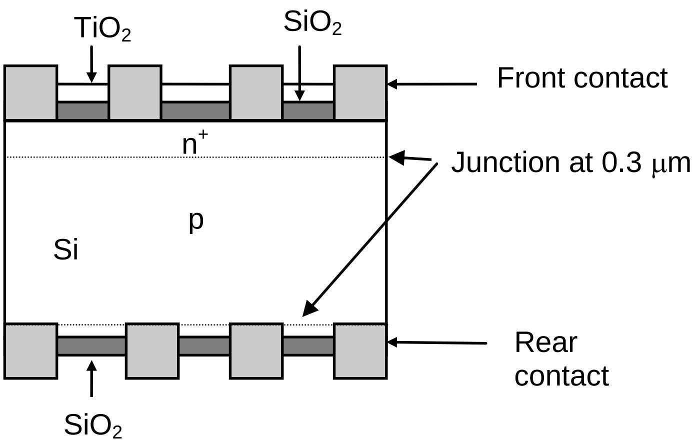

Figure 1 : Structure of the solar cell used for the characterization. Total thickness : 200μm

3. Results

In order to find which step needs to be improved, we have first characterised many solar cells with good and bad efficiencies. Some of the problems and defects detected are presented elsewhere.

3.1. Defects under interconnections

Sometimes, hot spots are present under interconnections between copper wires and solar cells contacts (see top right interconnection on figure 2). Welding step has been lightly modified in order to avoid these shuntings. Moreover a study has been performed in order to improve the solderability of contacts of multicrystalline silicon photovoltaic devices by electroless deposition of a thin layer of nickel or copper [8].

3.2. Solar cells with acid texturisation

If an acid solution is used instead of NaOH for the texturisation of the silicon, the optical properties of the solar cells are improved (lower reflectivity in visible range) because we obtain an uniform texturisation. We have measured the emissivity of such cells and a value of 0.7 has been found which is not very different than a NaOH texturised solar cells. Heatings are more important in acid texturized cells because of higher mechanical strains. That is why

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the solution used for acid texturisation has been greatly optimized (see figure 3) and solar cells with this type of texturisation are nearly commercialised.

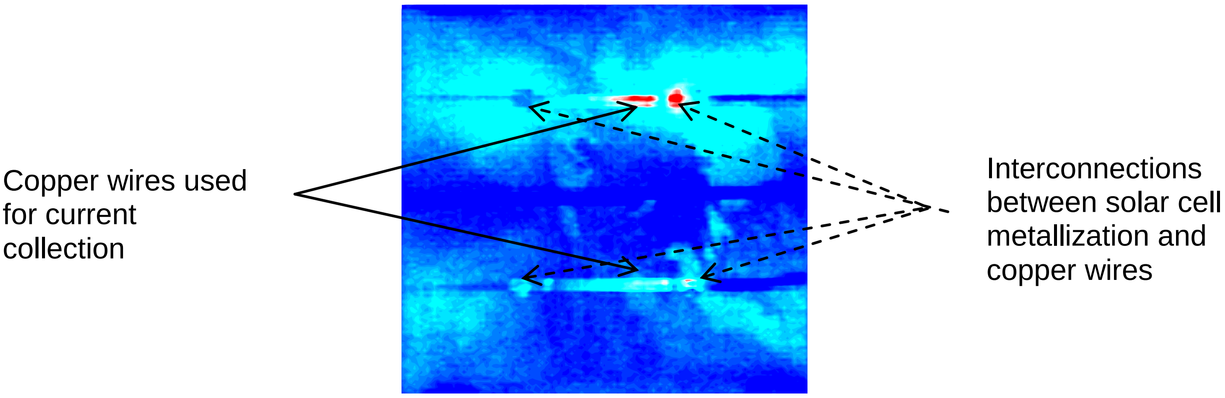

Figure 2 : IRT of 100 cm^2 solar cell under a current of 1A.

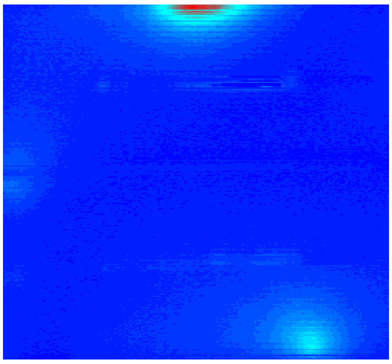

Figure 3 : IRT of a 100 cm^2 solar cell biased at -1V. Maximum heating : 0.5°C.

3.3. Shunting at the edges of the cell

There are often hot spots at the boundary of the solar cell due to an insufficient etching of the silicon edges during diode opening (see figure 4).
Two process have been compared : a plasma etching (figure 4) already industrialized and a chemical (wet) etching (figure 5) tested on five solar cells. The first still gives best results and is more easily industrialized ; however the second one may give good results if chemical solutions would be improved.

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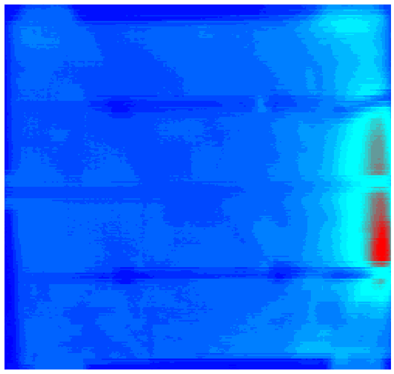

Figure 4 : IRT of a 100 cm^2 solar cell biased at -3V. Maximum heating : 3.15°C.

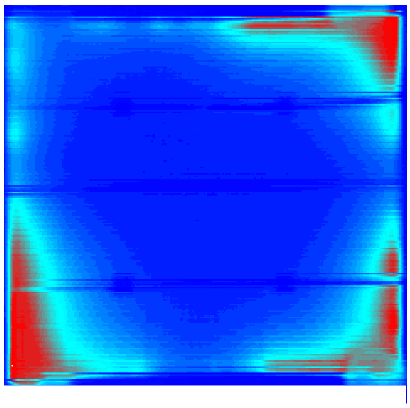

Figure 5 : IRT of a 100 cm^2 solar cell biased at -3V. Maximum heating : 3.2°C.

3.4. Defects in the material or at grain boundaries

Material quality could be also responsible of hot spots especially in multicrystalline silicon solar cells where recombinations could occur at grain boundaries. In this case, a correlation with LBIC mapping is interesting to perform. LBIC method consists in measuring the photocurrent of the cell scanned by a laser beam [9]. An exemple of LBIC picture of a hot spot detected by IRT is presented on figure 6 (left). A recombination area is visible. SEM picture (figure 6 right) reveals the presence of a grain boundary probably responsible of the hot spot in infrared picture.

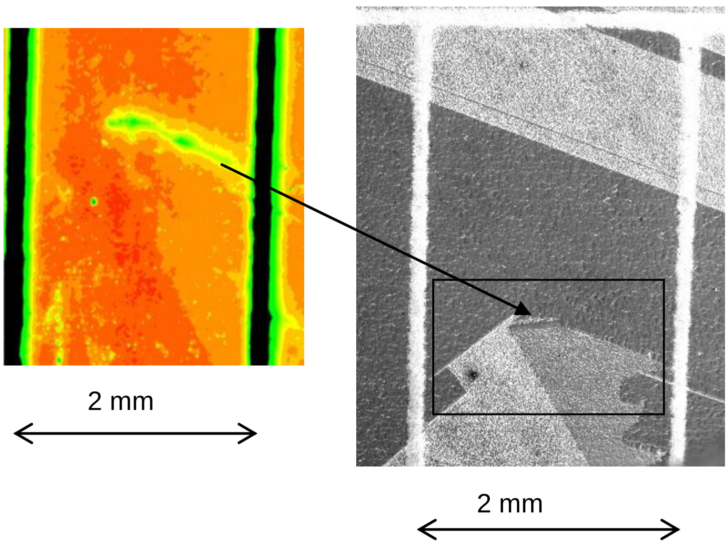

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Figure 6 : left : LBIC mapping of part of the cell where a hot spot is present in IRT picture ; right : SEM picture of the recombination region.

4. Conclusion

In conclusion, we have shown with this work that infrared thermography is a tool that can help to improve technological process of solar cells elaboration. It is interesting to correlate this technique to others non destructive methods of characterization like LBIC or EBIC (Electron Beam Induced Current) [7]. The application of IRT to the testing of modules on roofs is also useful to detect defectuous modules but images are more difficult to interprete [10].

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