An efficient method for monitoring the shunts in silicon solar cells during fabrication processes with infrared imaging*

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Abstract: In order to monitor the fabrication process, an infrared imaging system was established to detect the shunted regions in crystalline silicon solar cells. The temperature of the shunted region was obviously higher than that of the non-shunted region when the cell was biased under direct voltage due to the Joule heat effect, and the shunted region could be detected by infrared imaging. The shunts caused by seven different reasons can be identified using metallurgical microscopy, scanning electron microscopy, and energy dispersive X-ray spectroscopy. Approaches for diminishing shunts are presented. The methods are beneficial for the optimization of the cell fabrication processes and the improvement of the cell performances.

Key words: silicon; solar cell; shunt; infrared imaging

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1. Introduction

The electrical performance of crystalline silicon solar cells (c-Si SC) can be deteriorated by shunts having many possible causes, such as raw material defects, inappropriate handling and non-optimized process parameters. The shunts can decrease the fill factor, the open-circuit voltage, and hence the conversion efficiency[1]. The conventional approach to evaluate the shunts is carried out by extracting the shunt resistance from the *I*–*V* characteristics acquired under the condition of AM1.5 G at 25 °C. But the extracted value is only the overall effect of the whole tested solar cell, and it can not give detail information. By detecting the localized shunted regions and by identifying the shunting reasons with the help of other analysis methods, the optimization of cell fabrication process parameters and an improvement of the cell performance can be achieved.

The shunted region can be detected with electroluminescence (EL)[2,3], photoluminescence (PL)[4] or thermograph (TG)[5,6] imaging techniques. A liquid crystal sheet can also be used[7]. With a lock-in technique and a high quality camera, high temperature and spatial resolution thermo-images can be obtained[8,9]. An infrared imaging system has been designed and utilized in this paper. Although lock-in techniques were not used, the spatial resolution and boundary determination between the shunted and non-shunted regions were improved a lot due to the following approaches: firstly, the images were taken in non-steady-state condition to decrease the heat spreading in the silicon, i.e., once the leakage spots became clear, take the infrared image by the camera, and usually the leakage detection could be accomplished in less than 2 s; secondly the image could be analyzed with the software assisted with the hardware for better boundary determination between the shunted and non-shunted regions.

In the following sections of this paper, statistical results of different kinds of shunting reasons are presented first. Then different shunts produced in the fabrication processes are analyzed with the help of an optical microscope, a scanning electron microscope (SEM), and energy dispersive X-ray spectroscopy (EDS). Finally, conclusions are drawn.

2. Experiments

When a solar cell is biased a certain voltage, there is more Joule heat produced in the shunted regions than in the non-shunted regions. So, the temperature in the shunted region is higher than in the non-shunted regions. The temperature distribution on the surface of the cell was measured with an infrared imaging system. The higher temperature region corresponds to the localized shunted region. Then with the help of an optical microscope, SEM, and EDS, seven types of shunting reasons were identified. In the experiment, 100 crystalline silicon solar cells with a dimension of 125×125 mm^2 were tested and the statistical result is illustrated in Fig. 1. The sum of the probability was larger than one because more than one type of shunt might be present in the same cell in the whole production line.

3. Results and discussion

3.1. Shunts induced by plasma etching

3.1.1. Incomplete edge isolation

In order to isolate the front emitter (n^+) from the back

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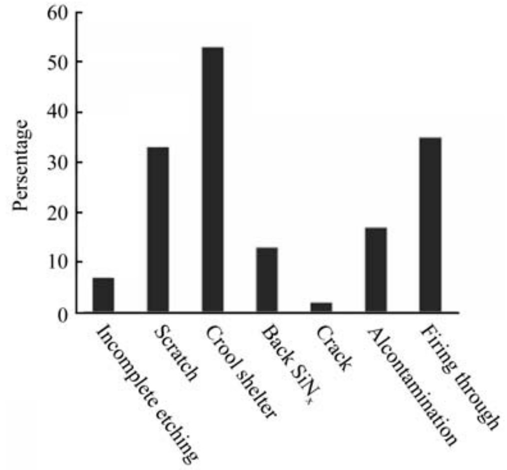

Fig. 1. Statistical result of shunting reasons.

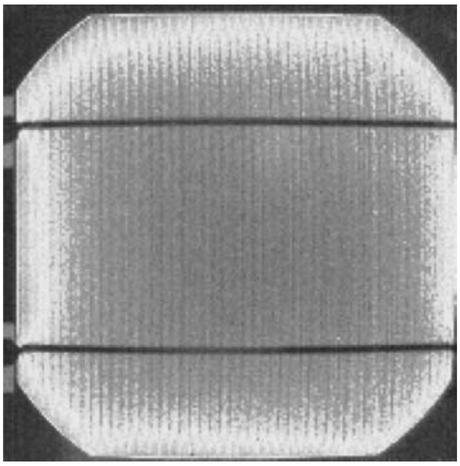

Fig. 2. Shunts caused by incomplete plasma etching.

contact, the heavily doped region on the periphery must be removed by plasma etching (PE). But if the PE parameters were not properly given, there would be residual emitter on the flank. Figure 2 shows the periphery shunted regions caused by incomplete PE, and this kind of shunts could be removed by prolonging the etching time or by increasing the PE power.

3.1.2. Scratches

The photovoltaic cells needed to be stacked together for large scale production. But the inappropriate handling could cause scratches on the wafer surface and then cause the base layer to be exposed. Then the exposed p-type base could be connected directly to the front emitter probably through the absorbed dusts and metal particles, and a shunt was induced. Figure 3(b) shows the SEM image of the scratched region A on the front cell surface, and the upper inset clearly depicted the damaged pyramids. Figure 3(a) is the thermo-image of the whole cell on which other scratched regions B, C, and D were also displayed. Careful handling during the fabrication could decrease the scratch induced shunts and improve the cell performance.

3.2. Plasma enhanced chemical vapor deposition (PECVD)

3.2.1. PECVD hook sheltering

The antireflection SiN$_x$ layer was deposited in a belt PECVD chamber, where the wafer was supported by four hooks at the four edges. The SiN$_x$ layer deposited on the places sheltered by the hooks is thinner than in other regions. The regions with thinner SiN$_x$ layers were then covered with screen-printed Ag-paste contacts, where the contacts could easily penetrate through the emitter. Figure 4 illustrates this kind of shunt in the regions under the four ends of the bus bars. Better hook devices and tube PECVD could avoid this problem.

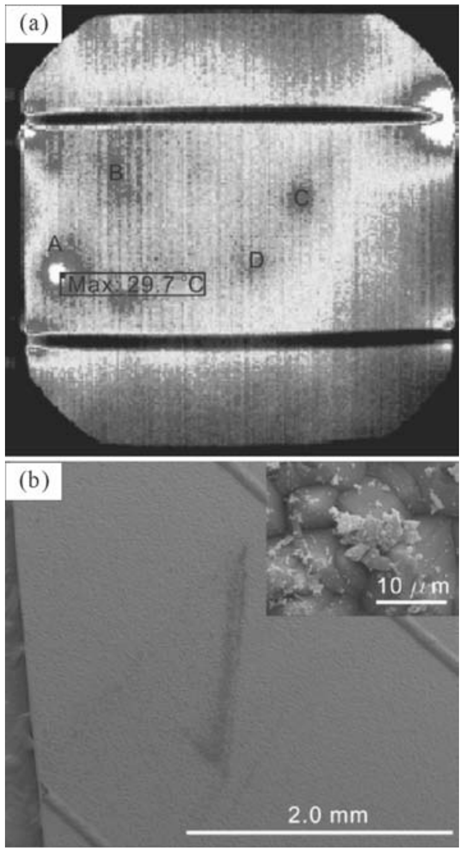

Fig. 3. (a) Thermo-image of the scratched solar cell; (b) SEM images of the worst scratched region A.

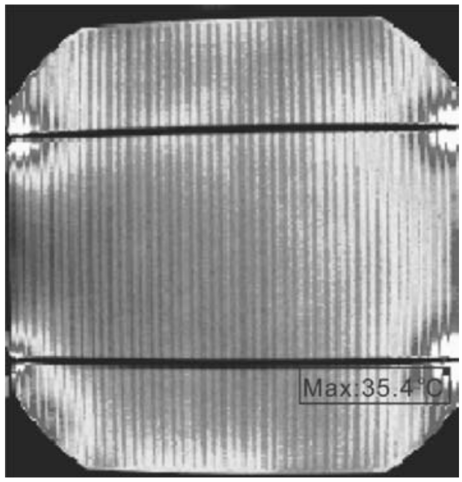

Fig. 4. Shunts caused by PECVD hooks under the four ends of bus bars.

3.2.2. SiN$_x$ layer on the back side

During the PECVD process, reactive gases could reach the rear side and a SiN$_x$ layer could form on the rear surface,

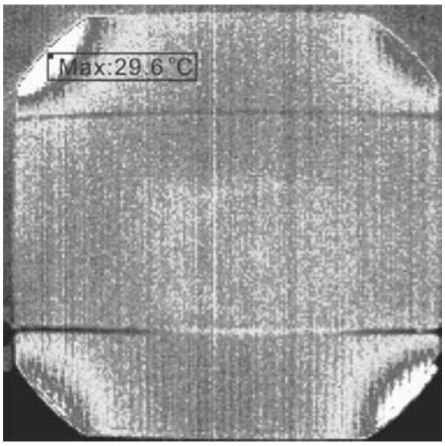

Fig. 5. Thermo-image of cell with shunts in the rear corners.

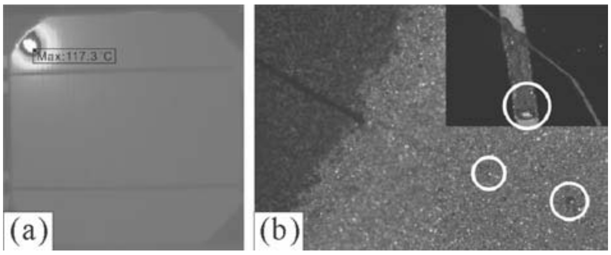

Fig. 6. Shunts caused by cracks: (a) Thermo-image of a shunted solar cell; (b) Optical micrographs of the shunted region.

which would prevent the Al atoms from compensation diffusion into the back n^+ layer. The residue p-n junction could result in a bad shunt, and this could happen more easily in the rear corners, which is illustrated in Fig. 5. A better chamber structure and tube PECVD could solve this problem.

3.3. Screen-printing

3.3.1. Cracks

A cracks in the started wafer or a crack due to inappropriate handling could give rise to leakage of the screen-printed paste through the crack to the opposite surface, resulting in a direct connection between the two sides. Figure 6(b) shows the Al paste running through the crack. It had a direct contact with the front silver finger. The leakage current was so large that the front silver finger was melted. As small printing pressure as possible and careful handling operation could decrease the crack shunts.

3.3.2. Al contamination under the front contacts

The front surface could be contaminated by Al-rich paste particles. The Al particles could penetrate through the SiN_x layer and compensate the n-type emitter, making the former emitter region become p-type during the sintering process. When the inversed p-type region was covered by the front contact, a bad shunted region could be present. Figure 7(a) shows the contaminated region by Aluminum marked with "A". Keeping the screen printing stage clean could decrease the contamination opportunity.

3.4. Sintering

The emitter could be easily penetrated by the front contacts during the sintering process if the sintering temperature is too high. Figure 8 shows the regions under the front contact bus bars with bad shunts. Getting stable and uniform temperature distribution in the firing furnace was vital for solar cell contact sintering.

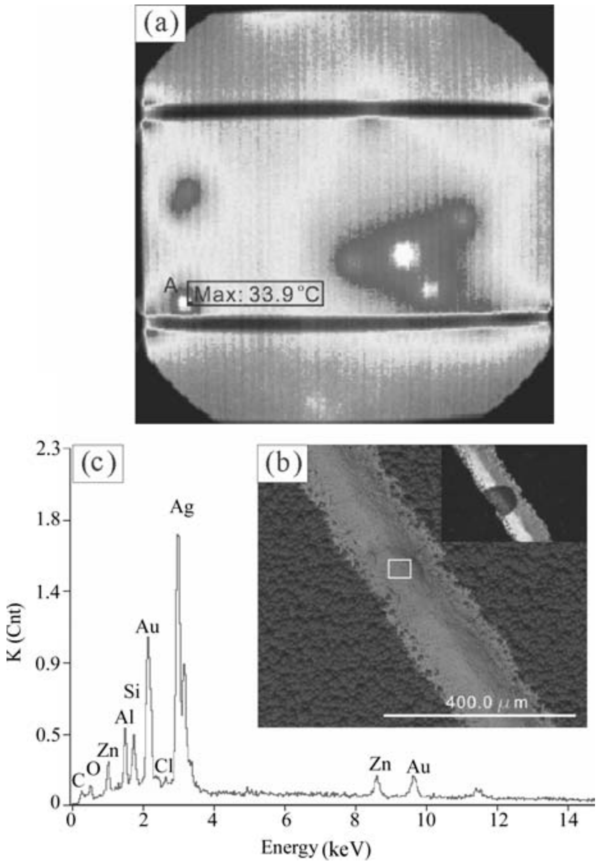

Fig. 7. Shunts caused by Al contamination on the front surface: (a) Thermo-image of the whole cell with A denoting the bad shunted region; (b) Back scattering electron image with the optical image in the corner; (c) Energy dispersive X-ray spectroscopy (EDS) of the box region showing the existence of aluminum.

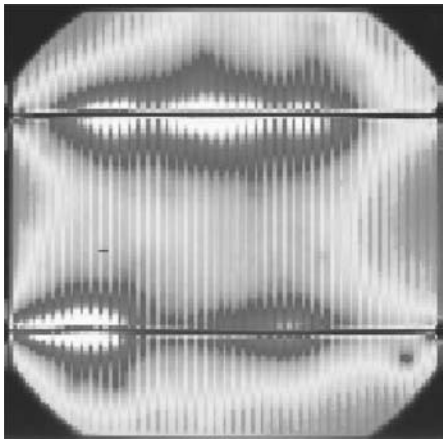

Fig. 8. Shunts caused by over sintering under the bus bars.

4. Conclusions

The shunted regions in crystal silicon photovoltaic cells were detected using an infrared imaging system. With the help of such analysis facilities as metallurgical microscope, a scanning electron microscope, and energy dispersive X-ray spectrometer, seven types of shunting reasons were identified and the corresponding potential methods to alleviate the shunts were proposed. The monitoring approaches can be used to find the problems in design, process parameters and handlings, which is of great importance in the improvement on the performance of solar cells. From the experimental results and discussions, we can conclude that shunts produced during various process steps can be removed or alleviated by using crack-free wafers, careful handlings, clean screen-printing stages, appropriate process parameters, and high-quality equipments.

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