THE CONNECTIONS BETWEEN DARK RINGS AND EFFICIENCY & THE ANALYSIS OF LOW EFFICIENCY IN MONOCRYSTALLINE SILICON SOLAR CELL

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ABSTRACT

This study would show the connections between dark ring and transfer efficiency. Through testing, it is indicated that there is no necessary relation between the low efficiency and dark rings, also, the cells with dark ring are not low efficiency necessarily. Slight dark ring can be detected with photoluminescence (PL), but not detected with electroluminescence (EL). Research shows that dark ring relates to the uneven distribution of minority carrier lifetime and the efficiency of solar cell depends on the whole lifetime of the wafer. It is shown that the silicon raw material and cell processing are the two main reasons leading to the low efficiency, if the cell keeps high lifetime after striping its surface, the influence of the material can be excluded. Reprocessing this type of wafer, the high efficiency cell can be gotten.

INTRODUCTION

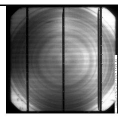
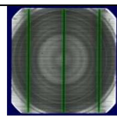
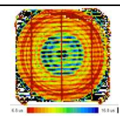
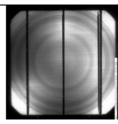
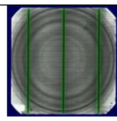
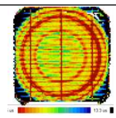
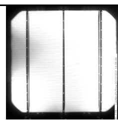
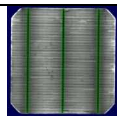
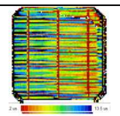
The dark ring of solar cell is closely related to the low efficiency. It is generally believed that dark ring is a reflection of inefficiency. Therefore, a lot of cell manufacturers are intolerable for cells of dark ring. Cell detection methods mainly include PL, EL, and minority carrier lifetime mapping. Owning to the difference of mechanisms, characterizations of these methods on dark ring are different to some extent. This study discussed and analyzed the relationship between dark ring and transfer efficiency, the causes of inefficient cells.

TEST AND RESULT

Corresponding relations of EL, PL and Minority carriers lifetime (MCLT) mapping

Three inefficient cells were selected for EL, PL, and minority carrier lifetime mapping to compare the three test methods. The results were shown that the three test methods were intensively corresponded to each other, in Table 1. The dark ring signifies the low minority carrier lifetime.

Table 1: EL, PL, and minority carrier lifetime images

No.	EL image	PL image	MCLT image
1			
2			
3			

The correlation between dark ring and transfer efficiency

The monocrystal with 19 ppma (ASTM-F121-83) oxygen content was sliced. From the top of the monocrystal, 300 continuous slices were prepared into cells. Meanwhile, 20 slices of them were randomly selected for transfer efficiency test and PL mapping. The cells appearing dark ring in PL mapping were further tested with EL for comparison. The test results were shown in Figure 1. Dark ring was found in the PL images of 7 cells, while was not found in the remaining 13 cells. The red box denoted the ransfer efficiency of the cells with dark ring in the PL mages, which included 5 efficient ones and 2 inefficient ones. The cells with no dark ring in the PL images nvolved 5 efficient ones and 8 inefficient ones. The dark ring appearing in PL image was unnecessarily correlated to the transfer efficiency of cells. Inefficient cells might not have dark ring, while the cells with dark ring could also be efficient.

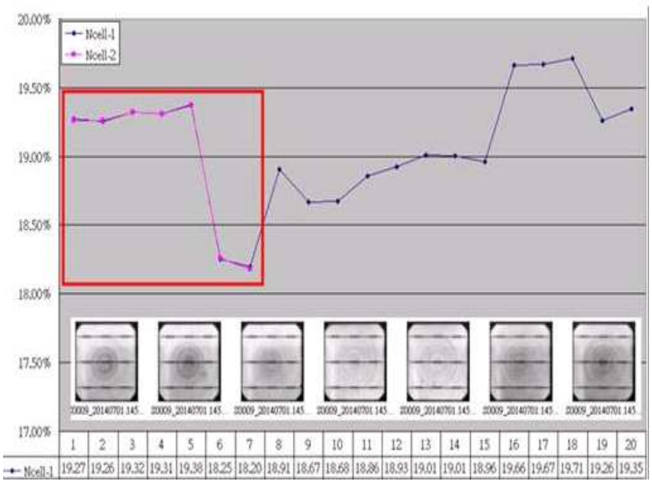


Figure 1: the transfer efficiency of cells (efficiency baseline,19.10%)

As shown in Figure 2, the PL images showed a light dark ring. Correspondingly, the EL images presented spots while unapparent dark ring.

a

b

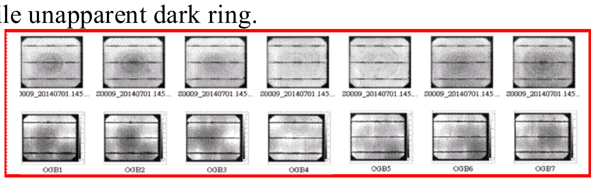
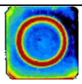
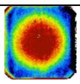
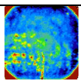
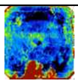


Figure 2: (a) PL images; (b) EL images

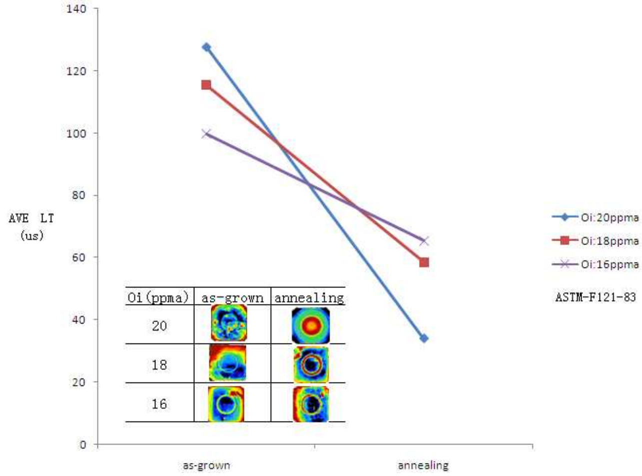
The relationship between dark ring and minority carrier lifetime

A large number of as-grown monocrystal silicon slices were conducted with minority carrier lifetime mapping to explore the relationship between dark ring and minority carrier lifetime. Table 2 listed the typical sample data that the silicon slices appearing dark ring in minority carrier lifetime mapping had high lifetime sometimes, while those without dark ring were provided with low lifetime sometimes.

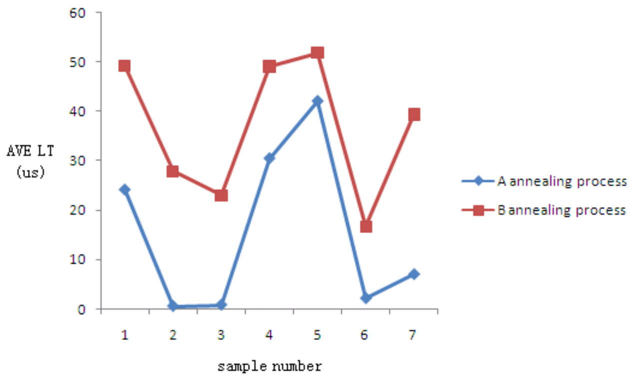
Table 2: Minority carrier lifetime images

No.	MCL-T image	Min (us)	Max (us)	Ave (us)
1		89	148	147.8
2		5	11	9.6
3		77	132	12.5
4		6.9	13.6	10.2

The silicon slices with high lifetime didn't mean efficient. Oxygen content and cell annealing process should be taken into account. After annealing process， lifetime would reduce. So the variety of lifetime with different oxygen content and annealing process was investigated. As shown in Fig.3(a), the higher oxygen content, the lower lifetime. In Fig.3(b), the same silicon slice was sliced into two parts. One part was annealed by A process. The other part was annealed by B process. It can be seen that the lifetime was greatly different by different annealing process. Therefore the cell manufactures should choose the proper value of oxygen and lifetime, according to their cell process.



（a）



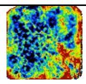
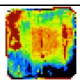
（b）

Figure 3:(a) The lifetime of different oxygen content (annealed by the same process); (b) The lifetime of the same silicon slice annealed by different process.

Analysis on the inefficient cells

By stripping the electrode, antireflection film, and PN junctions from the inefficient cells, silicon slices were reduced and conducted with minority carrier lifetime mapping. Table 3 displayed part of the results. After being stripped, the silicon substrates had high lifetime sometimes. Cell manufacturers found that the cells made by these silicon slices could recover the efficiency through texturing again.

Table 3: The minority carrier lifetime images of inefficient cell slices

No	MCL-T image	Min (us)	Max (us)	Ave (us)
1		43	95	73.5
2		25	31	27.5

Analysis and discussion

Crystal growth is symmetric about the central axis. The uneven distribution of impurities and defects etc. may cause the lifetime difference. In the case of large difference, dark ring would be observed. This phenomenon is correlated to the growth way of monocrystalline.

Illumination can excite the electron-hole pairs in silicon. As light disappears, electrons return to the base state and release photons. Then photons could be captured by camera to get radiation composite image[1]. Thus PL is an effective method for detection of raw materials. EL has similar principle with PL. The difference of them is that the nonequilibrium carriers need to be implanted through electrodes in EL. In the electrical implantation process, more factors need to be taken into consideration, including electrode, and sintering etc. Thus the dark ring of silicon material may be affected. As shown in Table 1, the cell present serious dark ring through PL mapping, and serious ring also can be observed by EL mapping. The reason of this phenomenon is that the dark ring quality of silicon plays the main role. When dark ring can not be detected in PL images, EL images also can not observe that. In Figure 2, PL images expose slight dark ring, while EL images present spots and insignificant dark ring. Under EL mapping, slight dark ring is subjected to the influences of other factors.

The two instruments can both reflect the minority carrier lifetime distribution. As shown in Table 1, the minority carrier lifetime of dark ring appearing in EL and PL images is lower than other regions. The cell without dark ring presents a uniform minority carrier lifetime distribution.

Dark ring is unnecessarily related to transfer efficiency. As shown in Table 1, the last cell without dark ring in EL and PL image is also inefficient. In Figure 1, the cells with dark ring in PL mapping may be efficient, while some cells without dark ring are inefficient. Therefore, the cell efficiency is determined by the whole lifetime of cell, while dark ring only reflects the uneven minority carrier lifetime distribution. As shown in Table 2, the silicon slices with dark ring may own high lifetime, while some silicon slices without dark ring show low lifetime.

Inefficiency is mainly determined by material and cell processing. For example, in the case of unfavorable texturing, the light reflectivity of cell will increase and influences light absorption; if the coating is in bad quality, the passivation on cell surface will be weakened and the minority carrier lifetime is influenced.

CONCLUSION

1) Dark ring is unnecessarily correlated with conversion efficiency. Inefficient cell may not have dark ring, while the cell with dark ring can be efficient.

2) Dark ring only reflects the nonuniform distribution of minority carrier lifetime. This is determined by the growth way of monocrystalline.

3) The cell efficiency depends on the overall lifetime of cell rather than dark ring.

4) Inefficiency is mainly determined by material and cell processing. The surface of the inefficient cell is stripped to reduce the silicon slices. In the case of the silicon slices keeping high lifetime, material influences can be excluded.

REFERENCES

[1] S.K. Chunduri, Photon International 01 (2011) 158.