THE INFLUENCING FACTORS AND FORMATION MECHANISM OF THE DARK RING OF MONOCRYSTAL SILICON CELLS

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ABSTRACT

The formation mechanism of p-type monocrystalline silicon solar cells’ dark rings in the electroluminescence images was researched by Fourier transform infrared spectroscopy, minority carrier lifetime mapping, photoluminescence mapping. It is shown that the minority carrier lifetime sharply decreases during the oversaturated interstitial oxygen precipitation. Because the center oxygen concentration and vacancy density are higher than the edge, the center is easier to form the oxygen precipitates. Therefore, the lifetime drops more at the center than the edge which results in the dark rings and solar cell efficiency losses. Except for the oxygen and carbon concentration of the wafer, the dark rings are also related to the thermal process in the cell processing. Furthermore, when the oxygen and carbon concentration are lower than a certain value, the dark rings would be disappeared.

INTRODUCTION

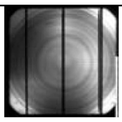
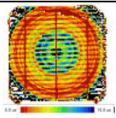
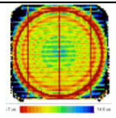
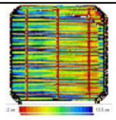
The dark rings of solar cells greatly reduce the conversion efficiency of cells. Fuyuki et al[1,2]. reported a method of using electroluminescent (EL) mapping to characterize the quality of silicon slices. This method has become an important mean for characterizing solar cells. However, the reasons of the monocrystal solar cells’ dark ring found in EL images have not been determined. This paper investigated the influencing factors and formation mechanism of the dark ring by EL mapping, Fourier transform infrared spectroscopy (FTIR), minority carrier lifetime (MCLT) mapping, and optical microscope.

SECTION

EXPERIMENT AND RESULTS

The relationship between EL and MCLT images. The p-type cells of different conversion efficiency were characterized via EL and MCLT mapping. The results are shown in Table 1. It can be seen that the black part in EL images is corresponded to the red part of the MCLT images and the cell without dark rings in EL mapping also have no ring defects in MCLT mapping. It can be concluded that EL and MCLT mapping can both characterize the ring defects of solar cells. Therefore, the ring defects were characterized by MCLT mapping in the following.

Table 1: The correspondence between EL and MCLT images

EL images	MCLT images
	
	
	

The relationship between pre-processing and ring defects. Three groups of p-type monocrystal silicon slices (resistivity: 2.2~2.1 Ω·cm) with oxygen content of 20 PPMa, with 30 wafers (200μm) for each group, were made into cells using the same technology after annealing at 650℃.

Table 2: The influences of low-temperature pretreatment on dark rings

Group	Time of treatment at 650℃ / min	Dark ring percentages
A	0	0.00%
B	20	12.00%
C	60	62.5%

Table 2 shows the influences of different pretreatment time on the dark ring ratios of cells. Fig.1 shows the relative conversion efficiencies of group A, B, and C. It is shown that the longer the low-temperature treatment time, the higher the dark ring ratios and the lower the conversion efficiency.

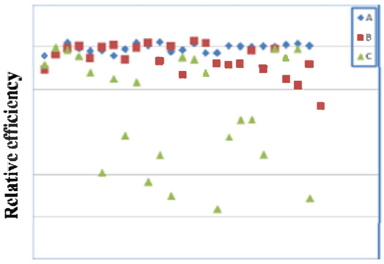


Figure 1: The influences of pretreatment time on dark ring. A: as-growth; B: annealing for 20 min at 650 ℃; C: annealing for 1 h at 650 ℃

The variations of oxygen content and MCLT with annealing time. The 2mm thickness p-type monocrystal wafers (2.5 Ω·cm) with interstitial oxygen (Oi) content of 20.4 PPMa and 19 PPMa were removed at different time points of the annealing. After rapid cooling, they were performed with MCLT mapping, FTIR and thermal treatment in sequence. The process was repeated for 4 times. Fig.2 shows the measurement results.

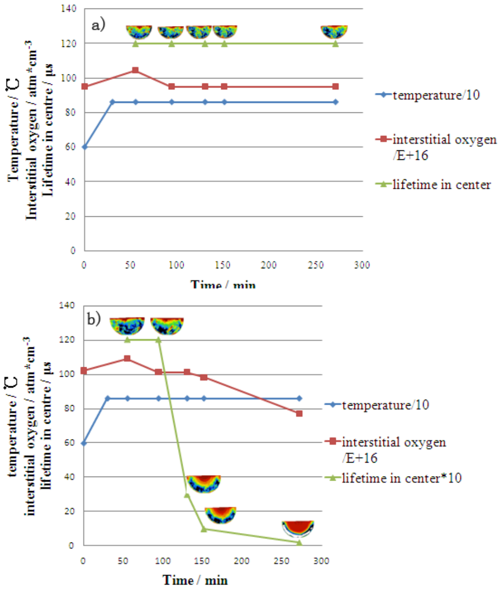


Figure 2: The MCLT of silicon wafers with different Oi contents and the variations of Oi content and MCLT with the annealing time. a) The silicon wafer with Oi content of 20.4 PPMa; b) The silicon wafer with Oi content of 19 PPMa

As the increase of annealing time, the MCLT of the silicon wafer with Oi content of 20.4 PPMa decreases, accompanying with the appearance of ring defects. In the case of serious ring defects observed, Oi content reduces. However, the Oi content reduction and ring defects are not detected with Oi content of 19 PPMa in the research time.

The relationship among ring defects, Oi and substitutional carbon (Cs) content. The high Oi content wafers (2mm thickness) with resistivity of 2.2 and 1.1Ω·cm were measured by MCLT mapping after annealing with simulating customer cell process. The mapping results are shown in Fig.3. It can be seen that the high Oi content position lies where ring defects locate.

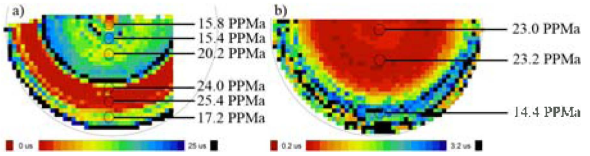
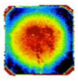
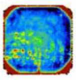


Figure 3: The MCLT images and oxygen content after thermal treatment. The number in the figure refers to the Oi content (PPMa). a) resistivity of 2.2 Ω·cm; b) resistivity of 1.1 Ω·cm.

Table 3 shows the results of the MCLT mapping after the annealing treatment of the 1.1Ω·cm resistivity silicon wafers (2μm thickness) with 4.4 PPMa and 1.1 PPMa Cs content, respectively. As it shown, even if the Oi content is very low, the wafer with high Cs content presents ring defects and low lifetime.

Table 3: the relationship among Oi and Cs content of as-cut wafers, lifetime and ring defects

as-cut slices		after annealing	
Oi / PPMa	Cs / PPMa	center LT/ μs	MCLT
15.2	4.4	1.9	
15.0	1.1	11.2	

The defects observation of the cell with dark rings. The p-type cell with dark rings was stripped and then etched to be about 100μm thickness. After Secco etching, optical images were observed, in Figure 4. Figure 4(a) shows no defects, while Figure 4(b) displays micro defects.

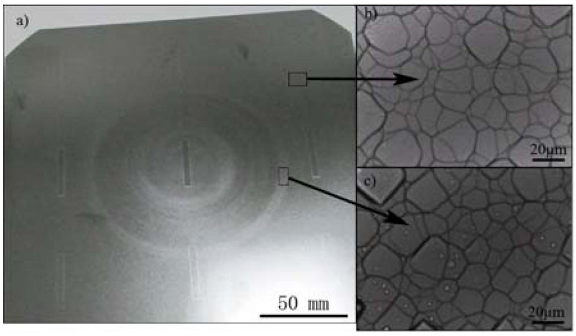


Figure 4: the optical images of the cell slices with dark ring. a) Macro image b) The intra-ring optical microscope images; c) the extra-ring optical microscope images

The relationship between Oi content and conversion efficiency. The 2μm thickness, resistivity of 2.2~2.1 Ω·cm monocrystal wafers with Oi content of 19 PPM and 10 PPM, respectively, were made into cells using traditional cell processing technology. Table 3 shows the conversion efficiency of the cells. The cells all present no dark rings in EL images.

Table 4: The *relationship between Oi content and efficiency*

Oi / PPMa	Average efficiency /%	wafer number
19	19.50	1000
10	19.46	1000

ANALYSIS AND DISCUSSION

The EL and MCLT images can both characterize the ring defects distribution in the cells. And, the ring defects in EL figure is intensively corresponded with that in MCLT mapping.

As shown in Figure 4(a), there are many micro defects in the ring. The Figure 2(a) suggests that, with the increase of annealing time, ring defects gradually were observed. Moreover, in the case of serious dark ring, interstitial oxygen reduces. This result proved that, since interstitial oxygen precipitates, micro defects can be detected by optical microscopy after Secco etching. However, the Figure 2(a) reveals that dark ring is unavailable once the oxygen content is below a certain value.

As suggested by Table 2, with the increasing the low-temperature pretreatment time, the dark ring proportion increases. The position with high oxygen content in Figure 3 is where the ring locates in. In Table 3, the silicon wafers with high carbon content also generate ring defects. The reason lies in that the nucleation formed in the pre-treatment, the convenient oxygen aggregation of high oxygen content, and the promotion effect of carbon facilitate the oxygen precipitation. All of these result in ring defects finally.

In table 4, it can be concluded that if oxygen content failing to induce dark ring, the conversion efficiency of cells made by traditional technology basically keeps consistent.

CONCLUSIONS

1) Ring defects are mainly caused by oxygen precipitation. The higher the oxygen content, the more serious the dark ring. As the oxygen content reduces below a certain value, dark ring is unavailable.

2) In the case of high carbon content, dark ring is observed, even if the Oi content is low.

3) Heat history and pretreatment influence the occurring rate of dark ring. The longer the pretreatment time and high-temperature time, the higher the dark ring proportion.

4) If ring defects fail to be induced, Oi content basically has no influences on the conversion efficiency of the cell made by traditional technology. Moreover, overlow oxygen content may reduce the mechanical strength of silicon slices and increase fragment rate. Therefore the oxygen content of the cells made by traditional technology could not be too low.

REFERENCES

[1] T. Fuyuki et al., Appl. Phys. Lett, 2005, 86, 262108.
[2] T. Trupke et al., Phys. Status Solidi RRL, 2011,5, 131