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# Effects of Metal Contamination with Oxygen Precipitates on Lifetime Degradation in Cz-Si for Solar Cells

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**Abstract**

**Lifetime degradation caused by oxygen precipitates combined with metal contamination in Cz-Si for solar cells was evaluated for the samples with different interstitial oxygen concentrations using PL imaging and IR–LST. It was confirmed that phosphorus diffusion gettering is effective for the samples with low oxygen concentration, however the lifetime never recovered for the samples with high oxygen concentration. The enhanced oxygen precipitation process made it more difficult to recover from the metallic contamination. We believe the high density and large size oxygen precipitates are harmful for the lifetime in combination with metal impurities.**

## 1. Introduction

Oxygen atoms incorporated during the crystal growth of the Si by the Czochralski (Cz) method stay at interstitial sites and can form precipitates during crystal growth and cell fabrication processes. The formation of oxygen precipitates can promote the carrier recombination therefore degrade lifetime [1]. Metal impurities incorporated into the solar cell from the feedstock or during the thermal process are also cause in a reduction of conversion efficiency. Gettering process can be used to remove the metal impurities, however the oxygen precipitates are also known as gettering sites for metals [2-3]. Therefore, it is important to understand the relation between oxygen precipitation and metal contamination.

In this study, the effect of phosphorus diffusion gettering (PDG) on the metal contamination accompanied with oxygen precipitation was investigated. Cz-Si wafers with different interstitial oxygen concentration were used to investigate the influence of the oxygen precipitates with the metal contamination on the lifetime degradation.

## 2. Experiment

In the experiment, Cz-Si wafers with the interstitial oxygen concentration in the range of 1.5 to $2.0\times10^{18}$ $cm^{-3}$ from the different heights in the same ingot (fraction solidified x = 0.03 to 0.3) were used. The surface damage layer was removed with $HF/HNO_3$ mixture. Some of them were subjected to the heat treatment to promote oxygen precipitation at 1100°C for 3 hours in an Ar atmosphere. The both samples with and without oxygen precipitation promotion process were then intentionally contaminated with $FeCl_3$ by dipping for 2 minutes and subsequent heat treatment at 800 ° C for 60 minutes in an Ar atmosphere so that Fe atoms diffused uniformly in the whole wafer at the same concentration. Finally, the phosphorus diffusion gettering (PDG) process, i.e. $P_2O_5$ spin coating and heat treatment at 800 ° C for 60 minutes, were carried out. The photo-luminescence (PL) imaging measurement was performed after each step using band pass filter (1140+/-90 nm) and a near infrared laser with excitation wavelength of 808 nm. The penetration depth of the laser is approximately 10 μm, and the bulk band-edge emission was measured. After the both surfaces of the sample were mirror polished, the precipitate density and diameter were measured by infrared light scattering tomography (IRLST).

## 2. Result and discussion

Figure 1 shows the average PL intensity for the as-slice samples before and after intentional Fe contamination and PDG. It was confirmed that phosphorus gettering can be performed effectively along with an increase in fraction solidified (lower oxygen concentration). The lifetime was degraded for the all samples by Fe contamination. Then, the degraded lifetime was recovered for the sample with lower oxygen concentration. The reason for this may be that minute oxygen precipitation nuclei or precipitates existed in the high oxygen concentration sample, and the metal impurities gettered at the precipitates removed by the PDG

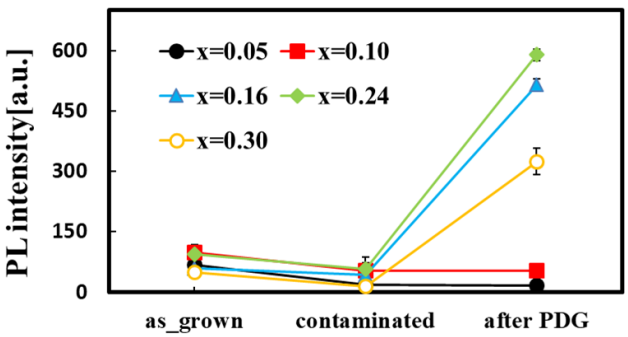


Fig.1 PL intensity after each process for as-slice

To verify this assumption, we next performed the thermal treatment to promote oxygen precipitation prior to the intentional Fe contamination and PDG experiment. Figure 2 shows FTIR spectra before and after the thermal treatment. From the infrared absorption spectrum, the absorbance increases around 1080 $cm^{-1}$ and 1225 $cm^{-1}$ after heat treatment. These were caused by oxygen precipitates. It was confirmed that oxygen precipitation was promoted by the heat treatment.

Figure 3 shows the average PL intensity after each step for the oxygen precipitation promoted samples. In samples with

a relatively high oxygen concentration (x=0.05, 0.10, and 0.16), the PL intensity reduction by the metal contamination was not recovered by PDG. This suggests that PDG was not effective for the wafers with high levels of interstitial ox gen concentration. On the other hand, for the samples with relatively low interstitial oxygen concentration, the lifetime degraded by Fe contamination was sufficiently recovered by PDG. This implies that the incorporated Fe impurities were removed from the samples and PDG was effective.

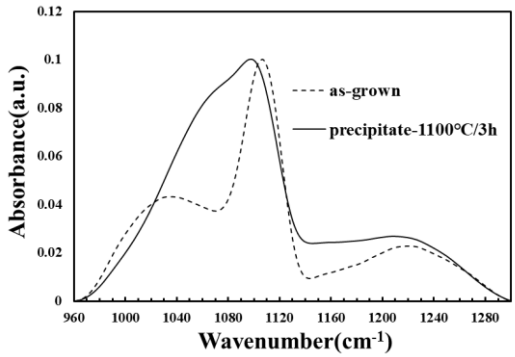


Fig. 2 FTIR spectra before and after the thermal treatment

Figure 4 shows the average bulk defect sizes and densities after PDG measured by IR-LST. Bulk defect size as the top side of the ingot (higher interstitial oxygen concentration) is apparently larger. This result suggests that the higher the interstitial oxygen concentration is, the larger the oxygen precipitate sizes. Similarly, the defect density also increased with increasing interstitial oxygen concentration.

For the wafers with high interstitial oxygen concentration the PDG shows no effect, while it shows highly effective for the low oxygen concentration wafers. This can be explained by the internal gettering effect by the oxygen precipitates. It was confirmed from Fig. 4 that the sample with high oxygen concentration had larger precipitate size and density. Since strain field induced by the oxygen precipitates may capture metal impurities to relax the strain and hard to release. In addition, dislocations induced around the oxygen precipitates may be also effective gettering sites for the metal impurities. In other words, since the internal gettering sources are abundant as samples with higher oxygen concentrations, it can be considered that intrinsic gettering is dominant rather than external gettering. Therefore, the PDG effect did not appear in the high oxygen concentration specimen where precipitation was promoted. In the low oxygen concentration sample, it can be considered that these internal gettering sites have extremely little influence comparing to the high oxygen concentration sample, and extrinsic gettering can be effectively performed by the phosphorus layer formed on the sample surface. Furthermore, it was suggested that the oxygen concentration affect extremely sensitively on metal gettering.

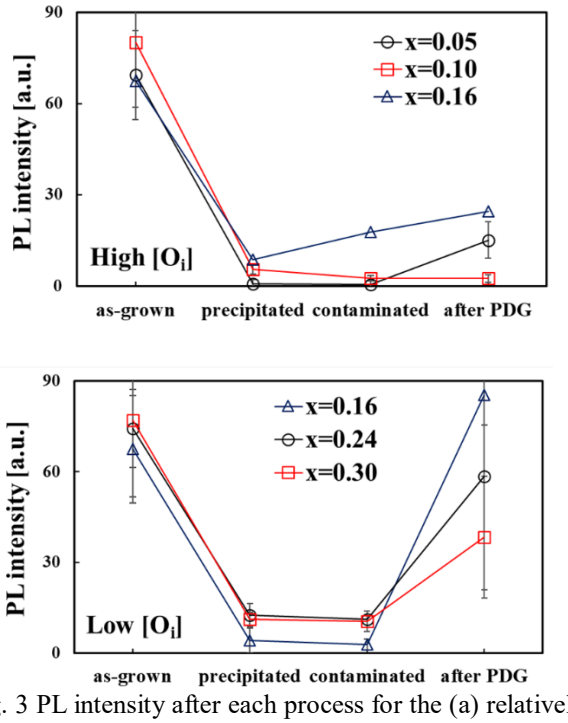


Fig. 3 PL intensity after each process for the (a) relatively high and (b) low interstitial oxygen wafers.

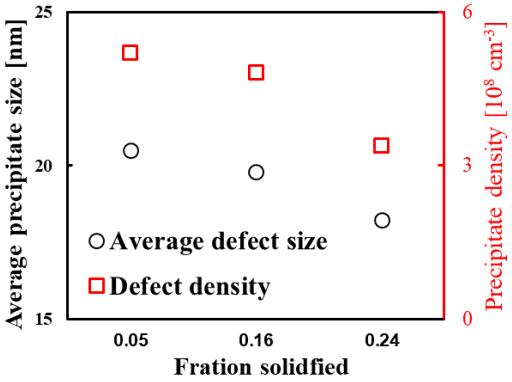


Fig. 4 Relation between fraction solidified (interstitial oxygen concentration) and average bulk defect size and density after PDG

## 4. Conclusions

In conclusions, the influence of oxygen precipitates on the extrinsic gettering, PDG, was evaluated. For the wafers in which the interstitial oxygen concentration was relatively high and/or the precipitate grew largely with high density, intrinsic gettering was dominant, and it was hard to effectively perform the PDG. On the other hand, when the interstitial oxygen concentration is relatively low, or the size and density of the precipitates are small, the PDG exerts a high effect. These experimental results suggest that PDG is sensitive to oxygen concentration and oxygen precipitation. Thus, the metal impurity contamination in crystal Cz-Si can be improved by PDG as the interstitial oxygen concentration is low and the precipitates are small. We would, therefore, conclude the oxygen precipitation degrade the lifetime more significantly in combination with metal contamination.

## Acknowledgements

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