Effect of Different Minority Carrier Lifetime of Multicrystalline Wafer on Solar Cell Performance

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Abstract: In this article, a study of the effect of different minority carrier lifetime (τ) of wafers on solar cell performance in a conventional industrial production line has been carried out. The results clearly showed that the ultimate efficiency of the solar cells made by wafers of 1μs<τ<1.2μs and 1.2μs<τ<1.5μs is much higher than that of solar cells made by wafers of τ<1μs. The gap of both is about 0.38%–0.53%. Differently, there is no significant difference between wafers of 1μs<τ<1.2μs and 1.2μs<τ<1.5μs. The results obtained are useful when the solar cell companies establish original wafers test standard in industry.

Keywords: Minority Carrier Lifetime; Multicrystalline Silicon; Cell Performance

1. Introduction

The material of boron-doped multicrystalline silicon is the most relevant material in today’s solar cell production. The minority carrier lifetime gives an indication of material quality and suitability for solar cell use. Because of the lattice defect, residual impurities such as carbon oxygen and metal ions, the minority carrier lifetime of multicrystalline silicon wafers is about 1μs. The lifetime of wafer is significantly effect by solar cell fabrication steps, so we tested the minority lifetime of wafers after phosphorus diffusion by a method of quasi steady state photoconductor (QSSPC). The QSSPC is a contactless, highly sensitive, area-averaged lifetime measurement method[1]. It can give similar results to a more sophisticated analysis with high-resolution mapping data. BERGER Single Cell Testing system performs all measurements of photovoltaic characteristics automatically and all data is saved to the system’s database. We want to establish the correlation between minority carrier lifetime of wafer and the ultimate efficiency of the solar cell in this study.

2. Experiment

The wafers used in the experiment were made in China. They are P-type multicrystalline silicon wafers; the area of wafers is 156mm×156mm. All of the wafers are divided into 4 groups as G1 (τ<1) G2 (τ<1) G3 (1<τ<1.2) G4 (1.2<τ<1.5). The production sequence is G1 G2 G3 G4 and all the groups run in the same line. The process starts with wafer thinning to about 180-200μm followed by texture etch. Then the front-surface field is formed by phosphorus diffusion, resulting in 60-70 Ω/sq front surface filed. After phosphorus glass removal rear side etch and edge isolation the PECVD SiN anti-reflection coating was deposited on front. Subsequently, the back and front contacts was screen-printed. Both contacts were co-fired in an infrared...
3. Discussion and results

3.1 Comparison of lifetimes after phosphorus diffusion

In Table 1, a significant improvement in lifetime from 1μs to 10μs is seen after the phosphorus diffusion\(^2\). Firstly the improvement is attributed to the removal contaminants and structural defects from the silicon surface after texture etch, secondly the surface passivation with the oxide layer formed during phosphorus diffusion and the phosphorus gettering of impurities present in wafers have contribution\(^3\). Via statistical analysis powered by JMP software, we can find the lifetime of wafer after phosphorus diffusion shows no significant difference between groups. The Figure 1 and Figure 2 show the details.

| GroupID | lifetime after diffusion/μs | Mean   |
|---------|-----------------------------|--------|
| G1      |                            | 9.85278|
| G2      |                            | 9.40345|
| G3      |                            | 10.4421|
| G4      |                            | 10.6846|

**Table 1. Summary of lifetime after diffusion**

![Oneway Analysis of lifetime after diffusion By GroupID](image)

**Figure 1.** Lifetime after diffusion distribution of each group.

**Figure 2.** The LSD threshold table shows the difference between the absolute difference in the means and the LSD (least significant different). If the values are positive, the difference in the two means is larger than the LSD, and the two groups are significantly different\(^4,5\).

3.2 Comparison of ultimate efficiency

**Table 2** display the mean of Ncell Uoc Isc and FF of each group. The Ncell gap between \(τ>1\mu s\) and \(τ<1\mu s\) is about 0.38%~0.53%. In Figure 3, the groups of \(τ<1\) (G1 G2) show significant difference in cell performance compared to the groups of \(τ>1\) (G3 G4) and the group of conveyor belt furnace. At the end all cells were tested and sorted by BERGER Single Cell Testing System. The minority lifetime of semi-finished cell was tested after phosphorus diffusion by a method of QSSPC. The instrument is the silicon wafer lifetime tester WCT-120 of sinton instruments.
1.0<τ<1.2 (G3) shows no significant difference in cell performance compared to the group of 1.2<τ<1.5 (G4). The Figure 4 shows the distribution of each group, and the groups of τ>1 (G3 G4) show better distribution than the groups of τ<1 (G1 G2)\(^6\).

| GroupID | NCell% | Voc/V | Isc/A | FF/|
|---------|--------|-------|-------|----|
| G1      | 0.15739| 0.6101| 8.09022| 77.564|
| G2      | 0.15858| 0.6107| 8.11859| 77.795|
| G3      | 0.16268| 0.6153| 8.29033| 77.599|
| G4      | 0.16238| 0.6146| 8.27585| 77.684|

Figure 3. The Tukey-Kramer HSD threshold matrix shows the actual absolute difference in the means minus the HSD, which is the difference that would be significant. Pairs with a positive value are significantly different.

Figure 4. NCell distribution of each group.

3.3 Quantum Efficiency (QE) test results

Four cells were tested QE with QEX7. In Figure 5, the cell with low NCell (low τ) has low quantum efficiency especially at long wavelength. The quantum efficiency ideally has a square shape, where the QE value is fairly constant across the entire spectrum of wavelengths measured. However, the QE for most solar cells is reduced because of the effects of recombination, where charge carriers are not able to move into an external circuit. Lower energy (long wavelength) light is absorbed in the bulk of a solar cell, and the wafer of low τ means more recombination. The carriers that the lower energy photons produce must pass through the longer distance to arrive at the PN junction, so the QE of low τ wafers are low at long wavelength\(^7,8\).
### 4. Conclusions

The lifetime of wafer after phosphorus diffusion shows no significant difference between groups, but the ultimate efficiency of the solar cell made by wafers of $1\mu\text{s} < \tau < 1.2\mu\text{s}$ and $1.2\mu\text{s} < \tau < 1.5\mu\text{s}$ is much higher than that of solar cell made by wafers of $\tau < 1\mu\text{s}$.

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