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SAND-97-2124CTHE EFFECT OF GETTERING ON AREAL INHOMOGENEITIES IN
LARGE-AREA MULTICRYSTALLINE-SILICON SOLAR CELLSJames M. Gee¹ and Bhushan L. Sopor²¹Sandia National Laboratories, Albuquerque, New Mexico (USA)²National Renewable Energy Laboratory, Golden, Colorado (USA)

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ABSTRACT: Multicrystalline-silicon (mc-Si) materials and cells feature large areal variations in material and junction quality. The regions with poor device quality have been predicted to have more recombination current at forward bias than a simple area-weighted average due to the parallel interconnection of the good and bad regions by the front junction. We have examined the effect of gettering on areal inhomogeneities in large-area mc-Si cells. Cells with large areal inhomogeneities were found to have increased non-ideal recombination current, which is in line with theoretical predictions. Phosphorus-diffusion and aluminum-alloy gettering of mc-Si was found to reduce the areal inhomogeneities and improve large-area mc-Si device performance.

INTRODUCTION

Multicrystalline-silicon (mc-Si) materials are a commercially important photovoltaic material. This material consists of individual crystalline-silicon grains. The crystal orientation and grain size distribution depends upon the specific crystal growth method, but the orientation is generally random and the size varies between a few millimeters to several centimeters. The intragrain dislocation density, impurity precipitate density, and intrinsic stress can vary significantly between grains. The net result is that there can be significant areal variations in material and junction quality in large-area mc-Si cells.

The effect of areal inhomogeneities has been examined theoretically by several research groups [1,2,3]. These models use a network model of the solar cell – i.e., the cell is divided into many small subcells that are connected in parallel through resistors that represent the front-surface junction and grid (Fig. 1). The areal inhomogeneities are represented in the equivalent circuit parameters of the small subcells. A significant result of these studies is that the recombination current in the poor regions at open-circuit and maximum-power voltages are greater than predicted by the area-weighted average of the subcell parameters; i.e., *the low-performing regions can act as "sinks" to dissipate power internally within the cell* [2] due to the parallel interconnection of the good and poor regions.

Experimentally demonstrating the enhanced recombination due to poor regions has been difficult. For example, mapping of the recombination current at any bias except short circuit is difficult because the parallel interconnection of the junction distributes the recombination current over a large area. The theoretical models suggest an indirect means to experimentally examine the effect of areal inhomogeneities. A solar cell is frequently modeled as two parallel diodes, a current source, and a series and shunt resistance. The diodes represent "ideal" and "non-ideal" recombination current, where the diode quality factor (n) is unity for ideal and $n > 1$

for non-ideal recombination. The models predict that cells with large areal inhomogeneities will exhibit large non-ideal recombination in the double-diode model [3].

We examined the effect of gettering on areal inhomogeneities in mc-Si substrates. Gettering refers to a process where deleterious impurities are removed from important regions of a solar cell to less important regions. As a result of the detailed device characterization for our experiments, we also make some observations on the effect of areal inhomogeneities on large-area mc-Si solar cell performance.

EXPERIMENT

Several types of large-area mc-Si cells were thoroughly characterized. The first group of cells were low-, medium- and high-performance production 100-cm² EFG cells from ASE Americas. This material consists of long (many centimeters) and narrow (less than 1 cm) grains, and has low oxygen and high carbon concentrations. The second group of 42-cm² mc-Si cells were fabricated at Sandia using HEM mc-Si from Crystal Systems. This mc-Si material has low carbon and oxygen concentrations and was used in the recent demonstration of an 18.6%-efficient 1-cm² mc-Si cell [4]. The Sandia cells included both control and gettered splits, where the gettering included phosphorus diffusion and/or aluminum alloy. The gettering step was performed and the gettering layer removed prior to cell fabrication. The fabrication sequence includes an aluminum-alloyed back-surface field and passivated emitter, and uses a photolithographically defined, evaporated metallization and an evaporated double-layer ARC [5].

The cell characterization included one-sun IV, dark-IV, absolute spectral response, hemispherical reflectance, and 1064-nm laser-beam-induced-current (LBIC) scans. The

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one-sun and dark-IV data was fitted to a double-diode model, and the recombination current distribution at maximum-power and open-circuit voltages were calculated. Histograms of the LBIC data provided a good graphical description of the areal inhomogeneities.

RESULTS

The histograms of the LBIC data for the ASE cells show a systematic improvement in areal homogeneity as the cell performance increases (Fig. 2). The LBIC histogram both narrows and the mean moves to higher response, which indicates that the material is both more uniform and of higher quality. The improvement in cell performance is reflected mainly in V_{oc} and I_{sc} (Table 1), while the cell parameters from the fitted dark-IV data show that there is a systematic decrease in the non-ideal recombination current with improved cell performance (Table 2).

The gettering experiment on the HEM material (Table 3) found significant improvement in device performance due to the gettering of around 2% absolute. Similar gettering experiments in our laboratory typically finds more modest improvements (on the order of 0.5% absolute) and is generally material specific. The large gettering effect for this particular experiment more clearly illustrates some of the effects of gettering on areal inhomogeneities in large-area mc-Si cell performance.

There was a dramatic improvement in non-ideal recombination with gettering for the 42-cm² HEM mc-Si cells. The non-ideal recombination represented around 18% and 5% of the recombination at V_{oc} and 60% and 30% of the recombination at V_{mp} for the non-gettered and gettered cells, respectively (Table 4). The histograms of the LBIC data (Fig. 3) again show an improvement in the areal uniformity for the gettered cells.

CONCLUSIONS

Gettering of mc-Si substrates was found to both reduce the areal inhomogeneities and improve large-area mc-Si cell performance. In line with theoretical predictions, we found that the non-ideal recombination current in large-area mc-Si cells is qualitatively correlated with larger areal inhomogeneities.

REFERENCES

1. K. Drope and H. H. Moller, "Modeling of the IV characteristics of multicrystalline solar cells with inhomogeneous distribution of electrical parameters," 12th Eur. PV Sol. Ene. Conf., 1359-1362 (1994).
2. Bhushan L. Sopori and Robert Murphy, "Theoretical analysis of a large-area inhomogeneous solar cell," 12th Eur. PV Sol. Ene. Conf., 1797-1799 (1994).
3. P.E. Mijnders, G.J.M. Janssen, and W.C. Sinke, "The second diode in the characteristics of semi-crystalline silicon solar cells," 11th Eur. PV Sol. Ene. Conf., 310-313 (1992).
4. A. Rohatgi, *et al.*, "Record high 18.6% efficient solar cell on HEM multicrystalline material," 25th IEEE PVSC, 721-724 (1996).
5. W.K. Schubert, *et al.*, "A simple single-photomask process for fabrication of high-efficiency multicrystalline-silicon solar cells," 1st World Conf. on PV Energy Conv., 1327-1380 (1994).

Table 1. ASE 100-cm² EFG mc-Si production cells.

| Cell | Eff | V_{oc} | J_{sc} | FF | V_{mp} |
|--------|------|----------|----------|-------|----------|
| High | 14.2 | 0.586 | 31.8 | 0.760 | 0.480 |
| Medium | 13.4 | 0.578 | 30.7 | 0.757 | 0.471 |
| Low | 12.8 | 0.567 | 30.1 | 0.752 | 0.460 |

Table 2. Distribution of recombination (%) in ASE cells. n1 and n2 refer to ideal and non-ideal recombination.

| Cell | V_{oc} | | V_{mp} | |
|--------|----------|-----|----------|------|
| | n1 | n2 | n1 | n2 |
| High | 94.9 | 4.6 | 68.1 | 26.2 |
| Medium | 94.4 | 5.2 | 67.2 | 27.9 |
| Low | 93.4 | 6.3 | 67.0 | 29.4 |

Table 3. Gettering experiment with 42-cm² cells on HEM mc-Si material. Gettering using Al and P simultaneously (Al/P) was ineffective, while gettering using Al or P individually (Alum and Phos) was effective.

| Cell Name | Split | Eff | V_{oc} | J_{sc} | FF |
|------------|-------|------|----------|----------|-------|
| NREL-17-3 | Alum | 15.1 | 0.607 | 31.3 | 0.796 |
| NREL-17-10 | Phos | 14.5 | 0.605 | 31.2 | 0.766 |
| NREL-17-4 | Al/P | 12.4 | 0.580 | 29.0 | 0.737 |
| NREL-17-5 | None | 12.6 | 0.577 | 30.4 | 0.714 |

Table 4. Recombination distribution (%) for HEM cells.

| Cell Name | Split Descr | V_{oc} | | V_{mp} | |
|------------|-------------|----------|------|----------|------|
| | | n1 | n2 | n1 | n2 |
| NREL-17-3 | Alum | 95.4 | 4.2 | 75.4 | 22.2 |
| NREL-17-10 | Phos | 93.6 | 5.6 | 51.3 | 40.6 |
| NREL-17-4 | Al/P | 80.0 | 19.6 | 32.1 | 63.7 |
| NREL-17-5 | None | 82.9 | 15.3 | 28.2 | 59.6 |

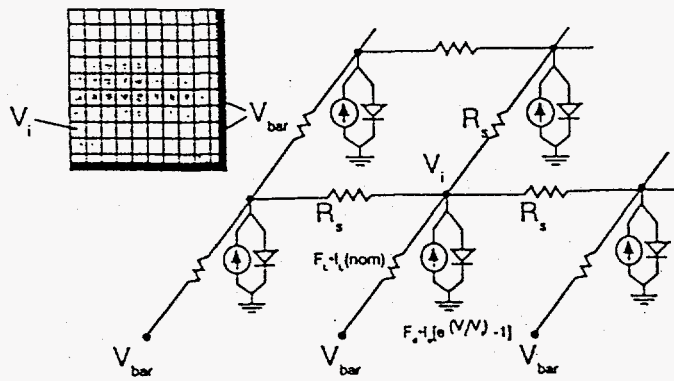
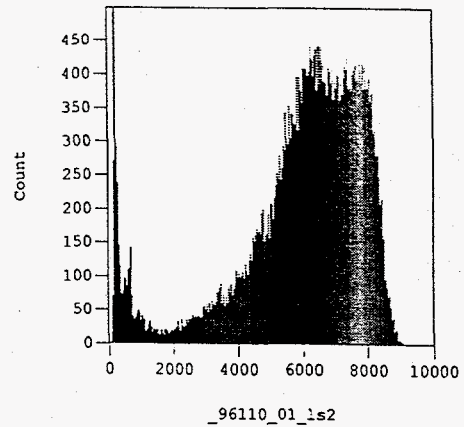
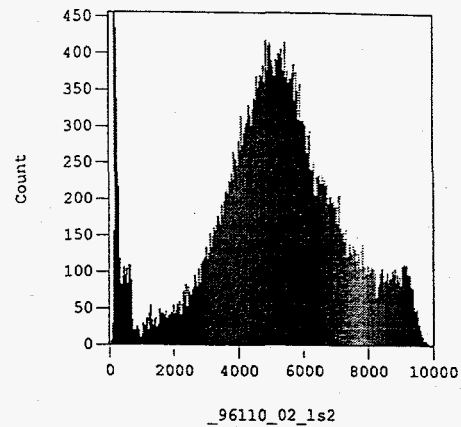


Figure 1. Network model of solar cell with areal inhomogeneities. The model assumes that the cell may be modeled as one-dimensional diodes connected in parallel by the emitter and grid on the front surface. The parameters of the one-dimensional diodes reflect the inhomogeneous properties of the solar cell. Note that only the dominant current component in the figure for clarity. From Sopori and Murphy [2].

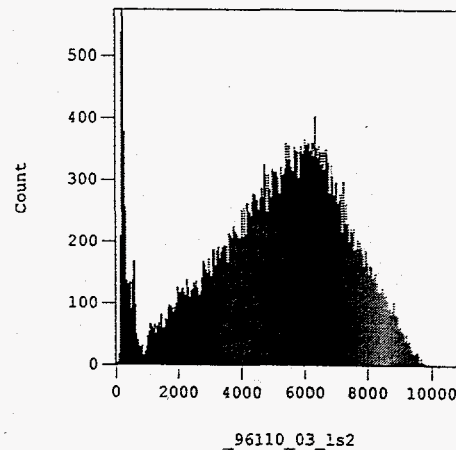
Figure 2. LBIC plots and histograms for ASE cells.



"High-performance" ASE cell.



"Medium-performance" ASE cell.



"Low-performance" ASE cell.

Figure 3. LBIC histograms of gettered and non-gettered HEM cells, respectively.

