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Polycrystalline Solar Cells on Metallurgical-Grade Silicon Substrates

T. Warabisako, T. Saitoh, H. Itoh, N. Nakamura, and T. Tokuyama Central Research Laboratory, Hitachi Ltd.

Kokubunji, Tokyo

The cell configuration of a thin but high quality active layer on low cost substrates is the most practical approach for cost reduction in fabricating silicon solar cells. Several efforts have been made to prepare silicon layers for epitaxial growth on various substrates.¹⁾, ²⁾ Recently, the feasibility of low cost silicon substrates has been demonstrated³⁾ with 3-6% efficiencies obtained for relatively large cell areas(~30 cm²). In this paper, thin film solar cells are fabricated on metallurgical-grade silicon substrates to confirm the feasibility of this approach. In addition, a method of evaluating polycrystalline solar cells is described.

The material used for substrates was metallurgical-grade silicon. A rod, about 3.5cm in diameter, was pulled by the Czochralski method, and sliced into 0.4mm thick wafers. They were polycrystalline with millimeter grain size, and were degenerated p-type wafers with a specific resistivity of 1.6×10^{-3} ohm.cm. As for included impurities, the related analytical data are shown in Table 1. The wafer surfaces were chemically etched to remove damaged layers. A 25µm thick p-type and a 0.5µm thick n-type layer with doping levels of 2.5×10^{17} cm⁻³ and 5×10^{19} cm⁻³ were grown successively on the wafer by decomposition of SiH₂Cl₂ at 1150°C and 1000°C, respectively. A Ti/Ag grid electrode was applied to the front surface and an Al electrode to the rear surface by vacuum evaporation followed by soldered overcoatings. Then, they were subjected to peripheral etching to realize a mesa diode structure. An SiO anti-reflection coating was applied by vacuum evaporation in some cases. An example of the surface of a cell is shown in Fig.1.

Typical current-voltage characteristics of this solar cell measured under illumination by an AM2(73mW/cm²) solar simulator are shown in Fig.2. A conversion efficiency of 5.7% was obtained with an open circuit voltage of 0.57V, short circuit current of ll.lmA/cm² and fill factor of 0.66 for an 8.3cm² cell area without anti-reflection coating. The conversion efficiency was improved to 7.3% after the application of an SiO film.

Spectral response curves for bare surface cells reached a maximum at around 0.7 μ m as shown in Fig.3. The diffusion length of the photocarrier in the p-layer, estimated from the spectral response curve⁴, was around 10 μ m. This agreed well with the value, 7.8 μ m, measured by scanning an electron beam across the cleaved surface perpendicular to the junction⁵.

Spacial distribution of the photocurrent was measured by scanning laser and/or electron beam, and an example of results is shown in Fig.4. This corresponds to the entire surface of the solar cell shown in Fig.1. A line scan along the indicated arrows is also shown. The histogram of photocurrent, shown in Fig.5, was obtained by sampling the photocurrent followed by pulse height analysis. These results indicate that photocurrent fluctuations are small around an inherent current level and the area with less photocurrent decreases exponentially with some degradation constant. Current suppression along the grain boundaries is rather drastic. However, the contribution of this effect to the total photocurrent is of minor importance. It is essential to elevate the inherent photocurrent level of the cell in order to improve cell performance.

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Concerning the photocurrent, computer simulation was carried out for a simple model where the photocarrier collection efficiency decreases exponentially with the distance from the edge of the depletion layer and is unity in the depletion layer. The photocurrent for boundary conditions similar to the structural parameters of this cell was calculated to be 20mA/cm² under AMI spectral irradiation. This is in good agreement with the measured values. To achieve a conversion efficiency of more than 10%, a photocurrent of more than 25mA/cm² is required, which corresponds to the photocarrier diffusion length of about 30µm. The value will be attainable even with the present structure.

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(A)

Table 1 Analytical data of the silicon wafers used for substrates.

Element	Al	В	Cr	Fe	Mn	Ni	Ti	v
Abundance (wt%)	0.01-	0.005-	<0.001<	0.001	0.005-	<0.005	<0.005	<0.001



Fig.1 Surface of a polycrystalline (B) silicon solar cell(dark image).



Fig.2 Current-voltage characteristics of a polycrystalline silicon solar cell.



1.cm

Fig.4 Photocurrent distribution of the cell shown in Fig.1 measured with (A) a scanning He-Ne laser, and (B) a line scan between arrows.





corresponding to Fig.4 (A).

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