B-4-6 Fabrication and Properties of Diffused Solar Cells Using Solar-Grade Silicon Prepared by Fluidized-Bed Reactor

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A feasible method of reducing the current price of silicon solar cells is to develop low-cost source materials for Czochralski(CZ) and/or ribbon crystal growth. Various methods very different from the present technology [1] have been attempted to produce such low-cost source materials. This is due to the fact that, in present wafer production, nearly half of the cost is that of the polycrystalline silicon sources.[2],[3] This paper describes a new method for producing low-cost,solar-grade(SOG) source materials. Furthermore, diffused solar cells are fabricated using silicon wafers CZ-grown from the materials.

The SOG-Si materials were prepared by reducing $SiCl_4$ gas with hydrogen and depositing it on tiny seed particles at 1150°C in an experimental fluidized-bed reactor. Power consumption of the SOG-Si deposition was as low as 70 kw-hr/kg-Si, or about one-fourth of that used in the present technology. Materials obtained in the reactor are polycrystalline and granular with diameters ranging from 0.5 to 2 mm, as seen in Fig.1. Various impurities with ppm level were included in the SOG-Si materials as indicated in impurity data of Table 1. The primary B and P impurities are considered to come from the $SiCl_4$ gas due to the similar vapor pressures of related chloride compounds. Other impurities such as Fe, Ni, and V are thought to come from the experimental reactor.

Crystalline rods with a 5 cm diameter were pulled using the Czochralski technique and sliced 0.4 mm thick wafers. The polycrystalline rod was p-type with a resistivity of 4 $\Omega\cdot$cm near the seed, and n-type at the tail, as indicated in Fig.2. The transition from p-type to n-type is due to the increase in phosphorus concentration with the crystal pulling by a lower impurity segregation coefficient than that of boron.

Sliced wafers were chemically etched to remove damaged layers and diffused using phosphorus oxytrichloride($POCl_3$) to prepare a 0.3 μm thick n^+ layer. Conventional Ti/Ag and Al-alloyed electrodes were evaporated onto the front and back sides, respectively. A spin-on type anti-reflection film was coated on the n^+ surface after peripheral etching.

Surface features of a solar cell fabricated from the SOG-Si materials are shown in Fig.3. The current-voltage characteristics of the diffused cells are shown in Fig.4 along with that for semiconductor-grade silicon crystals. An 11.3 % conversion efficiency was obtained for a cell using $SiCl_4$ gas. Efficiency is lower than 13.6 % for semiconductor-grade silicon crystals due to the relatively higher impurity contents as indicated in Table 1. However, conversion efficiency was improved by utilizing purified $SiHCl_3$ gas and improving the reactor. As a result, the maximum conversion efficiency for the SOG-Si material from $SiHCl_3$ gas attained was 13.3 % with a short-circuit current density of 29.1 mA/cm^2, an open-circiut voltage of 0.584 V, and a fill factor of 0.783.

Spectral response curves of the bare surface cells are shown in Fig.5. It is found that the peak positions shifted to the longer wavelength region and that peak heights increased with short-circuit current densities as indicated in Fig.4.

In conclusion, low-cost solar cells with efficiencies close to that of semiconductor-grade silicon can be realized with lower power consumption by using fluidized-bed SOG-Si materials, as compared with present technology.

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References

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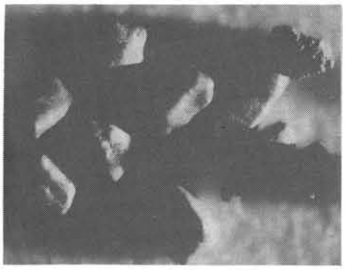
3) S.Pizzini, Materials Chemistry 4, 335(1979).



1 mm

Fig.1. Granular solar-grade silicon prepared using a fluidized-bed reactor.

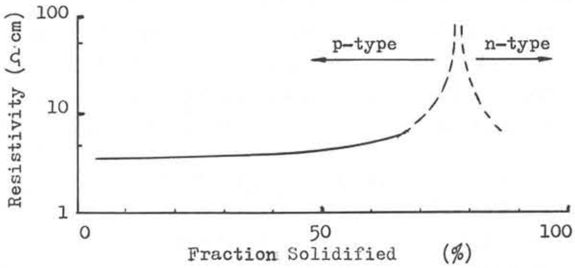


Fig.2. Variation of resistivity along a crystalline rod using SOG-Si materials from $SiCl_4$.

A fraction solidified is the ratio of the weight of a pulled crystal to that of SOG-Si charged in a crucible.

Table 1. Analytical data of granular Si using $SiCl_4$ (ppm)

B	P	Cu	Ni	Fe	Cr	V
6	4	2	3	15	2	5

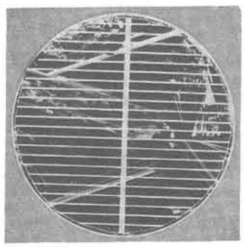


Fig.3.

Surface of a silicon solar cell using solar-grade materials.

1 cm

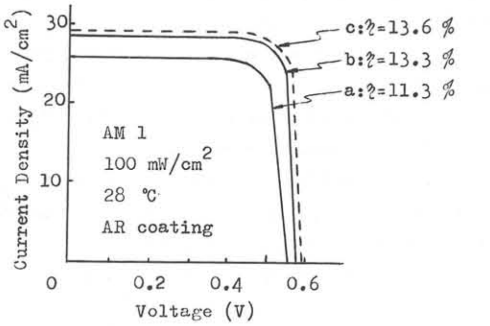


Fig.4. Current-Voltage characteristics of diffused solar cells using substrates grown from the SOG-Si (a and b) and semiconductor-grade silicon crystals (c). a: SOG-Si from $SiCl_4$

b: SOG-Si from $SiHCl_3$

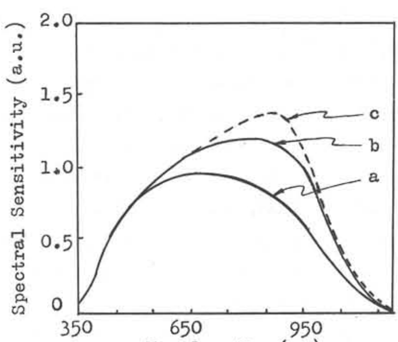


Fig.5. Spectral response curves of diffused solar cells corresponding to those in Fig.4, measured before coating anti-reflecting film.