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A-6-3 Dendritic Growth of Silicon Thin Films on Alumina Ceramic and Their Application to Solar Cells

T.Saitoh, M.Warabisako, H.Itoh, N.Nakamura, T.Tamura, S.Minagawa and T.Tokuyama
Central Research Laboratory, Hitachi Ltd.
Kokubunji, Tokyo

Recently, polycrystalline silicon films deposited on inexpensive substrates have been used to fabricate low-cost solar cells.[1] Our approach concerns a fabrication of silicon thin film solar cells on alumina ceramic.

The grain size of polycrystalline silicon, prepared by a conventional chemical vapor deposition technique, was usually less than 10 μm. This is considered one of the origins of low conversion efficiencies. Several efforts to improve cell efficiency by making thin films of a large grain size through recrystallization have been reported.[2),3)]

In this paper, a new melt-regrowth technique designed to prevent a molten silicon film from agglomeration, as well as to obtain a grain size of about 1 mm will be described. Also, the characteristics of the thin film solar cells fabricated on the recrystallized silicon will be described.

The substrates used were 96 % pure alumina ceramic and 25x25x1 mm in size. Prior to silicon deposition, titanium (about 0.2 μm thick) was deposited in a vacuum. In the silicon film deposition to a thickness of 20-30 μm, trichlorosilane was used as a source and diborane was added as a p-type dopant. In addition, a borosilicate glass film (1-2 μm thick) was chemically deposited on the film surface.

The polycrystalline silicon film thus prepared was melted and recrystallized under a normal freezing condition. The structural properties of the recrystallized film were investigated by x-ray diffraction and Sirtl etching. To fabricate a p-n junction on the recrystallized layer, a p- and an n-type layer were epitaxially deposited, successively. The aluminum electrode was evaporated on the n^+-type layer and a p^+-type region revealed by mesa-etching.

In general, the molten silicon film on the alumina surface tended to agglomerate and expose the alumina surface. The use of a borosilicate glass film on the silicon surface and a titanium layer inserted between the silicon and alumina was found to be most useful to prevent agglomeration. This is probably due to the decrease of the surface tension of the molten silicon and the improvement of the wettability of the molten silicon to the substrate.

A typical surface of recrystallized film (20 μm thick) is shown in Fig.1. Dendritic growth about 0.3 mm wide and a few millimeters long can be seen over the substrate. The x-ray diffraction showed [111] orientation to be more predominant than [110]. In addition to grain boundaries with irregular shapes, other types of defects were revealed by the Sirtl etching. Among them were tilt boundaries, dot-like and linear defects. The linear defects originated from the irregular grain boundaries and terminated in the grains, probably due to stacking faults and slip lines. Hall measurements indicated that the resistivity and the mobility were $1\times10^{-3}\,\Omega.cm$ and 40 $cm^2/V.s$.

From the forward current-voltage characteristics in the dark, the "n" values in the ln I vs.V relation were found to be less than 2 for better solar cells and more than 2 for poorer quality cells. The reverse currents of the better cells increased quadratically with the reverse voltage and indicated that the space-charge-limited current is dominant. On the other hand, the I-V characteristics of the poorer quality cells were almost ohmic, corresponding to a shunt resistance of several kΩ.

A current-voltage characteristic under an AM1 simulated solar irradiation is shown in Fig.2. The short-circuit current density, open-circuit voltage, fill factor and conversion efficiency without an antireflecting film were 7.0 mA/cm^2, 0.40 V, 0.67 and 1.9 %.

In order to determine the reason the short-circuit current is low, the spectral response curve was measured using a constant energy spectrometer. The lower value of the photocurrent at longer wavelengths suggests that the diffusion length of minority carriers is short. The electron diffusion length (L_n) was obtained using the following equation:[4]

$$I \propto \frac{\lambda \cdot \alpha \cdot L_n}{1 + \alpha \cdot L_n} \exp(-\alpha \cdot d)$$

where I is the photocurrent, λ the wavelength, α the absorption coefficient and d the n^+-type layer thickness. The electron diffusion length was about 1 µm. This is considerably lower than that of the single crystal cell.

To clarify local distribution of the conversion efficiencies, mesa-diodes of various size were fabricated on the same substrates and cell characteristics were compared. From these measurements, the fill factor was found to decrease as cell area increased, while the short-circuit current and open-circuit voltage were almost constant. This suggests that the density of the defects and grain boundaries does not affect to the photocurrent, but causes the fill factor to decrease. The relation between structural defects and the photocurrents was also investigated in detail using a laser scanning microscope.

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References

1) T.L.Chu, H.C.Mollenkopf and S.C.Chu, J.Electrochem.Soc.123(1)106(1974)
2) V.Y.Doo, J.Electrochem.Soc.111(10)1196(1964)
3) C.D.Ouwens and H.Heijligers, Appl.Phys.Letters 26(10)569(1975)
4) L.M.Terman, Solid-State Electronics 2(1)1(1961)

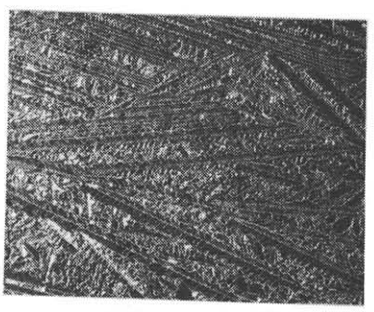

Fig.1 Dentritic silicon thin film on alumina ceramic

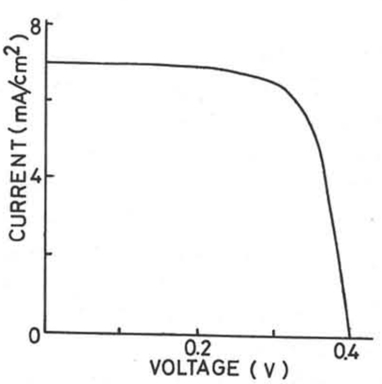

Fig.2 Current-voltage characteristics under an AM1 illumination for a $n^+/p/p^+$-silicon solar cell on alumina