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Superlattice Structure a-Si Films Prepared by Photo-CVD Method and Their Application to a-Si Solar Cells.

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Amorphous silicon superlattice structure (a-Si/a-SiC) films were fabricated by the photo-CVD method for the first time. Excellent properties were observed in photoluminescence and electrical conductivity of the superlattice structure films. A new type of solar cell was also developed using the superlattice structure as the p-layer of an a-Si solar cell, and a conversion efficiency of 10.5% was obtained. Furthermore the superlattice structure p-layer was found to be an effective layer for energy conversion (photovoltaic p).

1. Introduction

The a-Si superlattice structure film is recently gathering much attention as a new material. Previously reported a-Si superlattice structure films, however, have mainly been fabricated by a glow discharge method (GD).[1,2] In the glow dishcarge method, the interface properties are deteriorated by plasma damage, and this becomes a serious problem for superlattice structure films which have many interfaces. To prevent this, we fabricated a-Si superlattice structure films by the photo-CVD method for the first time.[3]

In this report, the structural, optical, and electrical properties of a-SiC:H/a-Si:H superlattice structure films are described, and the differences between the photo-CVD method and the glow discharge method as a fabrication process for a-Si superlattice structure films are discussed. Furthermore, the first application of a-Si superlattice structure films to the window layers of a-Si solar cells is mentioned.

2. Fabrication method and structural analysis

We fabricated a-Si superlattice structure films by the photo-CVD method for the first time. In the photo-CVD method, low pressure mercury lamps were used as the light source for the direct decomposition of Si_2H_6 (a-Si) or Si_2H_6+C_2H_2 (a-SiC). The reaction conditions are shown in Table 1. For comparison, a-SiC/a-Si superlattice structure films were also fabricated by the glow discharge method. Fig. 1 shows the reaction system for the superlattice structure films and solar cells.

Table 1 Typical reaction conditions of the photo-CVD method and glow discharge method

	photo-CVD		plasma-CVD (GD)	
	Barrier layer a-SiC	Well layer a-Si	Barrier layer a-SiC	Well layer a-Si
Gas flow rate(SCCM)	Si_2H_6 30 C_2H_2 10	Si_2H_6 30	SiH_4 10 CH_4 10	SiH_4 30
Substrate temp. (°C)	300	300	200	200
Pressure (Pa)	100	100	30	30
Depo. rate (Å/min)	25	25	20	50
Decomposition	light source 184.9nm:5mW/cm^2 253.7nm:30mW/cm^2 (low-pressure mercury lamp)		RF power:30mW/cm^2 (13.56MHz) capacitively coupled	

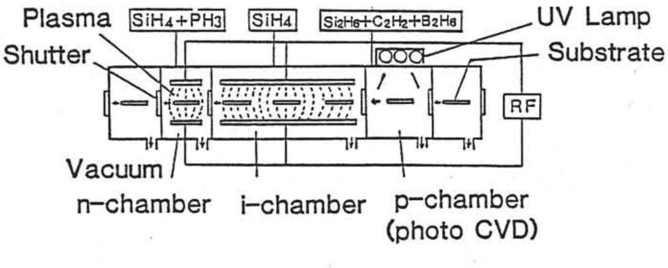

Fig. 1 Reaction system (consecutive, separated reaction chamber apparatus) of superlattice structure films and solar cells

In order to analyze the structure of the superlattice, a-Si:H of 25A and a-SiC:H of 25A were deposited by the photo-CVD method. The depth profiles of composition atoms (Si, C) were measured by AES (Auger electron spectroscopy), as shown in Fig. 2.

The atomic concentration of Si and C varies periodically, which corresponds to our design.

The X-ray diffraction of an a-Si superlattice structure film in which a-Si:H film of 50A and a-SiC:H film of 30A are stacked alternatively was measured. The Bragg reflection peak was shown at 1.10 degrees, which corresponds to the periodical structure of 80A. The first peak position of the Bragg reflection corresponds to the designed period.

Therefore, the atomic sharpness of the amorphous superlattice structure film prepared by the photo-CVD method was thought to be sufficient.

3. Comparison of fabrication methods

In order to compare the photo-CVD method with the glow discharge method as a fabrication method for a-Si superlattice structure films, the photoluminescence (PL) spectra were measured for an a-SiC alloy, an a-SiC/a-Si superlattice structure film fabricated by the glow discharge method, and an a-SiC/a-Si superlattice structure film fabricated by the photo-CVD method, as shown in Fig. 3. The PL intensity of the superlattice structure films was two orders higher than that of the alloy, and this is thought to be caused by the quantization effect. In the case of the photo-CVD method, the PL intensity was about 4 times higher than that of the glow discharge method, and this is thought to be due to the reduction of plasma damage. Therefore, the photo-CVD method was found to be suitable for the fabrication of a-Si superlattice structure films.

4. Current transport mechanism

The transport properties vertical to the interfaces of the superlattice structure films were investigated. The current-voltage characteristics vertical to the interfaces of the superlattice structure films are shown in Fig. 4. The experimental values, indicated by dots, correspond well to the calculated values, indicated by the solid line, which are based on

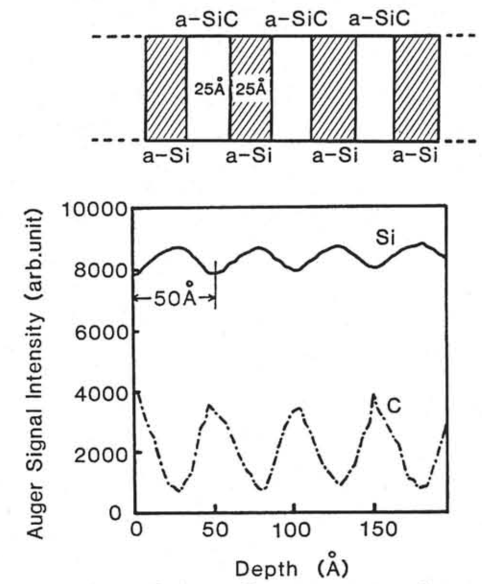

Fig. 2 Depth profiles of compositional atoms measured by AES

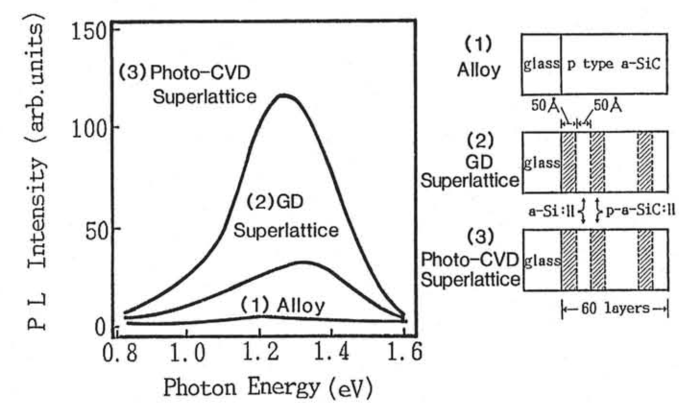

Fig. 3 Photoluminescence spectra of a-SiC alloy and a-SiC/a-Si superlattice structure films

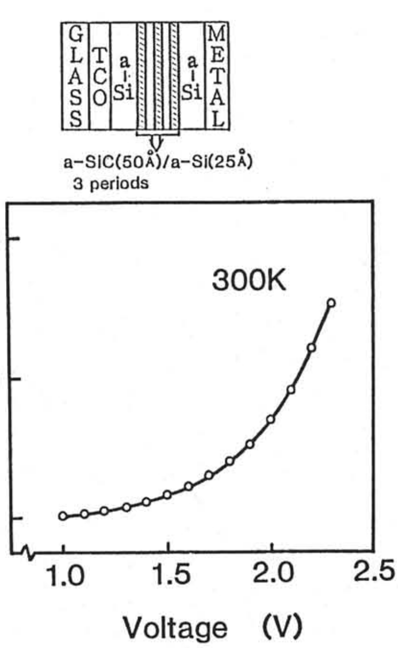

Fig. 4 Current-voltage characteristics of a-Si/ a-SiC superlattice structure film

the tunneling transport as given by equation (1).

$$I \propto V^2 \exp\left(-\frac{b}{V}\right) \quad \text{—— (1)}$$

$$b = \frac{4\sqrt{2m^*}\,(q\phi_o)^{3/2}\,d}{3q\hbar}$$

where ϕ_o is the barrier height of a-SiC:H to a-Si:H. The barrier height ϕ_o calculated from the slope of the $I/_V2$ vs. $1/_V$ plot was 0.3eV.

The activation energy of dark conductivity for the a-Si:H and a-SiC:H, which were used as the well layers and the barrier layers, respectively, was larger than 0.7eV, but that of the superlattice structure films was smaller than 0.4eV.

These results indicate that the carrier transport mechanism is mainly the tunneling effect in the superlattice structure films.

The photoconductivity and dark conductivity vertical to the interfaces of the a-Si/a-SiC superlattice structure films were measured. The results are shown in Fig. 5 as a function of the optical bandgap. Boron atoms were doped into a-Si:H films in the doped superlattice structure films. In the wide optical bandgap region, the photoconductivity of the superlattice structure films was much higher than that of a-SiC:H films fabricated by the glow discharge method, even in doped superlattice films.

The a-Si/a-SiC superlattice structure film was found to show good properties as a wide bandgap material.

5. Application to a-Si solar cells

The photoconductivity of an a-SiC/a-Si superlattice structure p-layer was improved to the level of $10^{-7}\ \Omega^{-1}\mathrm{cm}^{-1}$ with an optical bandgap of 2.1eV, which was one order higher than that of an a-SiC alloy with the same optical bandgap. Thus, we used the superlattice structure films as the window layer of an a-Si solar cell for the first time.

The collection efficiency spectra of a glass/TCO/p-superlattice structure (a-SiC/a-Si)/i(a-Si)/n(a-Si)/Metal solar cell is shown in Fig. 6. A remarkable increase in the collection efficiency in the short wavelength region was observed.

The increase in the collection efficiency can be explained as follows. The conventional p-layer (a-Si or a-SiC) has poor properties as an effective area for photovoltaic effect, and the i-layer is thought to be the main region for

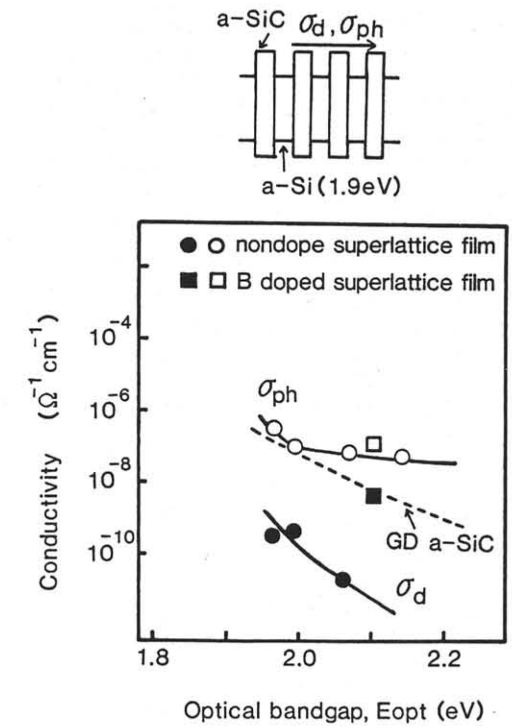

Fig. 5 Photoconductivity and dark conductivity vertical to the interface as a function of the optical bandgap

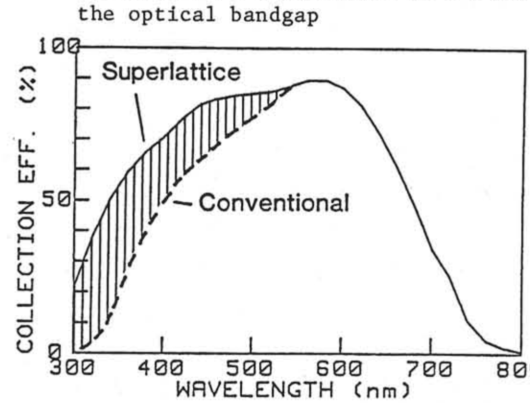

Fig. 6 Collection efficiency spectra of the superlattice structure p-layer solar cell

photovoltaic energy conversion. This is because the lifetime of minority carrier in the p-layer was small compared with that in the i-layer, which causes low photoconductivity and low photoluminescence intensity. On the other hand, the superlattice p-layer shows high photoconductivity and high photoluminescence intensity, compared with the conventional p-layer mentioned above. So we thought the superlattice structure p-layer could be an effective area for photovoltaic effect, and called it "photovoltaic p". In order to confirm this effect, we calculated the theoretical collection efficiency spectrum with the optical properties, such as the absorption coefficient spectrum and interference effect, as shown in Fig. 7. In the figure, when the internal quantum efficiency (P) in the p-layer is 0, the calculated collection efficiency spectrum is quite different from the experimental value, as shown in the broken line. When P is 0.7, the calculated spectrum is relatively similar to the experimental value. So, the superlattice structure p-layer is thought to be an active area for photovoltaic effect.

A conversion efficiency of 10.5% was obtained for this type of superlattice structure p-layer a-Si solar cell, as shown in Fig. 8.

6. Conclusion

Amorphous silicon superlattice structure films were fabricated by the photo-CVD method for the first time. The accuracy of the structure of the a-Si/a-SiC superlattice structure film was confirmed by AES and Bragg reflection of X-ray. It was found that the photoluminescence intensity of superlattice structure films fabricated by the photo-CVD method was about four times larger than that of similar films fabricated by the glow discharge method. The carrier transport mechanism vertical to interfaces of the superlattice film was thought to be mainly the tunneling transport.

We have also developed a new type of cell using the superlattice structure as the p-layer of an a-Si solar cell for the first time. A remarkable increase in the collection efficiency in the short wavelength region was observed, and the superlattice structure p-layer was found to be an active layer for energy conversion, which we called "photovoltaic p". A conversion efficiency of 10.5% was obtained for a glass/TCO/p-superlattice structure/in/Metal a-Si solar cell.

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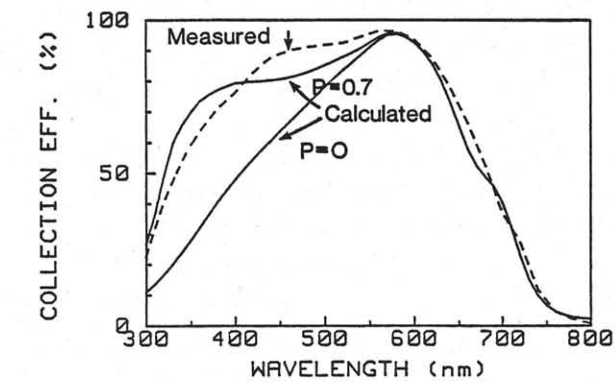

Fig. 7 Measured and calculated collection efficiency spectra of the superlattice structure p-layer solar cell

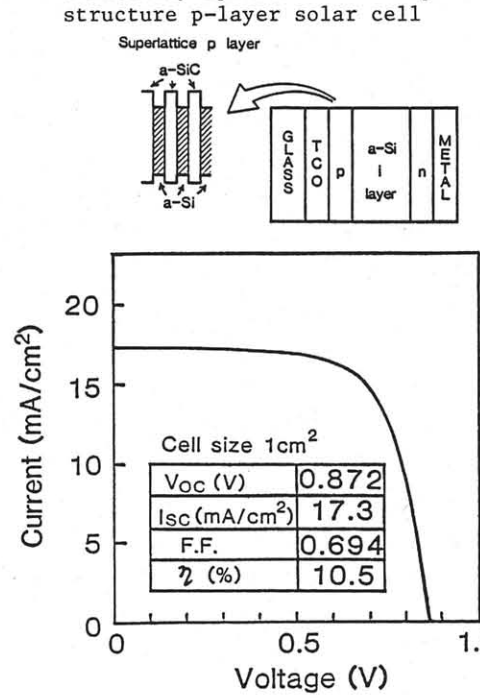

Fig. 8 Illuminated I-V characteristics of the superlattice structure p-layer solar cell

References

1) B. Abeles et al. : Phys. Rev. Lett. 51 (1983) 2003

2) M. Hirose et al. : J. Non-Crist. Solids 66 (1984) 327

3) S. Nakano et al. : Proceedings of Materials Research Society (1986)