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Fabricating high performance a-Si solar cells by alternately repeating deposition and hydrogen plasma treatment method

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Abstract

The performance of a p-i buffer layer in pin amorphous silicon solar cell was improved by the "alternately repeating deposition and hydrogen plasma treatment method (ADHT)". The optical bandgap of the a-Si film was increased by hydrogen plasma treatment. The wide optical bandgap and the high photoconductive a-Si:H films without carbon could be fabricated by the ADHT method. The conversion efficiency of the solar cell with a-Si:H buffer layer was almost the same as that using an a-SiC:H buffer layer. Second, the a-Si (ADHT) films were applied to the n-i buffer layer. The insertion of a-Si (ADHT) films between the i-layer and the n-layer was effective to improve the cell performance, especially the fill factor. With the use of high performance a-Si p-i and n-i buffer layer deposited by ADHT method, a cell conversion efficiency of 12.9% was obtained.

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1. Introduction

In order to improve the performance of pin-type a-Si solar cells, we have developed p-type (a-Si/a-C)n multilayers [1] and inverted carbon graded a-SiC:H layer [2]. We tried to improve the property of the p-i buffer layer for good absorption of sun light in the i-layer. On the other hand, we have reported that the novel fabrication method of "alternately repeating deposition and hydrogen plasma treatment (ADHT)" was effective to change the optical bandgap of a-Si films

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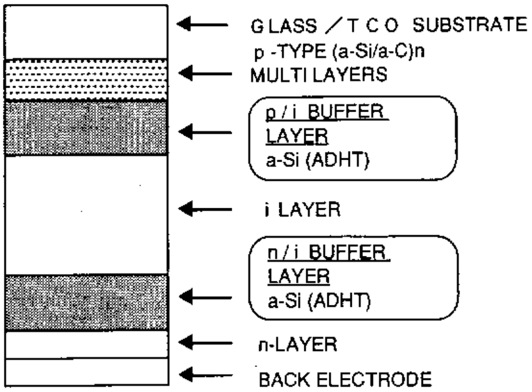

Fig. 1. The structure of amorphous silicon solar cells in this study.

without deteriorating the electrical property [3]. From these results we tried to apply a-Si (ADHT) films to n-i buffer layer. We have simulated the effect of insertion of a weak n-type a-Si film between the i- and n-layer. It is expected that the n-i buffer layer is effective to increase the electrical field in the i-layer near the n-layer and the film properties of the n-i buffer layer mainly affected the fill factor of the cell [4]. In this paper, the film properties of a-Si:H films deposited by the ADHT method and the results of application of these films to p-i and n-i buffer layers are described.

2. Experimental

A typical cell structure investigated in this study is glass/SnO_2/p/p-i buffer/i/n-i buffer/n/back electrode as shown in Fig. 1. The alternately repeating deposition and hydrogen plasma treatment were applied to the a-Si film deposition. The a-Si films were deposited by glow discharge of SiH_4 and H_2 gas. After each deposition of a-Si thin films of thicknesses 2 nm, the deposited layers underwent hydrogen plasma. This deposition/treatment procedure was repeated alternately. The typical deposition condition of a-Si p-i buffer layer is shown in Table 1. The deposition and hydrogen plasma treatment were carried out in the same chamber and the residual gas was evacuated between deposition and treat-

Table 1
Typical deposition condition of a-Si p-i buffer layer using the ADTH method, p/i buffer layer

	Deposition of a-Si films	H2 plasma treatment
Source gases	$\frac{SiH_4}{H_2}=1$	H2
T_s (set)	200°C	
RF power	0.04 W/cm^2	0.25 W/cm^2
Thickness	2 nm	–
Time	45 s	0–120 s

Table 2
Typical deposition condition of a-Si n-i buffer layer using the ADHT method, n/i buffer layer

	a-Si:H	H_2 plasma treatment
Source gases	SiH_4, 3 sccm	H_2, 30 sccm
T_s (set)	200°C	
RF power	0.04 W/cm^2	0.05 W/cm^2
Thickness	1–5 nm	–
Treatment time	–	20 s

ment. In this study, the thickness of the p-i buffer layer was 10 nm. The i-layer was deposited by glow discharge of pure SiH_4 and its thickness was 550 nm. Also, the ADHT method was applied for fabricating the n-i buffer layer. The typical deposition condition of a-Si n-i buffer layer is shown in Table 2. The n-i buffer layer was $n^{-''}$ a-Si:H film, and its thickness was changed 0–15 nm. The anti reflection layer on the glass surface, ITO and Ag were prepared by an electron beam evaporation method.

3. Results and discussion

3.1. Application of alternately deposition and hydrogen plasma treatment method (ADHT) to the fabrication of a-Si films

Fig. 2 shows the defect densities of a-Si films measured by CPM plotted against the optical bandgap. Solid circles refer to a-Si films deposited by the conventional method and open circles refer to a-Si films deposited by alternately deposition and

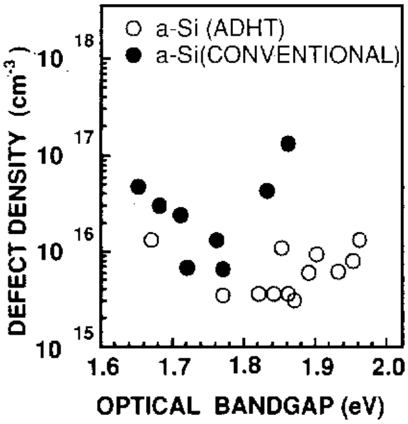

Fig. 2 The defect densities of a-Si films measured by CPM plotted against the optical bandgap: ○ a-Si (ADHT) films, ● conventional.

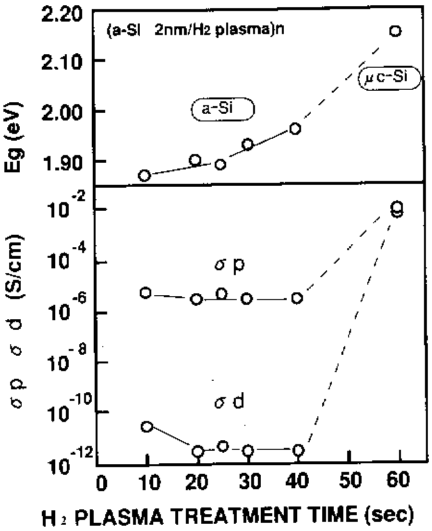

Fig. 3. The optical band gap derived from Tauc's plot, photoconductivity and dark conductivity of a-Si (ADHT) films as a function of the hydrogen plasma treatment time.

hydrogen plasma treatment method (ADHT). The hydrogen content was changed over a wide range from 4 to 32% by the ADHT method. The wide optical band gap of 1.95 eV with the lower defect densities of less than 10^{16} cm^{-3} comparing with conventional a-Si films was obtained. It is speculated that the defects of the a-Si films were compensated by atomic hydrogen supplied from hydrogen plasma. Therefore, the wide gap and highly photoconductive a-Si films were obtained by using the ADHT method.

3.2. Application of wide gap a-Si films to p-i buffer layer

The wide gap and low defect density a-Si films were fabricated by the ADHT method. The optoelectric properties of the a-Si (ADHT) films are shown in the Fig. 3. The optical bandgap of a-Si films derived from Tauc's plot was increased by the hydrogen plasma treatment and high photoconductivity of more than 10^{-6} S/cm was attained. Moreover, the transition from a-Si to micro crystalline silicon phase was observed with a long hydrogen plasma treatment time of 60 s. The relationships between the photoconductivity and the optical bandgap of the a-Si and a-SiC films are shown in Fig. 4. The optical bandgap was increased while retaining photo-conductivity greater than 3×10^{-6} S/cm [1]. The wide optical gap and high photoconductive a-Si films, the same properties with a-SiC films, were obtained by the ADHT method.

Fig. 5 shows the solar cell characteristics applied a-Si film (ADHT) to the p-i buffer layer as a function of the hydrogen plasma treatment time. The cell characteristics correspond to the a-Si film properties such as optical bandgap in

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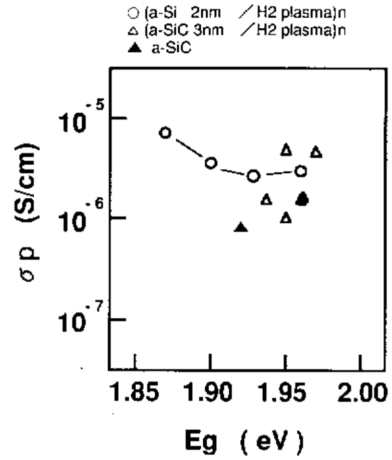

Fig. 4. The relationship between the photoconductivity and the optical bandgap of the a-Si films and a-SiC films.

the region of 10–30 s. On the other hand, the open-circuit voltage and short-circuit current dropped with the process time of more than 30 s. This drop is ascribed to the hydrogen plasma damage such as the a-Si film etching and micro crystallization by the excess hydrogen plasma treatment more than 40 s. The cell characteristics using a-Si:H buffer layers deposited under optimized condition comparing with that using a-SiC buffer layer is shown in Table 3. The cell conversion efficiency

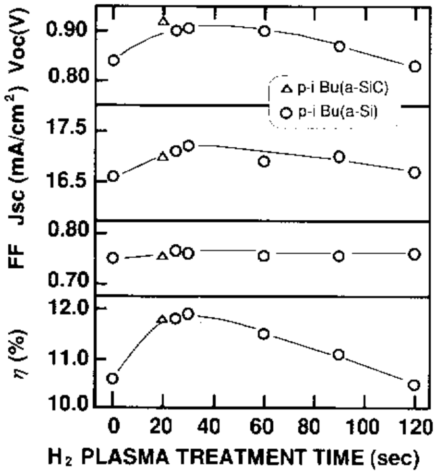

Fig. 5. The characteristics of solar cells using a-Si (ADHT) p-i buffer layers as a function of hydrogen plasma treatment time.

Table 3
The cell characteristics using a-Si:H buffer layers deposited under optimized condition comparing with that using a-SiC buffer layer

P-I buffer layer	V_{oc} (V)	J_{sc} (mA/cm^2)	FF	EFF. (%)
a-SiC (ADHT)	0.923	17.0	0.752	*11.8*
a-Si (ADHT)	0.903	17.2	0.762	*11.9*

obtained for a-Si buffer layer was almost the same with that using a-SiC buffer layer.

3.3. Application of widegap a-Si films to n-i buffer layer

The effect of insertion of the wide gap a-Si films deposited by ADHT method between i-layer and n-layer was investigated. The characteristics of a-Si solar cell provided with a-Si n-i buffer layer is shown in Fig. 6. The n-i buffer layer was deposited in the N-chamber, then a-Si films were slightly doped with phosphorous. The open-circuit voltage was increased by the incorporation of the n-i buffer layer and the fill factor was improved. As a result, the cell conversion efficiency was improved by the incorporation of weak n-type a-Si (ADHT) film, in the region of 3–6 nm. These results are well accounted for by the results of simulation (programmed by Tasaki et al. [5]) that the low quality film is formed at the initial stage of n-layer deposition and quenches the electric field and the n-i buffer layer recovers the electric field in the i-layer near the n-layer.

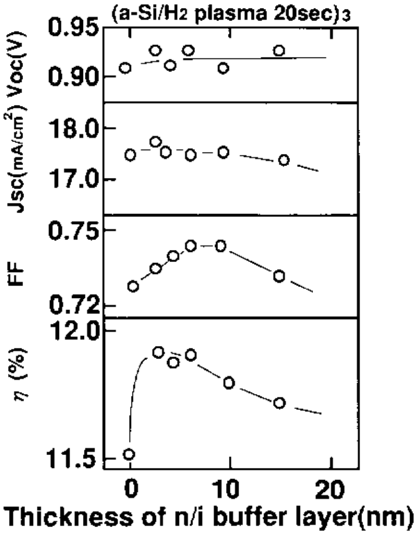

Fig. 6. The solar cell characteristics applied a-Si (ADHT) films to the n-i buffer layers as a function of the thickness of n-i buffer layer.

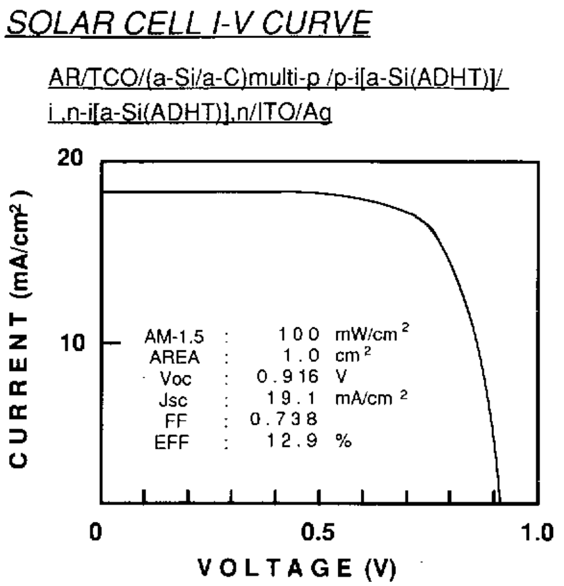

Fig. 7. The solar cell $I-V$ curve applied a-Si(ADHT) films to the p-i and n-i buffer layer.

As a result, an efficiency of 12.9% on the single junction a-Si solar cell without a-SiC film was obtained by using p-i and n-i a-Si buffer layers with highly reflecting back electrode and AR coating film, as shown in Fig. 7. Moreover, the simulation indicated that the effectiveness of the insertion of an n-i buffer layer depended on the defect densities in i-layer, so that effective improvement of the cell performance is expected in case the defect density of i-layer is less than 10^{15} cm^{-3}.

4. Conclusion

High performance a-Si p-i and n-i buffer layers were fabricated by the ADHT method. The low defect density of less than 10^{16} cm^{-3} was obtained with a wide optical band gap for p-i and n-i buffer layers.

The application of a-Si (ADHT) films to p-i and n-i buffer layers were found to be effective to improve the cell performance. The trend of experiment data on the insertion of n-i buffer layer between i-layer and n-layer is consisted with the result of simulation.

As a result, a cell conversion efficiency of 12.9% was obtained using widegap a-Si films for the p-i and n-i buffer layer.

Acknowledgements

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