Amorphous / Microcrystalline Silicon Solar Cell Fabricated on Metal Substrate and Its Pilot Production

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Abstract : High efficiency amorphous /microcrystalline silicon solar cells fabricated on stainless steel substrate have been developed by using a multi-chamber system in which all layers can be deposited without breaking the pressure on 30 cm × 40 cm area. It was found that n-type microcrystalline layer fabricated by VHF, CO_2 glow at the interface between the top and bottom cell and new p-type microcrystalline with a small amount of SiH_2Cl_2 increase the tandem cell performance.

As a result, an initial cell efficiency of 14.5 % (Voc=1.49V, Jsc=13.7 mA/cm^2, FF=0.711) and module efficiency of 8% have been achieved on 3 cm^2 cell area and 0.75 m^2 module area under standard testing conditions. The relationship

between the outdoor performance in Thailand and the deposition conditions has been investigated. The pilot production of such module is being carried out.

Introduction

The tandem type, amorphous and microcrystalline (μc-Si) solar cell developed by IMT group [1] is one of the promising cell structures. Some previous work has used the glass coated with textured SnO_2 as the substrate and focused on microcrystalline cell [2]. On the other hand, some work on tandem cell structure has been done on stainless steel substrate as well. For example, Canon has developed the tandem cell with efficiency of more than 12% [3] on the stainless steel substrate. However, the work on module size has not been reported yet.

In this research, we have studied the method to increase the efficiency of the tandem cell on stainless steel both under the standard condition and outdoor testing conditions. Furthermore, a prototype module has also been developed and prototype production has been started.

Experimental

A cluster-type, multi-chamber system in which various films (Ag, ZnO, ITO, a-Si and μc-Si films) can be deposited on 30 cm x 40cm area without breaking the pressure has been developed. Its chamber layout is shown in Fig. 1.

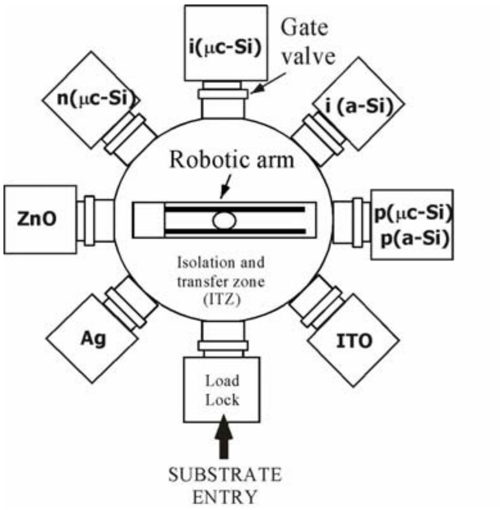

Figure 1. Chamber layout of the system used for cell fabrication.

Our detailed cell structure is stainless steel / hot Ag / ZnO / n(μc-Si) – i(μc-Si) – p(a-Si) or p(μc-Si) / ZnO / n(μc-Si) –i(a-Si) – p(μc-Si) / ITO. Thin Ag fabricated at 400^{o}C and ZnO was used to increase the current of the bottom μc-Si cell, while another transparent ZnO was inserted between two cells in order to increase the current of the top a-Si cell.

All silicon films except p-layer were fabricated by using VHF and new type electrode in order to get good film uniformity over 30 cm x 40cm area. Frequency up to 100MHz is used for i(μc-Si) and 60 MHz for a-Si deposition, respectively. In order to check the effect of n(μc-Si) on the μc-Si cell performance, the frequency used for its deposition is varied from 13.56 MHz to 60 MHz and finally 70 MHz.

No gas purifier, no slight boron-doping in the i-layer and no substrate bias were used in this work. Cell performance was measured under AM1.5, 100 mW/cm^2 at 25 ^oC.

Results and Discussion

1. Development of top cell.

As known, for substrate/nip type cell structure, p-layer has to be good microcrystalline layer [4]. Many approaches such as VHF utilization [4], low temperature deposition, new BF_3 doping gas have been carried out. Besides that, in this work we have developed a new p(μc-Si) using conventional gas mixture (SiH_4+B_2H_6+H_2) with small amount of SiH_2Cl_2 as the doping gas. Fig. 2 shows the absorption coefficient of developed films with various SiH_2Cl_2 gas flow rate. It was found that lower absortion coefficient and higher conductivity can be achieved with suitable amount of SiH_2Cl_2 gas. This may come from the the fact that Cl in SiH_2Cl_2 promotes the crystallinity [5]. As the result, higher cell efficiency has been achieved with this new p-layer.

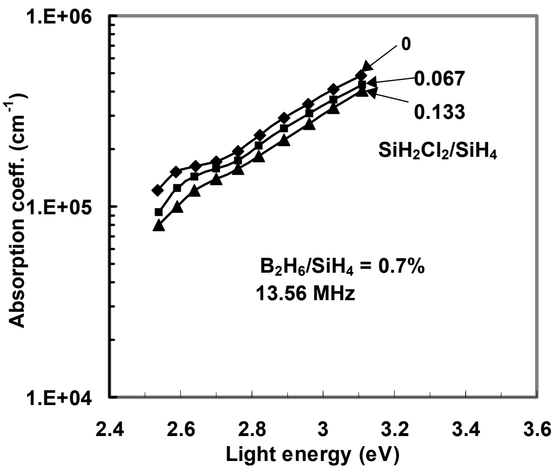

Figure 2. Change of absorption coefficient by small amount of SiH_2Cl_2 for p(μc-Si) made from conventional gas mixture (SiH_4+B_2H_6+H_2)

2. Development of μc-Si bottom cell.

It was found that the performance of the microcrystalline bottom cell depends on the crystallinity of n(μc-Si) layer deposited before it, as shown in Table 1. The crystallinity of n(μc-Si) was varied by both its thickness and the frequency used for its deposition. Cells with thicker n(μc-Si) layer show better performance while higher frequency is preferred since better crystallinity and higher deposition rate could be achieved. This may be due to the fact that with good microcrystalline n-layer, i-layer deposited on it becomes more crystalline which results in higher cell performance [6].

Table 1. Comparison of μc-Si cell performance under different frequency and deposition time used for n-layer deposition.

F (MHz)	Time (sec)	Voc (V)	Jsc (mA/cm^2)	FF	Eff (%)
13.56	1500	0.46	20.0	0.575	5.59
41	1500	0.48	22.0	0.588	6.45
41	1800	0.48	22.4	0.583	6.58
70	900	0.53	20.5	0.635	7.24

3. Development of good interface between bottom cell and intermediate ZnO.

As known, the interface property of p/ZnO is not as good as p/ITO, so when we make the tandem cell structure having intermediate ZnO between the bottom and top cell, there should be the problem at the interface of p-layer of the bottom and intermediate ZnO. This will act as a reverse diode.

Various types of p-layer have been used. As the result, we found that the tandem cells with p(μc-Si) or p(a-Si) with CO_2 glow show better cell performance. Table 2 shows the summary of the results.

Table 2. Summary of the cell performance for various types of p-layer at the bottom cell.

Type of p-layer for the bottom cell	Voc (V)	Jsc (mA/cm^2)	FF	Eff (%)
p(a-Si)	1.26	13.4	0.634	10.7
p(μc-Si)	1.41	13.1	0.639	11.8
p(a-Si)/CO_2 glow	1.42	13.4	0.636	12.1

4. Cell and module performance.

By applying the previous mentioned technology, an initial efficiency of 14.5 % (Voc=1.49 V, Jsc = 13.7 mA/cm^2, FF= 0.711) has been achieved on 3 cm^2 active cell area.

Cells with larger area (298 cm^2) and module (7502 cm^2) were developed by applying the copper wire pressed on the front of the cell in order to collect the current.

Their performance can be summaried as shown in Table 3. Up to now, the module efficiency of 8% has been achieved.

Table 3. Summary of the best performance achieved so far for larger cell area.

Area (cm^2)	Pmax (W)	Voc (V)	Isc (A)	FF	Eff (%)
298	3	1.51	2.92	0.678	10.1
7502	57.2	32.3	2.88	0.598	8.00

5. Development of the cell with good outdoor performance.

It is understood that the performance of this kind of tandem cell will be different under outside conditions in Thailand because of the different light spectrum or AIR MASS. We checked the outside performance and found that its outside current is only 60% of that measured by a solar simulator.

By changing the cell structure using no intermediate ZnO and by varying the deposition condition such as the thickness and deposition temperature of the top cell, the performance difference due to different AIR MASS, has been solved.

6. Prototype production.

The prototype production of the above-mentioned type module has been started. The prototype production capacity is around 180W per day. The first 1kW system with grid connection has been installed at Chiang Mai Province in the northern part of Thailand for evaluation as shown in Figure 3.

Figure 3. First PV system using the developed modules.

Acknowledgement

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