Available online at www.sciencedirect.com

SciVerse ScienceDirect

Physics Procedia 32 (2012) 308 – 313

Physics Procedia

18th International Vacuum Congress

Study of a-Si:H/a-Si:H/μc-Si:H PIN type triple junction solar cells in a single chamber system

X. X. Zheng, X. D. Zhang*, S. S. Yang, S. Z. Xu, C. C. Wei, J. Sun, X. H. Geng, Y. Zhao

Institute of Photo-electronic Thin Film Devices and Technology of Nankai University, 300071 Tianjin, P.R.China

Abstract

Low cost triple junction solar cells, which are very important for the development of industry, have been studied in this paper. Based on the amorphous silicon/amorphous silicon tandem solar cells realized in industry using completely single chamber deposition technique, amorphous silicon /amorphous silicon/microcrystalline silicon (a-Si:H/a-Si:H/μc-Si:H) triple junction solar cells with 9.13% initial conversion efficiency have been fabricated by changing deposition condition for n/p tunnel junction treatments which include H plasma treatment, variation of μc-Si:H n layer deposition conditions, and variation of p layer thickness in a single chamber developed by us. It has proved that amorphous silicon thin film solar cell now in industry can be progressed by introducing single chamber microcrystalline silicon thin film solar cells technique.

PACS: 88.40.jj; 85.30.Mn; 88.40.jp.

Keywords: Silicon thin film solar cells; tunnel junction; Triple junction; Single chamber; Microcrystalline silicon.

1. Introduction

Increasing the stabilized efficiency of the solar cell and reaching minimum cost are two key issues in the area of thin film silicon based solar cell technology. Plasma deposition of thin film silicon based solar cells in a single-chamber reactor leads to considerable simplifications and reduced costs as compared to multi-chamber processes. The two most important energy loss mechanisms in single band gap cells are the incapacity to absorb photons with energy less than the band gap and thermalization of photon energies excess the band gap. These two mechanisms alone occupy the loss of about half of the incident solar energy in solar cell conversion to electricity [1]. The present trend of thin film silicon based solar cell is to move from one-junction to double-junction, triple-junction and multi-junction structures. The concept of proposing two a-Si:H cells is based on the reduction in the Staebler–Wronski effect which can be obtained by keeping each individual i-layer as thin as possible. However, it will not on a better utilization of the solar spectrum [2]. The a-Si:H/a-Si:H/μc-Si:H triple junction solar cells can absorb different sections of the solar spectrum to reduce the lost energy to a certain degree. Also a reduction of the top a-Si:H component cell thickness can improve the stability of triple junction solar cells.

At present, many research papers about design and deposition of NIP type triple junction solar cells have been published [3-6]. The a-Si:H/a-SiGe:H/nc-Si:H NIP type triple junction solar cells with a initial conversion efficiency

* Corresponding author. Tel.: 0086-22-23502778; fax: 0086-22-23502778.
E-mail address: xdzhang@nankai.edu.cn.

 doi:10.1016/j.phpro.2012.03.561

of 15.4% have been attained in United solar company[3]. Few research institutes were involved with PIN type triple junction solar cells [7]. Compared to NIP type solar cells, the advantage of PIN type solar cells is that they can be deposited on glass substrates which are suitable for 3 steps laser scribing process to realize series connection. So, PIN type triple junction solar cells deposited in a single chamber is a worthy area to develop.

The current popular method is to use a tunnel junction to combine different cells [8].The tunnel junction is the region that connects the top and bottom cells. It should show ohmic, not rectifying, behavior to recombine electrons of the top cell and holes of the bottom cell [9]. All photo generated electrons of the top cell and photo generated holes of the bottom cell must be recombined at the tunnel junction. If the recombination process does not proceed properly, piled charges will corrupt the electric field inside the cell and the cell performance will be degraded [10]. To fabricate a high efficient triple junction solar cell, it is important to design and fabricate a better tunnel junction.

In order to obtain high efficiency a-Si:H/a-Si:H/uc-Si:H triple junction solar cells, the deposition condition of μc-Si:H N and P layer for n/p tunnel junction was optimized in this paper.

2. Experiment

The a-Si:H/a-Si:H tandem top cells were directly purchased from Jinneng company. The μc-Si:H bottom cells were deposited in a single chamber of a cluster CVD system. Each layer of the solar cells was deposited at the same electrode distance, deposition temperature and excitation frequency. The structure of the triple junction solar cell was glass/SnO_2/a-Si:H solar cell/a-Si:H solar cell/μc-Si:H solar cell/Al. Raman scattering experiment was performed using a 325nm and 632.8 nm wavelength laser. Crystalline volume fraction (Xc) described the crystallinity of the films：

$Xc = (I_{510} + I_{520}) / (I_{480} + I_{510} + I_{520})$ [11] (1)

I-V characteristics of the solar cells were measured under illumination with an AM 1.5 (100mA/cm^2) solar condition.

3. Results and discussion

As has been reported, it is important to design and fabricate better n/p junctions that allow very high recombination rates, pass current under reverse bias with a low resistance, have negligible optical absorption, and should be easily integrated into the multi-junction deposition process [10, 12]. The N layer of a-Si:H/a-Si:H tandem top cells purchased from company is a-Si:H which is not suitable for tunnel junction. Therefore intentionally making a thin μc-Si:H N recombination layer with high defect state density and high conductivity on the top of a-Si:H N layer can help the tunnel junction carrier transport.

3.1 Optimization of H plasma treatment time

The a-Si:H/a-Si:H tandem solar cells has exposed to atmosphere, a layer of oxide on the surface which has a pernicious influence on n/p tunnel junction were formed [13]. In addition, it is not easy to obtain crystallization on amorphous substrate. H plasma treatment before depositing μc-Si:H N layer is necessary to get a-Si/μc-Si double N layer with a super performance. Raman curves of the a-Si:H/a-Si:H tandem solar cells at different H plasma treatment times to form a-Si/μc-Si double N layer were shown in Fig 1. Inset in Fig. 1 also indicates the Xc of sample calculated from Raman curves. It can be seen that the Xc values slightly increase then decrease as H plasma time increases. A possible reason is as follows: H plasma time was so short that only few Si-Si weak bonds were broken. At appropriate time, material held a maximum of broken Si-Si weak bonds and so the most of SiH_n were formed. The nets of a-Si/μc-Si double N layer were matched well which was helpful for μc-Si N layer development. Too long H plasma treatment time enhanced etching which indicated an detrimental effect on μc-Si N layer growth [14]. Fig.2 shows the Jsc, Voc, FF, and efficiency values for a-Si:H/a-Si:H tandem cells as a function of H plasma time. The Jsc and FF values change little. The Voc values slightly increase then decrease as H plasma time increases. The maximum for Voc and conversion efficiency arrived at 30s H plasma time.

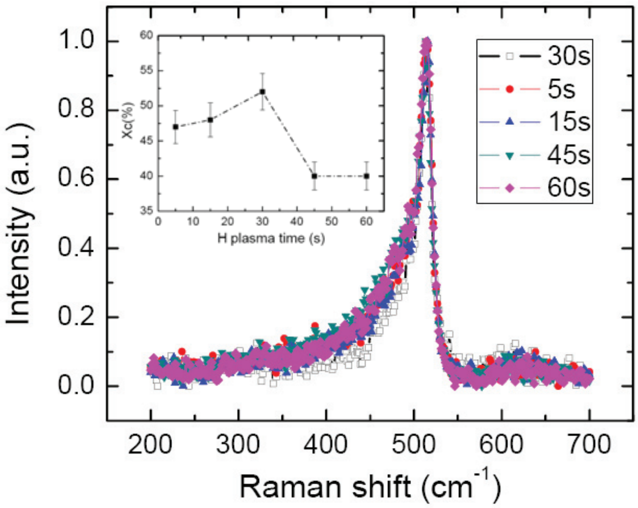

Fig.1 Raman curves of the a-Si:H/a-Si:H tandem solar cells with a-Si/μc-Si double N layer for different H plasma treatment times (325nm laser). Inset indicates the Xc of sample calculated from Raman curve.

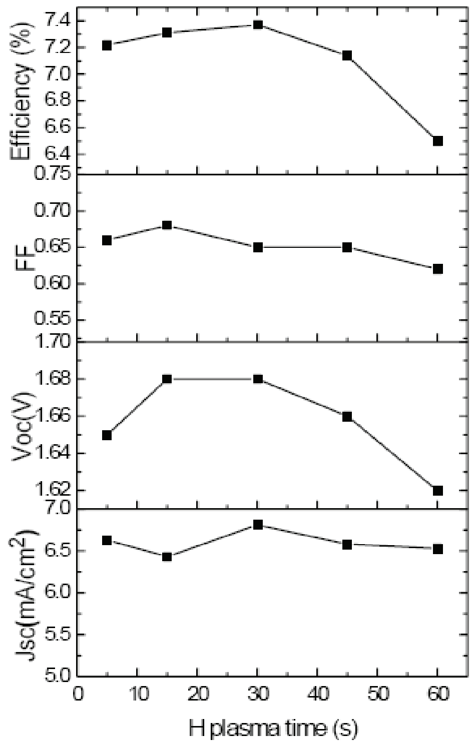

Fig.2 Performance of a-Si:H/a-Si:H tandem solar cells with a-Si/μc-Si double N layer as a function of H plasma glow time.

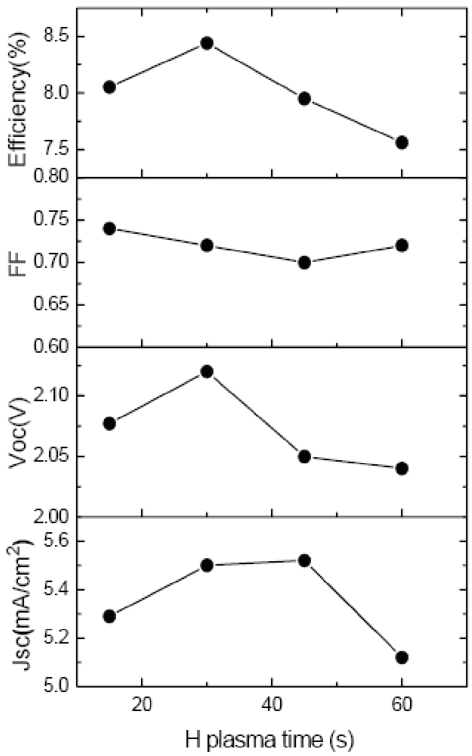

Fig.3 J–V characteristics of a-Si:H/a-Si:H/μc-Si:H triple junction solar cells as a function of H plasma treatment time

Based on the above treatment technique, microcrystalline bottom solar cell was incorporated into it. Fig.3 demonstrated that the Jsc, Voc, FF, and efficiency values for a-Si:H/a-Si:H/μc-Si:H triple junction solar cells with different H plasma times. It is also shown that the Voc values and conversion efficiency attained the highest value at 30s H plasma time. Combining Fig.1 inset, Fig.2 and Fig.3, it can proved that the fabricated tunnel junction with higher Xc of μc-Si:H layer improves the carrier transport at the conjunction of the middle and bottom cell.

3.2 Optimization of μc-Si:H N layer deposition conditions

In order to obtain a better n/p tunnel junction, we optimized μc-Si:H N layer deposition conditions with the same H plasma treatment time. Table1 shows the performance of solar cell for different μc-Si:H N layer deposition conditions. Sample 1# is a baseline cell. Increasing power (2#) and high H dilution (3#) improve crystallization and reduce band gap of μc-Si:H N layer[15]. Heavily doped μc-Si:H N layer has higher defect state density and makes the Fermi level move close to bottom of conduction band. Carrier concentrations are comparatively high on the edge of NP tunnel junction. All of these are helpful to enhance carrier recombination then increase current and also reduce the loss of light voltage in tunnel junction. In addition, the increase of Jsc did also not exclude the influence of current cross section.

Table1 Performance of solar cells for different μc-Si:H N layer deposition conditions

Deposition condition	Performance of solar cells			
	Jsc (mA/cm^2)	Voc (V)	FF	η (%)
1# power18W (baseline cell)	4.87	2.04	0.69	6.86
2# power 25W	5.52	2.01	0.66	7.32
3# heavy doping, power 18W	5.32	2.05	0.73	7.96
4# high H dilution, power 18W	5.59	1.99	0.68	7.56

3.3 Performance of solar cells with different μc-Si:H P layer thickness

Except for the optimization of the μc-Si:H n layer deposition conditions and H plasma treatment time, the μc-Si:H p layer thickness were also optimized. Since estimating thickness is not easy, triple junction solar cells with different μc-Si:H P layer deposition times were made. Fig.4 reveals J–V characteristics of a-Si:H/a-Si:H/μc-Si:H triple junction solar cells as a function of P layer deposition time. Voc values decrease with P layer deposition time increase, while Jsc has an opposite variation. To better illustrate this problem, Raman curves with 632.8-nm excitation of a-Si:H/a-Si:H/μc-Si:H triple junction solar cells for different P layer deposition time were given in Fig. 5. It is observed that Xc slightly increases as P layer deposition time increases which proves that the high Xc of p layer will induce the microstructure change for subsequent i layer. This also confirms the microcrystalline silicon evolution with the thickness [16].

Through the above research, we know that the characteristics of triple junction solar cells are closely related with deposition condition for n/p tunnel junction treatment. Based on the above parameters optimized, amorphous silicon /amorphous silicon/microcrystalline silicon triple junction solar cells with 9.13% initial conversion efficiency have been fabricated in a single chamber system. I-V curve is shown in Fig.6.

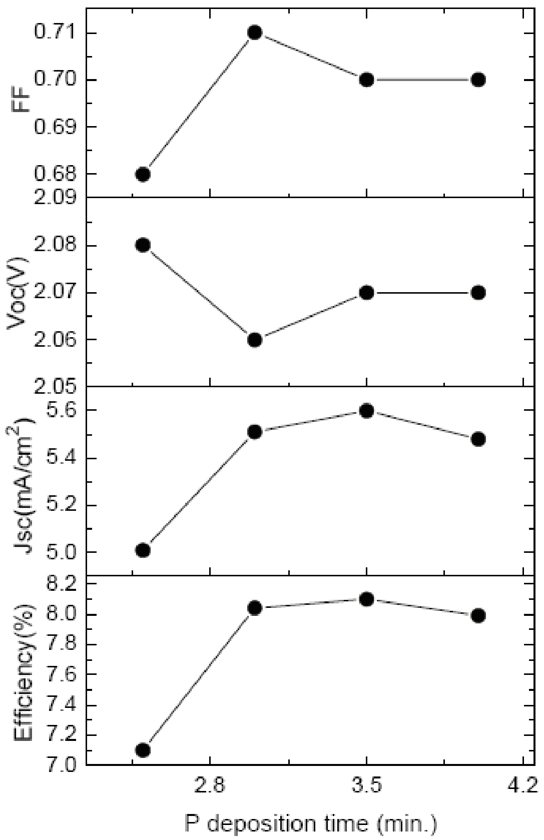

Fig.4 J–V characteristics of a-Si:H/a-Si:H/μc-Si:H triple junction solar cells as a function of P layer deposition time.

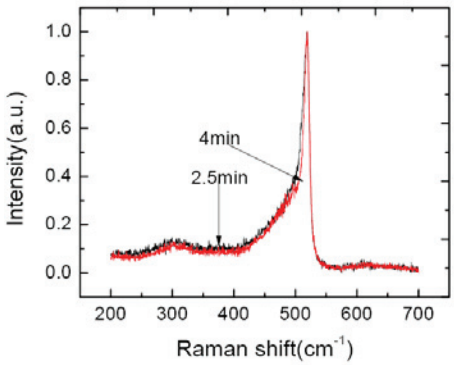

Fig.5 Raman curves of a-Si:H/a-Si:H/μc-Si:H triple junction solar cells for different P layer deposition time (632.8nm laser).

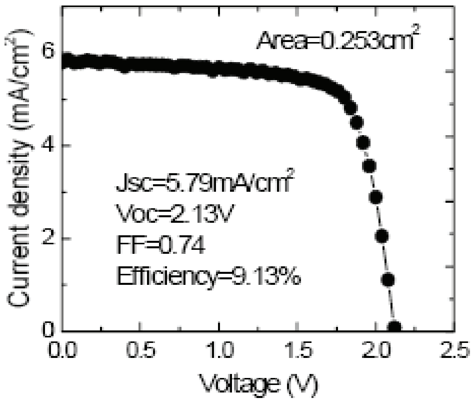

Fig.6 I-V curve of a-Si:H/a-Si:H/μc-Si:H triple junction solar cells.

4. Conclusion

Based on plasma deposition of p-i-n microcrystalline silicon solar cell in a single chamber, low cost amorphous silicon/amorphous silicon tandem solar cells realized in industry using completely single chamber deposition technique have been upgraded to a-Si:H/a-Si:H/μc-Si:H PIN type triple junction solar cells in a single chamber. By optimizing H plasma treatment time, μc-Si:H N layer deposition condition, and μc-Si:H P layer thickness for n/p tunnel junction treatment, amorphous silicon /amorphous silicon/microcrystalline silicon triple junction solar cell with 9.13% conversion efficiency has been fabricated.

Acknowledgements

Project supported by Hi-Tech Research and Development Program of China (Grant no. 2011CB201605, 2011CB201606), Science and technology support project of Tianjin (Grant no.08ZCKFGX03500), National Natural Science Foundation of China (Grant no.60976051), International Cooperation Project between China-Greece

Government (Grant no.2006DFA62390, 2009DFA62580), and Program for New Century Excellent Talents in University of China (Grant no.NCET-08-0295).

References

[1] M. Green, Progress in Photovoltaics: Research and Applications 8 (2001) 123-135.
[2] H. Keppner, J. Meier, P.Torres, D. Fischer, A. Shah, Appl. Phys. A69 (1999) 169–177
[3] J. Yang, B.J. Yan, S. Guha, Thin Solid Films 487 (2005) 162–169.
[4] J. Krc, Sol. En. Mat. Sol. Cells 86 (2005) 537-550.
[5] J. Meier, 3rd World Conference Photovoltaic Energy Conversion 2003.
[6] K. Yamamoto, A. Nakajima, M. Yoshimi, et al, Solar Energy 77 (2004) 939–949.
[7] P. Sichanugrist, N. Pingate, and C. Piromjit, MRS 0989-A18-08 2007 Spring.
[8] I. M. Dharmadasa, Sol. En. Mat. Sol. Cells 85 (2005) 293-300.
[9] X. Deng, E.A. Schiff, Handbook of Photovoltaic Engineering, John Wiley (2002) 45.
[10] J. Kwak, S.W. Kwon, K.S. Lim, Journal of Non-Crystalline Solids 352 (2006) 1847–1850.
[11] C. Droz, E. Vallat - Sauvain, J. Bailat, et a1.17th European Photovoltaic Solar Energy Conference Munich，Germany 20012917.
[12] S.S. Hegedus , F. Kampas, J. Xi, Appl Phys Lett 67(6) (1995) 813.
[13] M. Saad, A. Kassis, Sol. En. Mat. Sol. Cells 79 (2003) 507–517.
[14] G.J. Li, [Master's Thesis] Tianjin: Nankai university (2010) 55.
[15] F. Zhu, [Ph.D. Thesis], Tianjin: Nankai university (2006) 108-111.
[16] S. Guha and J. Yang, Subcontract Report NREL/SR-520-43191 May 2008.