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Fabrication of Si thin-film solar cells by hot-wire chemical vapor deposition and laser doping techniques

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1. Introduction

Thin-film polycrystalline silicon (poly-Si) solar cells are expected to become the major type of solar cells, since both the production cost and the amount of silicon material used can be reduced in comparison with bulk-type solar cells. In recent years, hot-wire chemical vapor deposition (HWCVD [1], also called catalytic chemical vapor deposition [2]) shows a promising technique to obtain device-quality poly-Si material at a high deposition rate. An n-i-p cell using poly-Si as i-layer has been investigated by many groups [3-6] and yields an efficiency more than 4 %.

In this study, the silicon thin films were prepared by HWCVD method. The amorphous silicon (a-Si), microcrystalline silicon (μc-Si) or poly-Si thin films have been prepared by HWCVD with silane diluted in various hydrogen gas flows on the Corning glass substrate [7]. All the doped layers are made by laser doping process [8]. We present a novel low-temperature process for fabricating a Si thin-film solar cell on a glass substrate.

2. Experimental details

The solar cell structure used in this study is composed of glass/ITO/n-type poly-Si/intrinsic Si/p-type poly-Si/Al. There are three kinds of intrinsic Si used in this structure; i.e. poly-Si, μc-Si and a-Si. First, a 100-nm-thick a-Si film was deposited by the HWCVD process. The deposition temperature was kept at about 250°C. Then the laser doping process was performed at room temperature. The laser-doping apparatus consists of an Nd-YAG laser operating at the wavelength of 355 nm. The laser doping process was carried out with the laser energy density of 180-220 mJ/ cm^2. Then the intrinsic Si films (~1.5 μm) were deposited on these laser annealed Si films by HWCVD process at a temperature less than 250°C. Typical HWCVD conditions for fabricating the above i-layers and their properties were listed in Table 1. Finally, an n-i-p junction was formed by the deposition of p-type μc-Si (also fabricated by laser doping technique). Using these conditions, a low temperature process for fabricating Si thin film solar cell can be obtained. The structural properties of the samples have been studied by Raman spectroscopy, transmission electron microscopy (TEM) and Hall measurements. Current density -voltage (J-V) measurements were taken under AM1.5 (100 mW/cm^2) white light from a dual beam solar simulator.

3. Results and discussion

Fig. 1 shows the Raman spectra of the Si films prepared under different growth parameters. As a result, the deposition condition was within the transition region from amorphous to polycrystalline phase. The crystalline volume fraction of the poly-Si, μc-Si and a-Si structures are 93, 73 and 12%, respectively. Fig. 2 shows cross-sectional TEM micrographs of intrinsic layer structured made at different HWCVD parameters. From this figure, it is clear that the structure of the absorbing layer depends heavily on the hydrogen dilution of the silane gas during deposition. At a dilution ratio H_2/SiH_4= 50, the absorbing layer shows fully polycrystalline, with a V shaped columns. In contrast to this, the absorbing layer made using a dilution ratio H_2/SiH_4= 10 becomes microcrystalline. The absorbing layer made using pure silane shows fully amorphous. There is a noticeable transformation in various hydrogen dilutions. The crystalline properties correlate well with the results observed by the Raman measurements.

Fig. 3 shows the current-voltage characteristics of the n-i-p solar cells with poly-Si, μc-Si and a-Si intrinsic layer (under AM1.5 illumination. Table 2 gives an overview of the performance of these solar cells. For these cells, the short-circuit current density is rather low. It may be due to that photo-/dark conductivity ratio is lower as compared with the device quality level [9]. The best solar cells were made with material deposited at the transition from the microcrystalline to the polycrystalline regime. This cell has a fill factor of 0.42, an open-circuit voltage of 0.52 V, a short-circuit current density of 8.79 mA/cm^2 and an initial efficiency of 1.9 %. To our surprise, the efficiency is obviously higher than that of the poly-Si cell (1.5 %). This difference could be mainly caused by the higher open-circuit voltage of the μc-Si solar cell. In order to further improve the efficiency of these solar cells, it is therefore necessary to incorporate a (textured) back reflector and to increase the photo-/dark conductivity ratio. The optimum conditions of HWCVD parameters and laser doping process are investigated on the way. Nevertheless, the results on the material properties and solar cells clearly indicate the large potential of hot-wire deposited μc-Si and laser doping method for future thin-film solar cell applications.

Table 1. Major deposition parameters and material properties of the intrinsic Si absorber layers

Parameter	poly-Si	μc-Si	a-Si
T wire (°C)	1700	1700	1700
T sub (°C)	250	250	250
Dilution ratio H_2/SiH_4	50	10	0
Pressure (Pa)	0.1	0.1	0.1
Deposition rate (nm/s)	0.5	0.8	1.4
Crystalline fraction (Xc)	93%	73%	12%
Band gap (eV)	1.12	1.23	1.66
Photo-/ dark conductivity ratio	15	26	96

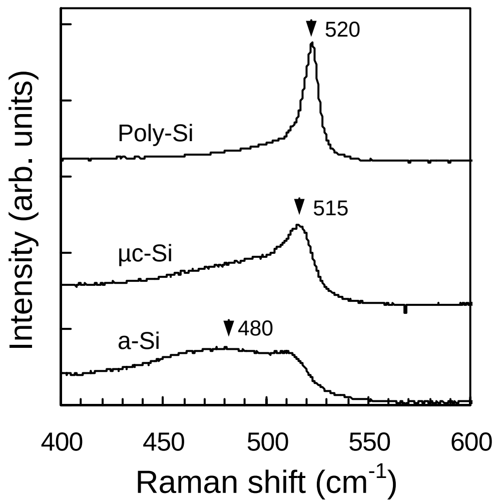

Fig. 1. Raman shift spectra of various Si films made using various deposition parameters.

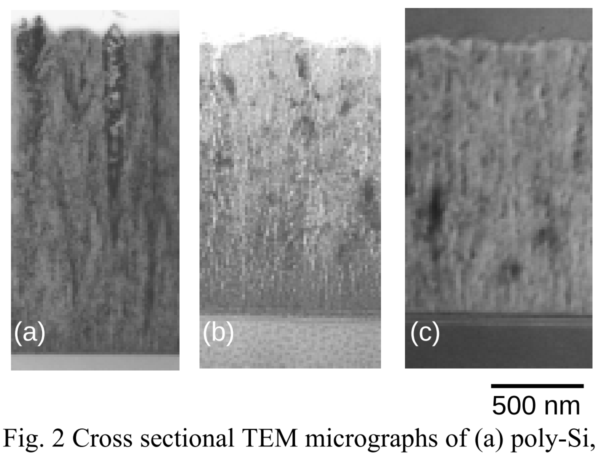

Fig. 2 Cross sectional TEM micrographs of (a) poly-Si, (b) μc-Si and (c) a-Si intrinsic layer structured made at different HWCVD parameters.

Table 2. Solar cell parameters obtained from various n-i-p type cells on ITO/glass substrates

#No.	i-layer	FF	V_{oc} (V)	J_{sc} (mA/cm^2)	η (%)
1	a-Si	0.42	0.41	7.17	1.23
2	μc-Si	0.42	0.52	8.79	1.92
3	poly-Si	0.5	0.44	6.86	1.5

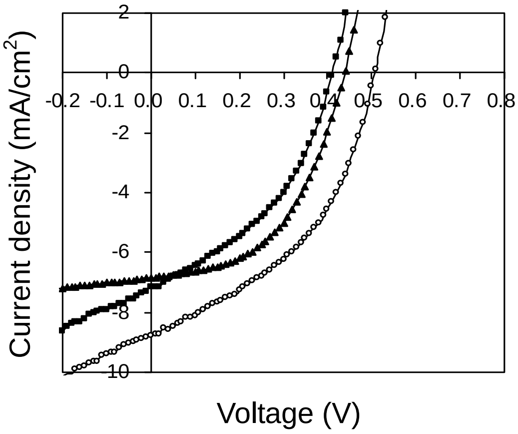

Fig. 3. J-V characteristics of n-i-p structured solar cells with poly-Si (▲), μc-Si (○) and a-Si (■) intrinsic layer.

4. Conclusions

A combination of the low-temperature (250°C) laser doping and HWCVD techniques was developed to fabricate Si thin-film solar cell on glass substrate. The material properties of the hot-wire deposited intrinsic silicon films are presented. The influence of the hydrogen dilution during deposition of silicon layer on the material and solar cell quality was investigated. Optimum material properties were found for material made close to the transition from the microcrystalline to the polycrystalline regime. An initial efficiency of 1.9% was obtained for an n-i-p structured solar cell on an untextured glass substrate, which shows a clear improvement, as compared to the best polycrystalline cell.

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References

[1] A. H. Mahan, J. Carapella, B. P. Nelson, R. S. Crandall, I. Balberg, J. Appl. Phys. 69 (1991) 6728.
[2] H. Matsumura, Jpn. J. Appl. Phys., 25 (1986) L949.
[3] Q. Wang, E. Iwaniczko, Y. Xu, W. Gao, B. P. Nelson, A. H. Mahan, R. S. Crandall, H. M. Branz, Mat. Res. Soc. Symp.
[4] A. Masuda, H. Matsumura, Thin Solid Films, 395 (2001) 112.
[5] R. E. I. Schropp, Thin Solid Films, 403 –404 (2002) 17.
[6] S. Klein, F. Finger, R. Carius, O. Kluth, A. L. B. Neto, H. Wagner, M. Stutzmann, Proc. the 17th ECPVEC, 2001, p.2965.
[7] D. S. Wuu, et. al, The 3rd Asian Conference on Chemical Vapor Deposition, Taipei, Taiwan, Nov. 12-14, 2004, No. A22.
[8] D. S. Wuu, S. Y. Lien, J. H. Wang, H. Y. Mao, I. C. Hsieh, B. R. Wu, and P. C. Yao, *Mater. Sci. Forum*, 475-479 (2005) 3791.
[9] R. I. E. Schropp, M. Zeman, Amorphous and microcrystalline silicon solar cell: modeling, materials and device technology, Kluwer Academic Publishers, Boston, 1998.