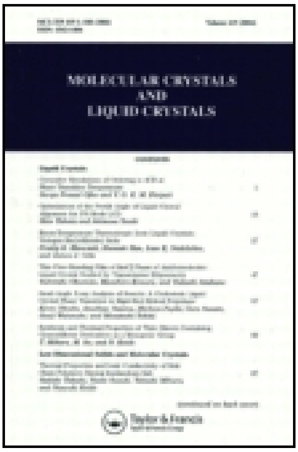

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Characteristics of Hydrogenated Amorphous Silicon Germanium Thin Film Solar Cells by GeH4 Flow Rate

Won-Ho Son [a], Ho-Joon Jung [a], Jin-Eui Kim [a] & Sie-Young Choi [a]
[a] School of Electronics Engineering, Kyungpook National University, 1370 Sankyuk-dong, Pook-gu Daegu, 702-701, Republic of Korea

Version of record first published: 18 Oct 2011

Mol. Cryst. Liq. Cryst., Vol. 551: pp. 242–248, 2011

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2011.601157

Characteristics of Hydrogenated Amorphous Silicon Germanium Thin Film Solar Cells by GeH4 Flow Rate

WON-HO SON, HO-JOON JUNG, JIN-EUI KIM, AND SIE-YOUNG CHOI*

School of Electronics Engineering, Kyungpook National University, 1370 Sankyuk-dong, Pook-gu Daegu, 702-701 Republic of Korea

Hydrogenated amorphous silicon germanium alloys thin films had been grown by PECVD method. This article shows characteristics of hydrogenated amorphous silicon germanium thin film solar cells with GeH_4 flow rates. The optical bandgap of hydrogenated amorphous silicon germanium alloy decreased from 1.78 eV - 1.54 eV with increasing in GeH_4 flow rate from 0 sccm – 100sccm. The various values of V_{oc}, J_{sc}, FF, and conversion efficiency were measured by the solar simulator. These results show that the conversion efficiency of the a-SiGe:H solar cells was very high when the GeH_4 flow rate was 60 sccm.

Keywords a-Si:H; a-SiGe:H; thin film; optical bandgap; solar cells; conversion efficiency

Introduction

Thin-film hydrogenated amorphous silicon (a-Si:H) based solar cells are promising candidates for low-cost photovoltaic energy generation. The main advantage of thin-film a-Si:H solar cells over their crystalline counterparts is the potential reduction in costs when produced in sufficiently large volumes [1]. An amorphous silicon based solar cell consists of three active layers in a p-i-n structure. The p-doped and n-doped layers cause an electrical field across the intrinsic absorber layer, which is sandwiched between the doped layers. Absorbed light in this layer results in the generation of electrons and holes, which is separated by the electric field. The electrons and holes are collected at the opposite contacts of the solar cell. The a-SiGe:H alloys were investigated as an optoelectronic material with a lower bandgap than the a-Si:H, which allows an increase of the utilization of the solar spectrum at a long wavelength and the stabilized efficiency of solar cells [2–4]. One of the attractive features of a-SiGe:H alloys is due to the possibility of changing in the optical properties of these material with composition to match the absorption to the solar spectra [5]. It was a possible to control the optical bandgab in a-SiGe:H alloys to lower energy by adding Ge to the composition of the alloys [6]. A lower bandgap increased the absorption to the solar spectra. so it expects a possible to improve the characteristics of a-SiGe:H solar cell with the enhanced optical absorption for longer wavelengths. In this paper, the p-i-n solar cells

*Corresponding author. E-mail: sychoi@ee.knu.ac.kr

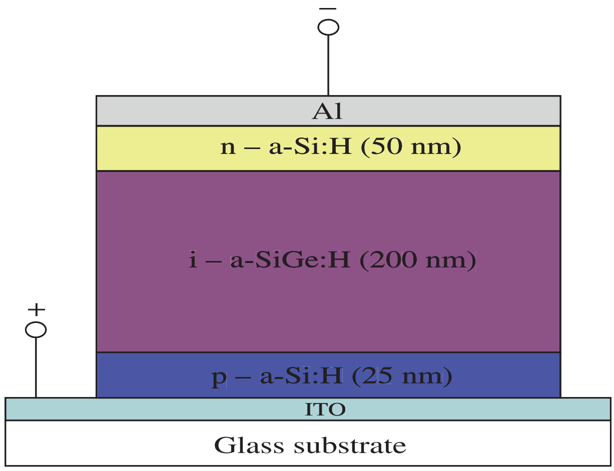

Figure 1. The structure of the p-i-n solar cell.

characteristics of the hydrogenated amorphous silicon germanium (a-SiGe:H) alloys were investigated with different GeH_4 flow rates in intrinsic layers by the PECVD method.

Experimental & Measurements

The hydrogenated amorphous silicon germanium thin film p-i-n solar cells have been deposited on ITO (indium tin oxide) glass by 13.56 MHz PECVD (plasma enhanced chemical vapor deposition) method at the substrate temperature of 250°C. The working pressure was 750 mTorr. The SiH_4 gas was used as a gas source and the doping process was done by gas admixture of B_2H_6 and PH_3 for p-layer and n-layer respectively. All of the solar cells that were fabricated on the top of glass, which was coated with an ITO based on the p-i-n structure as shown in Figure 1. The thicknesses of the p-layer and n-layer were fixed to 250 Å and 500 Å respectively. Table 1 shows the deposition conditions of the layers, also the intrinsic layer's deposition condition is shown by Table 2. The hydrogenated amorphous silicon germanium (a-SiGe:H) was deposited using a mixture of SiH_4 and GeH_4. The GeH_4 flow rates varied in the range of 0 – 100 sccm. The intrinsic layer's thickness was 2000 Å and the film's thickness was measured by an α-Step analysis. The optical properties of the

Table 1. Deposition Conditions of p-layer and n-layer

	p-a-Si:H	n-a-Si:H
Gas	SiH_4/B_2H_6	SiH_4/PH_3
Gas Flow rate (sccm)	100/30	100/20
RF power (W)	100	100
Substrate temperature (°C)	250	250
Reaction pressure (mTorr)	750	750
Thickness (nm)	25	50

Table 2. i-layer Deposition conditions of a-SiGe:H

Item	Conditions
Substrate temperature	250°C
RF power	150 Watt
RF frequency	13.56 MHz
Reaction pressure	750 mTorr
Gas flow rate:	
SiH_4	100 sccm
H_2	100 sccm
GeH_4	0–100 sccm

films were measured by UV-VIS Spectrometer analysis. The various values of V_{oc}, J_{sc}, FF, and conversion efficiency were measured by the solar simulator. Table 3 shows external parameters of the a-SiGe:H p-i-n solar cells in GeH_4 flow rate. The J-V characteristic and the QE (quantum efficiency) of this cells have been measured.

Results and Discussion

Figure 2 and Figure 3 show the transmittance spectra and optical bandgap for a series of a-SiGe:H thin films in different GeH_4 flow rate obtained by an UV-VIS Spectrometer. The UV-VIS Spectrometer analysis of a-SiGe:H alloys thin films shows that the bandgap absorption spectra of a-SiGe:H alloys shift to lower photon energy during the increase in the GeH_4 flow rate [0–100 sccm]. The optical bandgap decreased during the increase of the GeH_4 flow rate. The absorption coefficient and optical bandgap was calculated according to the equations (1) and (2).

$$\alpha = -(1/\mathrm{d}) \, \mathrm{In} \, \mathrm{T}(\lambda) \tag{1}$$

$$\alpha = \mathrm{A}(\mathrm{h}\upsilon - \mathrm{E}_{\mathrm{opt}})^{1/2}/\mathrm{h}\upsilon \tag{2}$$

where d and T (λ) denote the thickness of the film and transmittance as functions of the photon wavelength respectively. The optical bandgap (E_{opt}) was determined using the equation from $h\upsilon$ versus ($\alpha h\upsilon$), in which ($h\upsilon$) denotes the photon energy.

Table 3. External parameters of the a-SiGe:H p-i-n solar cells as a function in GeH_4 flow rate

	V_{oc} (V)	J_{sc} (mA/cm^2)	FF	η (%)
a – Si:H (0 sccm)	0.49	8.55	0.45	1.89
a – SiGe:H (20 sccm)	0.43	12.60	0.48	2.60
a – SiGe:H (40 sccm)	0.41	17.80	0.48	3.50
a – SiGe:H (60 sccm)	0.41	18.96	0.49	3.79
a – SiGe:H (80 sccm)	0.43	15.08	0.47	3.11
a – SiGe:H (100 sccm)	0.41	12.00	0.48	2.36

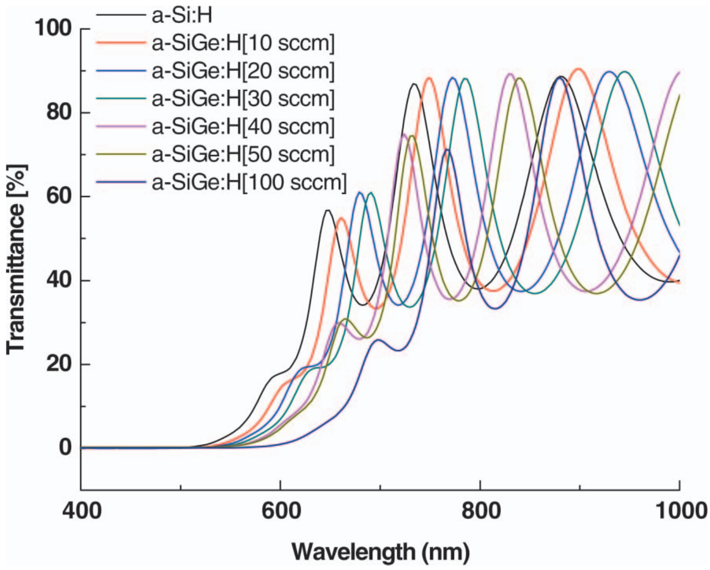

Figure 2. Transmittance spectra of the a-SiGe:H in GeH_4 flow rate.

Figure 4 shows the illuminated J-V characteristics of the solar cells with the GeH_4 flow rate [0–100 sccm]. The illuminated J-V characteristics were improved by increasing the GeH_4 flow rate [0–60 sccm]. However, the range of the GeH_4 flow rate [80–100 sccm] deteriorated the characteristics. The illuminated J-V graph plots the current density linearly against the applied voltage. This graph describes the photovoltaic behavior of the solar cells under standard illumination conditions, air-mass 1.5 (AM 1.5), and 300 K.

Figure 5 shows the External parameters of the a-SiGe:H p-i-n solar cells during the increase with the GeH_4 flow rate under AM 1.5 illumination. The V_{oc} was decreased slightly by decreasing the band gap. The J_{sc} increased from 8.55 mA/cm^2 – 18.96 mA/cm^2 with increasing in GeH_4 flow rate from 0 sccm – 60sccm but the range of the GeH_4 flow rate

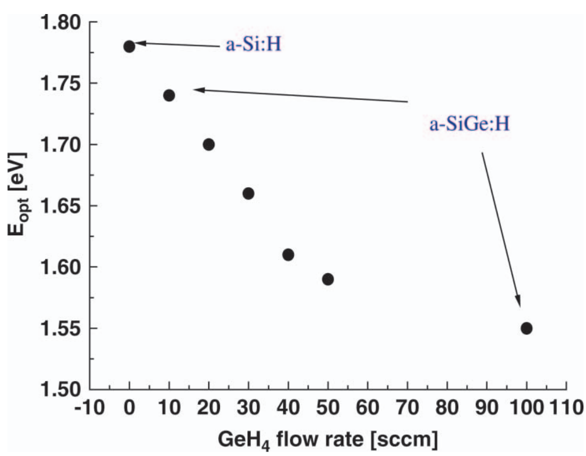

Figure 3. Optical bandgaps of the a-SiGe:H in GeH_4 flow rate.

[80–100 sccm] decreased the J_{sc} values. This is because many defects of a-Ge were located to trap the charge carriers. It reduces the mobility-lifetime products of both electron and holes. The main external parameters of the solar cell can be determined from this plot. The three parameters V_{oc}, J_{sc}, and FF are sufficient to calculate the energy–conversion efficiency (η) of the solar cell. It is defined by the ratio of maximum power that is extracted from the cell to the total illumination power. It is represented by the following equation (3),

$$\eta = (\mathrm{FF} \cdot V_{oc} \cdot I_{sc})/\Phi_{in} \tag{3}$$

where Φ_{in} is the total incident power of the photons. The J-V plot is a helpful tool to identify the influence of material properties and different parts on the solar-cell structure and its behavior and performance. The best performance of open-circuit voltage (V_{oc}), short-circuit density current (J_{sc}), fill factor (FF), and conversion efficiency (η) are of 0.41 V, 18.96 mA/cm^2, 0.49, and 3.79%, respectively at 60 sccm.

Figure 6 shows the quantum efficiency of the solar cells in GeH_4 flow rate. We found that a higher GeH_4 content enhanced the longer wavelength absorption. For a certain wavelength, when the band gap drops, the absorption increases. The EQE (External quantum efficiency) is defined as the ratio of collected charge carriers versus incoming photons at each wavelength. This ratio combines the absorption, the (internal) quantum efficiency, and the collection efficiency as shown in equation(4).

$$\mathrm{EQE}(\lambda) = \sum_{\mathrm{layer}} \mathrm{QE}_{\mathrm{OP}}(\lambda)\eta_g(\lambda)\mathrm{QE}_{\mathrm{el}}(\lambda) \tag{4}$$

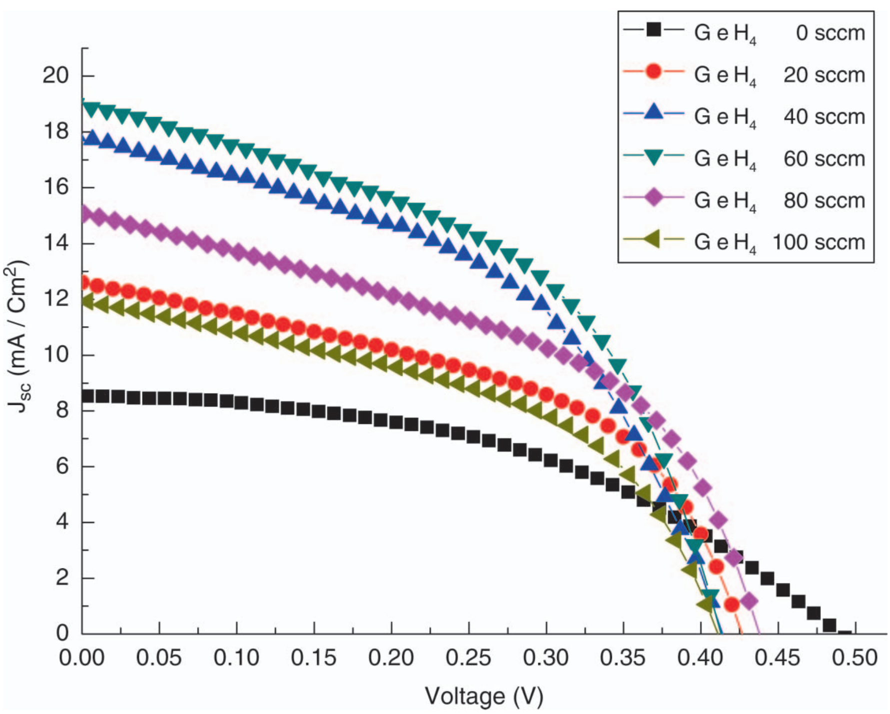

Figure 4. The illuminated J-V characteristics of fabricated a-SiGe:H p-i-n solar cells.

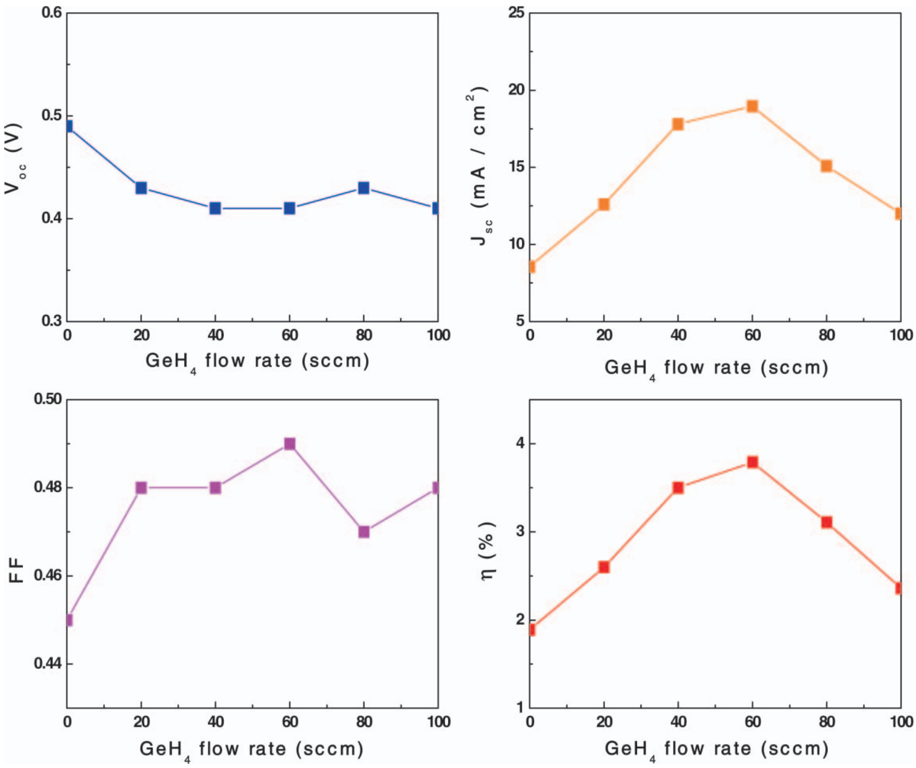

Figure 5. External parameters of the a-SiGe:H p-i-n solar cells as a function in GeH_4 flow rate.

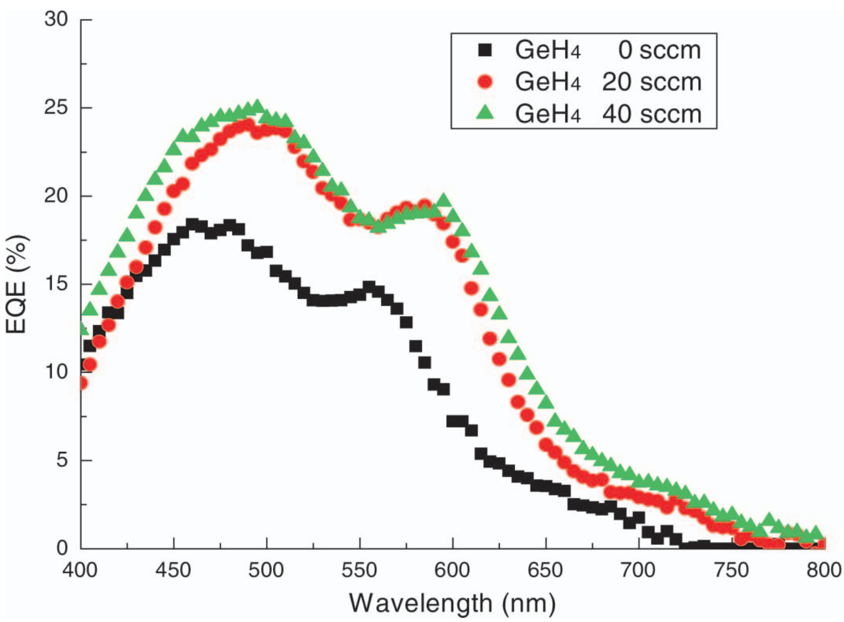

Figure 6. Quantum efficiency graph of the solar cells in GeH_4 flow rate.

Here, QE_{op} gives optical efficiency, i.e. the ratio of absorbed photons versus incoming photons. The η_g gives the number of generated charge carriers per incident photon, which is unity in the visible range of the spectrum. QE_{el} is the collection efficiency, i.e. the ratio of collected versus generated charge carriers. The quantum efficiency (QE) measurement is another useful diagnostic tool to characterize the performance of solar cell devices.

Conclusion

We have investigated the optical properties and the J-V characteristics of the a-SiGe:H solar cells deposited by the PECVD method. We confirmed that The optical bandgap of the a-SiGe:H film had decreased by increasing the GeH_4 flow rate. The illuminated J-V characteristics were improved by increasing the GeH_4 flow rate [0–60 sccm]. The reason is that J_{sc} is increasing because of optical absorption is raised up by decreasing band gap. However, the range of the GeH_4 flow rate [80–100 sccm] deteriorated the characteristics. It infers that collection probability of carriers went down due to the defect which has a lot of germanium alloy. This study also verified the best characteristics of the a-SiGe:H p-i-n solar cells as the values of V_{oc}, J_{sc}, FF, and η which 0.41 V, 18.96 mA/cm^2, 0.49 and 3.79% respectively. These results show that the conversion efficiency of the a-SiGe:H solar cells was higher than the GeH_4 flow rate at 0 sccm (V_{oc}, J_{sc}, FF, and η which 0.49 V, 8.55 mA/cm^2, 0.45, and 1.89%) when the GeH_4 flow rate was 60 sccm. The results of this study also found that higher GeH_4 content enhanced the longer wavelength absorption.

Acknowledgment

This work was supported by grant No. (R12-2002-055-01003-0) from the Basic Research Program of the Korea Science & Engineering Foundation and Kyungpook National University Research Fund 2010

References

[1] S. Hegedus. (2006). *Progress photovoltaics.*, **14**, 393–411.

[2] A. Terakawa, M. Shima, K. Sayama, H. Tarui, H. Nishiwaki, and S. Tsuda. (1995). *Jpn. J. Appl. Phys.*, **34**, 1741–1747.

[3] Q. Wang, E. Iwaniczko, J. Yang, and S. Guha. (2001). *The NCVP Program Review Meeting*, Colorado, 14–17.

[4] D. Dimova-Malinovska and L. Nedialkova. (1993). *Solar Energy Mat & Solar Cells*, **31**, 283–289.

[5] G. Nakamuwa, K. Sato, and Y. Yukimoto. (1982). *Proceedings of the 16th IEEE Photovoltaic Specialist's Conference*, 1331.

[6] P.Wickbolt. D. Pang, W. Paul. J.H. Chen. F. Zhong, C.-C. Chen, J. D. Cohen, and D.L. Willamson. (1997). *J. Appl. Phys.*, **81**, 6252.