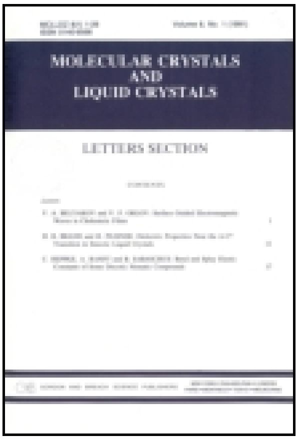

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Characteristics of Amorphous Silicon Thin-Film Solar Cells of a-Si:H/a-SiGe:H Superlattices in Different Thickness for Barrier and Well Layers

Won Ho Son [b] , Sang Kwon Lee [b] , Young Soon Moon [a] , Tae Yong Lee [b] & Sie Young Choi [b]

[a] Department of Sensor and Display Engineering , Kyungpook National University , Daegu , 702-701 , Korea

[b] Department of Electrical Engineering & Computer Science , Kyungpook National University , Daegu , 702-701 , Korea

Published online: 08 Jan 2014.

Mol. Cryst. Liq. Cryst., Vol. 586: pp. 61–68, 2013

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2013.851502

Characteristics of Amorphous Silicon Thin-Film Solar Cells of a-Si:H/a-SiGe:H Superlattices in Different Thickness for Barrier and Well Layers

WON HO SON,[2] SANG KWON LEE,[2] YOUNG SOON MOON,[1] TAE YONG LEE,[2] AND SIE YOUNG CHOI[2,*]

[1]Department of Sensor and Display Engineering, Kyungpook National University, Daegu, 702-701, Korea
[2]Department of Electrical Engineering & Computer Science, Kyungpook National University, Daegu, 702-701, Korea

Amorphous silicon (a-Si:H)/amorphous silicon-germanium (a-SiGe:H) superlattices were deposited by 13.56 MHz plasma enhanced chemical vapor deposition (PECVD) method using a mixture of SiH_4, GeH_4 and H_2. The superlattice materials consist of alternating layers of a-Si:H and a-SiGe:H. The a-Si:H layers were used as barrier material and a-SiGe:H layers were used as well material. It was found that the optical bandgap was controlled by changing the thickness of the barrier layer of a-Si:H (2–10 nm). Based on these results, fabricated the pin-type a-Si:H based solar cells of superlattice structures in different thickness for barrier and well layers. The various values of open-circuit voltage (V_{oc}), short-circuit current density (J_{sc}), and conversion efficiency were measured under 100 mW/cm^2 (AM 1.5) solar simulator irradiation. In the fabricated structure, we achieved a higher conversion efficiency ($\eta = 4.52\%$) than general a-Si:H solar cell ($\eta = 2.10\%$) and a-SiGe:H solar cell ($\eta = 3.06\%$).

Keywords amorphous silicon; amorphous silicon-germanium; superlattices; band-gap; pin-type solar cell

Introduction

Hydrogenated amorphous silicon (a-Si:H) based thin-film solar cells have the advantages of relatively low price, large area production (larger than 1 m^2), low temperature (<300°C) deposition and the possibility of growing on a variety of substrates (e.g. glass, metal and plastic). Alloys of a-Si:H, particularly with carbon or germanium, play an important role in the overall solar cell development picture. The purpose of alloying is to shift the optical absorption spectrum to higher or lower photon energies. By alloying with germanium the band gap of hydrogenated amorphous silicon-germanium (a-SiGe:H) can be varied from 1.0 eV to 1.7 eV by changing the composition [1,2]. Consequently, better optoelectronic properties in the longwave part of the spectrum than a-Si:H [3,4]. Like a-SiGe:H alloys, a-Si:H based superlattice [5–8] structures are also able to control optical and electrical properties. Lately, the concept of a-Si:H based bandgap engineering using superlattices and

*Address correspondence to Prof. Sie Young Choi Department of Electrical Engineering & Computer Science Kyungpook National University, Sangyuk-dong, Buk-gu, Daegu, 702-701, Korea (ROK). Tel: (+82)53-940-8618; Fax: (+82)53-950-6837. E-mail: sychoi@ee.knu.ac.kr

quantum dots has received considerable attention as an generic approach to further extend the range of materials available to realize solar cells with improved spectrum utilization [9].

In this work, each of a-Si:H and a-SiGe:H was selected as barrier material and well material for superlattice structures. The optical bandgap was controlled by changing the thickness of the barrier layer (1.57–1.65 eV). From these results, indicate that the a-Si:H/a-SiGe:H superlattices have a lower band gap than a-Si:H (1.78 eV) under the same deposition conditions. Having a lower bandgap is to absorb more widen wavelength range of sunlight, so it is useful to use as an absorber material in solar cell. Thus, we proposed pin-type a-Si:H solar cell of superlattice structures to improve the performance of a-Si:H based p-i-n solar cell. All films of amorphous materials were deposited by 13.56 MHz plasma enhanced chemical vapor deposition (PECVD) method. The optical properties of the films were measured with UV-VIS Spectrometer. The superlattice structure was confirmed by X-ray reflectivity (XRR) analysis. Each solar cell was measured with XEC-301S solar simulator under standard AM 1.5G conditions.

Experimental Details

A. a-Si:H/a-SiGe:H Superlattices

Superlattice samples were fabricated by alternating deposition of a-Si:H and a-SiGe:H layers. They were deposited on the Corning 1737 glass substrate by 13.56 MHz PECVD process in which the composition of the reactive gases was changed periodically in the reaction chamber without breaking the vacuum. The deposition conditions were: working pressure 500 mTorr, rf power 50 W for the a-Si:H/a-SiGe:H superlattice and substrate temperature in 250°C. More detailed information about the deposition conditions can be found in Table 1. Figure 1 shows the existence of well-defined layers for a-Si:H/a-SiGe:H superlattice by the X-ray reflectivity (XRR) measurement. Here, the total number of layers were 16 in superlattice of a-Si:H (2 nm)/a-SiGe:H (2 nm). Figure 2 shows the results of optical bandgap modulations (1.57–1.65 eV) of a-Si:H/a-SiGe:H superlattice in different thicknesses for a-Si:H layers. The a-SiGe:H layer thickness was held fixed at 2 nm, the

Table 1. Deposition conditions of pin-type a-Si:H thin-film solar cells with a-Si:H/a-SiGe:H superlattice

		Superlattices		
	p-a-Si:H	i-a-Si:H	i-a-SiGe:H	n-a-Si:H
Gas	SiH_4/B_2H_6	SiH_4/H_2	$SiH_4/H_2/GeH_4$	SiH_4/PH_3
Gas flow rate (sccm)	100/30	100/100	100/100/20	100/20
RF frequency (MHz)	13.56	13.56	13.56	13.56
RF power (W)	100	50	50	100
Reaction pressure (mTorr)	750	500	500	750
Substrate temperature (°C)	250	250	250	250
Thickness (nm)	30	2–10	2–10	60
		200		

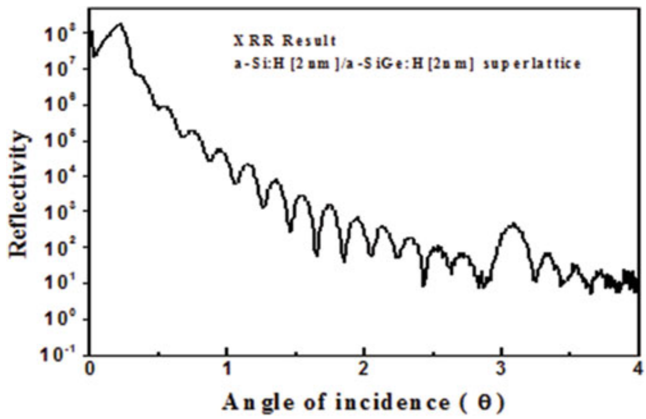

Figure 1. XRR analysis of thin film of a-Si:H (2 nm)/a-SiGe:H (2 nm) superlattice.

a-Si:H layer thickness was varied from 2–10 nm. Details information of the optical bandgap modulations have been given previously [10].

B. Pin-type a-Si:H Solar Cell with a-Si:H/a-SiGe:H Superlattices

The pin-type a-Si:H solar cells with a simple structure of glass/ITO (Indium Tin Oxide)/p-a-Si:H (30 nm)/i-amorphous semiconductor superlattices (200 nm)/n-a-Si:H (60 nm)/Al (200 nm) was fabricated. Figure 3 shows the schematic of pin-type a-Si:H solar cell with a-Si:H/a-SiGe:H superlattices. The deposition conditions were: working pressure 750 mTorr, rf power 100 W for the dopant layer, substrate temperature 250°C. 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.

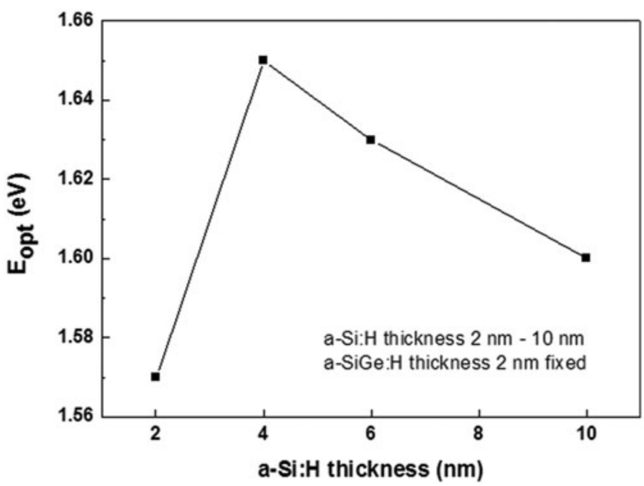

Figure 2. Optical bandgap of thin films of a-Si:H/a-SiGe:H superlattice in different thicknesses for a-Si:H layers as barrier material.

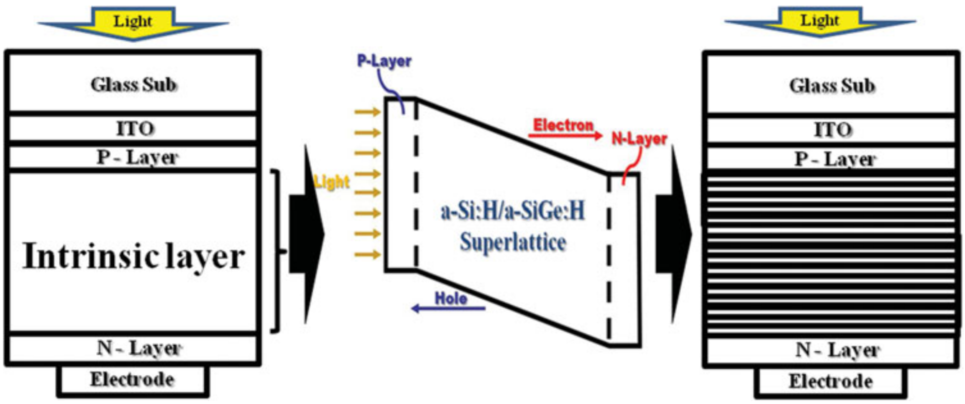

Figure 3. Schematic of pin-type a-Si:H solar cell with a-Si:H/a-SiGe:H superlattices.

Results and Discussion

A. Comparison of Solar Cell Performances in Different Thickness for a-Si:H and a-SiGe:H Layers

The performances on pin-type a-Si:H solar cells of a-Si:H/a-SiGe:H superlattices with a fixed a-SiGe:H thickness (2 nm) and a range of a-Si:H thickness varying from 2–10 nm was studied. The photocurrent density-voltage (J-V) characteristics of the cells are shown poor performance in Fig. 4(a). Thus, this technique was proven as not useful for improvement of cell performance. Figure 4(b) and Figure 5 show the J-V characteristics and the external parameters on pin-type solar cells of a-Si:H/a-SiGe:H superlattices in different thickness for the well layers of a-SiGe:H under AM 1.5 illumination. For the series of superlattices of the a-Si:H layer was kept constant while the a-SiGe:H layer thickness was varied from 2–10 nm, and total number of layers were diversified between 32 and 100. It is observed that the cell of a-Si:H (2 nm)/a-SiGe:H (6 nm) superlattices has the highest short-circuit current density of 22.01 mA/cm^2 and the highest conversion efficiency of 4.52%, respectively. From

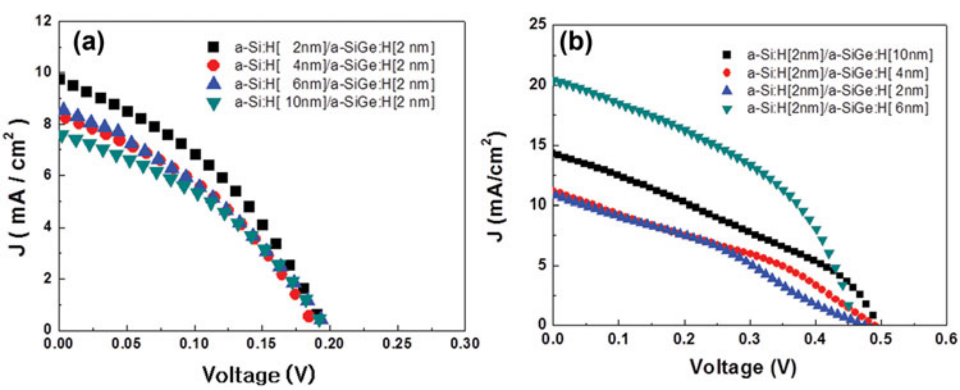

Figure 4. Photocurrent density-voltage (J-V) characteristics of pin-type a-Si:H solar cells with a-Si:H/a-SiGe:H superlattices in different thickness for (a) a-Si:H (2–10 nm) and (b) a-SiGe:H (2–10 nm) layers.

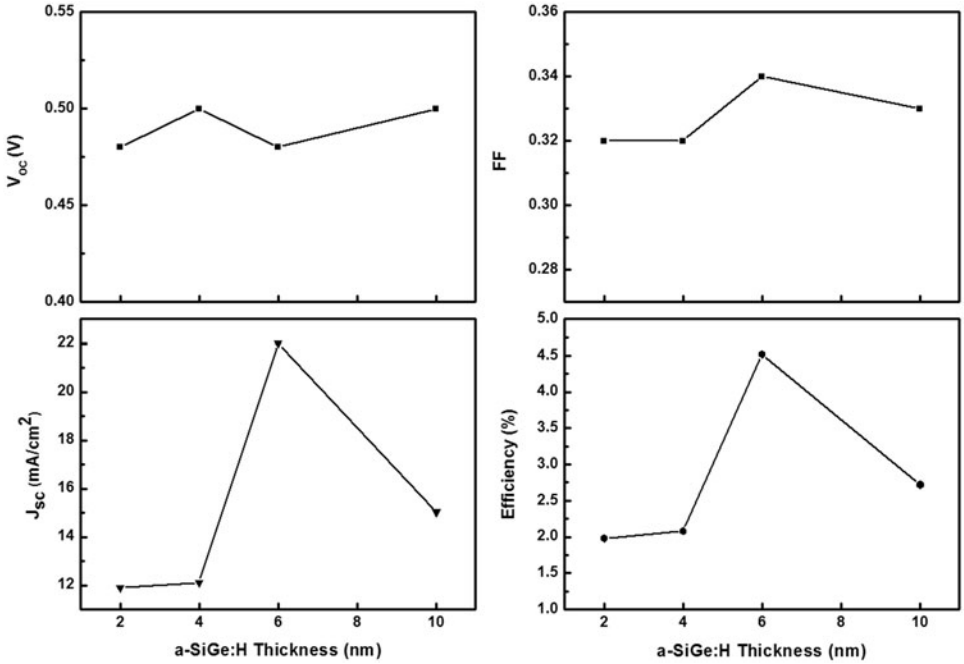

Figure 5. External parameters of pin-type a-Si:H solar cells with a-Si:H/a-SiGe:H superlattices in different thicknesses for a-SiGe:H layers as well material.

these results, we found that the performances on pin-type a-Si:H solar cells of superlattice structures depend on thickness of barrier and well layers with quantum size effects.

Figure 6 shows the absorptance spectra of a-Si:H/a-SiGe:H superlattices in different thickness for a-SiGe:H layers (2–10 nm) in the range of 400–800 nm. From the fig. 6,

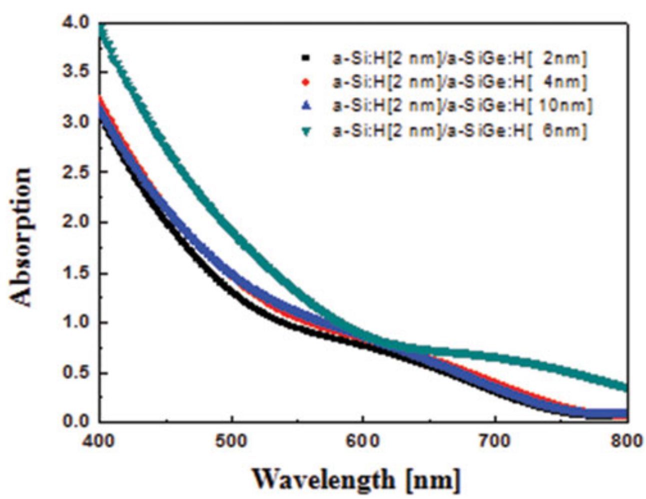

Figure 6. Absorption analysis of thin films of a-Si:H/a-SiGe:H superlattice in different thicknesses for a-SiGe:H layers as well material.

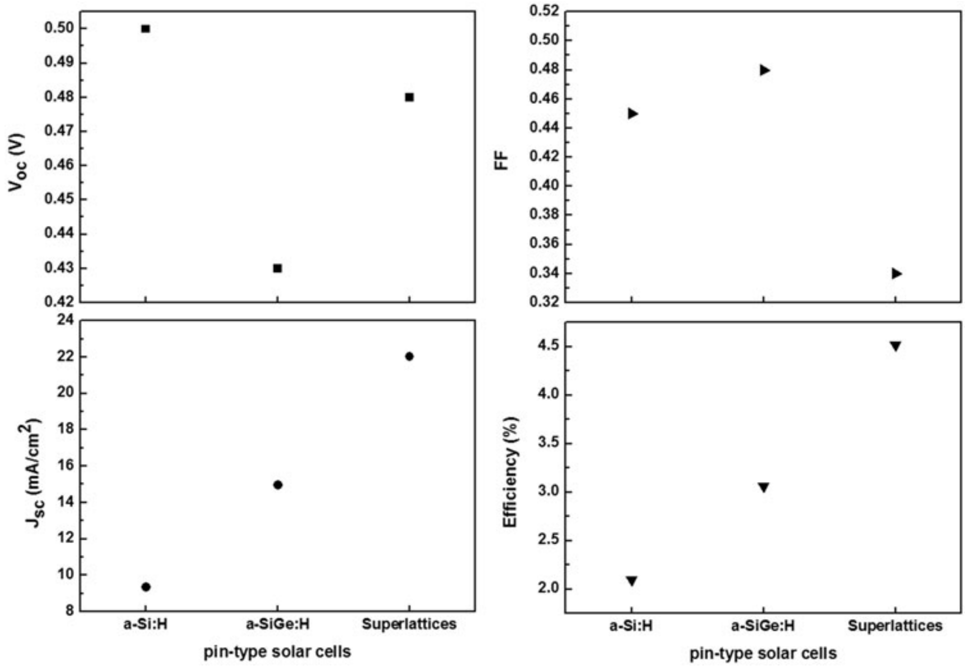

Figure 7. External parameters of pin-type a-Si:H solar cells with differently prepared i-layer.

demonstrated that the superlattice of a-Si:H (2 nm)/a-SiGe:H (6 nm) has a higher absorption in the visible range than others.

B. Comparison of Pin-type a-Si:H Based Solar Cells with Differently Prepared i-Layer

To confirm performance of fabricated solar cell, compared the characteristics of different structures cells with general pin-type a-Si:H solar cell, pin-type a-SiGe:H solar cell (constant 40 sccm flow rate of GeH_4, $E_G = 1.61$ eV) and pin-type a-Si:H/a-SiGe:H superlattices solar cell. Figure 7 shows the external parameters of pin-type a-Si:H based solar cells with differently prepared i-layer under AM 1.5 illumination. The conversion efficiency of the pin-type a-Si:H/a-SiGe:H superlattices solar cell has been improved to 4.52%. While, the solar cells of general pin-type a-Si:H and a-SiGe:H showed the conversion efficiency of 2.10% and 3.06%, respectively. The performance of the pin-type a-Si:H/a-SiGe:H superlattices solar cell is $V_{oc} = 0.48$ V, $J_{sc} = 22.01$ mA/cm^2 and FF = 0.34, respectively. Especially, it has improved the value of short-circuit current density which 31.5% better than pin-type solar cell of a-SiGe:H layer.

Figure 8 shows the external quantum efficiency (EQE) as function of the wavelength for various pin-type a-Si:H based solar cells with differently prepared i-layer. The external quantum efficiency was defined as the ratio of collected charge carriers versus incoming photons at each wavelength. The figure shows that the EQE curve of an pin-type a-Si:H/a-SiGe:H superlattices solar cell still has positive value until wavelengths of about 800 nm. On the other hand, the EQE curves of a-Si:H solar cell and a-SiGe:H solar cell are already low in the whole wavelength range. From the fig. 8, it is shown that solar cell performance can be improved by using an absorption layer of a-Si:H/a-SiGe:H superlattices.

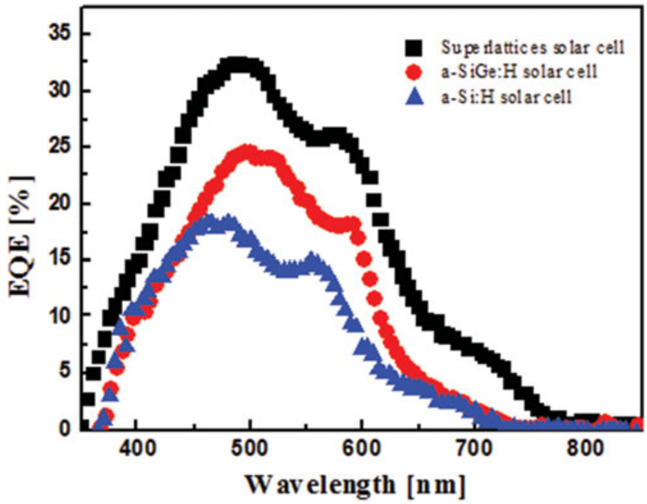

Figure 8. Comparison of external quantum efficiency graph with pin-type a-Si:H solar cells of different structures.

Conclusions

In this work, we deposited the a-Si:H/a-SiGe:H superlattices by PECVD method, and studied their optical properties using XRR and UV-VIS Spectrometer. Moreover it was found that the a-Si:H/a-SiGe:H superlattices have a lower optical bandgap (1.57–1.65 eV) than a-Si:H (1.78 eV). In addition to that is able to do the bandgap engineering on the a-Si:H/a-SiGe:H superlattices with different thickness. Based on these results, we fabricated the pin-type a-Si:H solar cells of superlattice structures in different thickness for a-Si:H layers (2–10 nm) and a-SiGe:H layers (2–10 nm). To confirm performance of fabricated solar cells with a-Si:H/a-SiGe:H superlattices, compared the characteristics of different structure cells, and observed that the solar cell of a-Si:H (2 nm)/a-SiGe:H (6 nm) superlattices has the highest conversion efficiency of 4.52% than general pin-type a-Si:H based solar cells. Further, the a-Si:H (2 nm)/a-SiGe:H (6 nm) superlattices solar cell has the highest short-circuit current density of 22.01 mA/cm^2 due to appropriate quantum size effects in the wells.

Acknowledgment

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education, Science and Technology(2012R1A1A2007685).

References

[1] Stutzmann, M., Street, R., Tsai, C., Boyce, J., & Ready, S., (1989). *J. Appl. Phys.*, *66*, 569.
[2] Son, W. H., Jung, H. J., Kim, J. E., & Choi, S. Y., (2011). *Mol. Cryst. Liq. Cryst.*, *551*, 242.
[3] Khamakava, Y. (Ed.): *in: Amorphous Semiconductors and Instruments Based on Them* [Russian translation], Metallurgiya, Moscow, 159, (1986).
[4] Najafov, B. A., Bakirov, M. Ya., & Mamedov, V. S., (1991). *Phys. Status Solidi (a)*, *123*, 67.
[5] Abeles, B., & Tiedje, T., (1983). *Phys. Rev. Lett.*, *51*, 2003.

[6] Hirose, M., & Miyazaki, S., (1984). *J. Non-Cryst. Solids.*, *66*, 327.
[7] Ibaraki, N., & Fritzsche, H., (1984). *Phys. Rev. B.*, *30*, 5791.
[8] Kakalios, J., Fritzsche, H., Ibaraki, N., & Ovshinsky, S. R., (1984). *J. Non-Cryst. Solids.*, *66*, 339.
[9] Conibeer, G., Green, M., Corkish, R., Cho, Y., Cho, E.-C., Jiang, C.-W., Fangsuwannarak, T., Pink, E., Huang, Y., Puzzer, T., Trupke, T., Richards, B., & Shalav, A., (2006). *K.-l. Lin, Thin Solid Films.*, *511–512*, 654–662.
[10] Kim, J. E., Shin, J. W., Son, W. H., & Choi, S. Y., (2010). *Cryst. Liq. Cryst.*, *532*, 15.