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레이저 가공에 의한 비정질 실리콘 박막 태양전지 모듈 제조

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Laser patterning process for a-Si:H single junction module fabrication

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Key words : a-Si:H solar cell(비정질 실리콘 태양전지), laser patterning(레이저 가공), module integration(모듈 제조)

Abstract : Recently, we have developed *p*-i-*n* a-Si:H single junction thin film solar cells with RF (13.56MHz) plasma enhanced chemical vapor deposition (PECVD) systems, and also successfully fabricated the mini-modules (>300cm^2), using the laser patterning technique to form an integrated series connection. The efficiency of a mini-module was 7.4% (Area=305cm^2, Isc=0.25A, Voc=14.74V, FF=62%). To fabricate large area modules, it is important to optimise the integrated series connection, without damaging the cell. We have newly installed the laser patterning equipment that consists of two different lasers, SHG-YVO_4 (λ=0.532μm) and YAG (λ=1.064μm). The mini-modules are formed through several scribed lines such as pattern-1 (front TCO), pattern-2 (PV layers) and pattern-3 (BR/back contact). However, in the case of pattern-3, a high-energy part of laser shot damaged the textured surface of the front TCO, so that the resistance between the each cells decreases due to an incomplete isolation. In this study, the re-deposition of SnOx from the front TCO, Zn (BR layer) and Al (back contact) on the sidewalls of pattern-3 scribed lines was observed. Moreover, re-crystallization of a-Si:H layers due to thermal damage by laser patterning was evaluated. These cause an increase of a leakage current, result in a low efficiency of module. To optimize a-Si:H single junction thin film modules, a laser beam profile was changed, and its effect on isolation of scribed lines is discussed in this paper.

1. a-Si:H-based thin film solar cells

Hydrogenated amorphous Si (a-Si:H)-based thin film solar cells have been considered as one of the most promising thin film solar cells, and expected to reduce the PV cost [1]. We have recently developed a-Si:H single junction solar cells by newly installed RF(13.56MHz) or VHF(40.68MHz) plasma enhanced chemical vapor deposition (PECVD) systems, and obtained successfully the conversion efficiency of 9.9% (A=0.09cm^2). Moreover, we have developed large area thin film solar cell mini-modules (>300cm^2) as seen in Fig. 1, with the first step for the mass production, and optimised the integrated series connection to fabricate large area modules by using laser patterning method. The electrical series connection of multiple solar cells by laser patterning is a key issue for large area a-Si:H single junction or a-Si:H/µc-Si tandem modules[2,3]. However, very little work has been reported on laser patterning, although its great sensitivity to the PV property of module.

In present talk, we report the fabrication of *p*-SiC/i-Si/*n*-Si a-Si:H single junction thin film modules by laser patterning, and discuss the optimisation of laser patterning process.

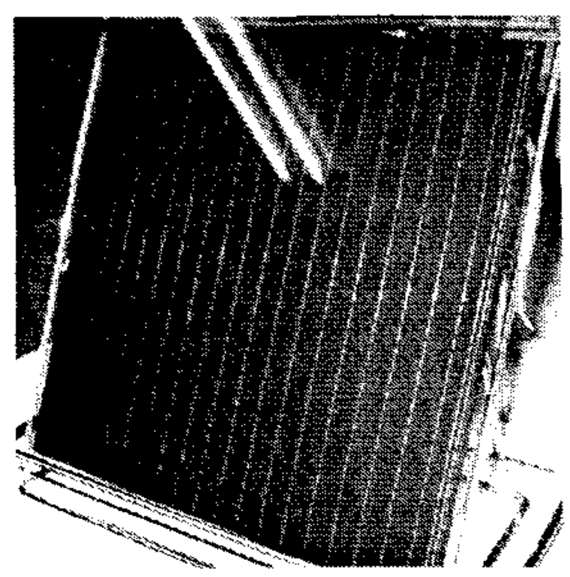

Fig. 1 Large area a-Si:H single junction mini-module fabricated by us

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2. Fabrication of a-Si:H single junction mini-modules

p-i-n a-Si:H single junction thin film solar cells were deposited by 13.56MHz RF-PECVD systems on glass/TCO (SnO_2:F) substrates at 200°C temperature. The back reflector (BR) layer (ZnO, T=200nm) and back contact (Al=300nm) were deposited by sputtering method, respectively. In order to fabricate the mini-modules, two different lasers, SHG-YVO_4 (λ=0.532μm, Q-switch= 10~30㎑) and yttrium-aluminium-garnet (YAG, λ=1.064μm, Q-switch=0.1~ 100㎑), were used. The cross sectional Field Emission-Scanning Electron Microscope (FE-SEM) image of scribed portion by the laser beam, and optical micrograph of scribed lines for TCO layer, PV layer and Metal are shown in Fig. 2 (a) and (b), respectively. Here, all of scribed lines were formed by the laser beam through the transparent glass substrate. a-Si:H single junction mini-modules were fabricated as follows,

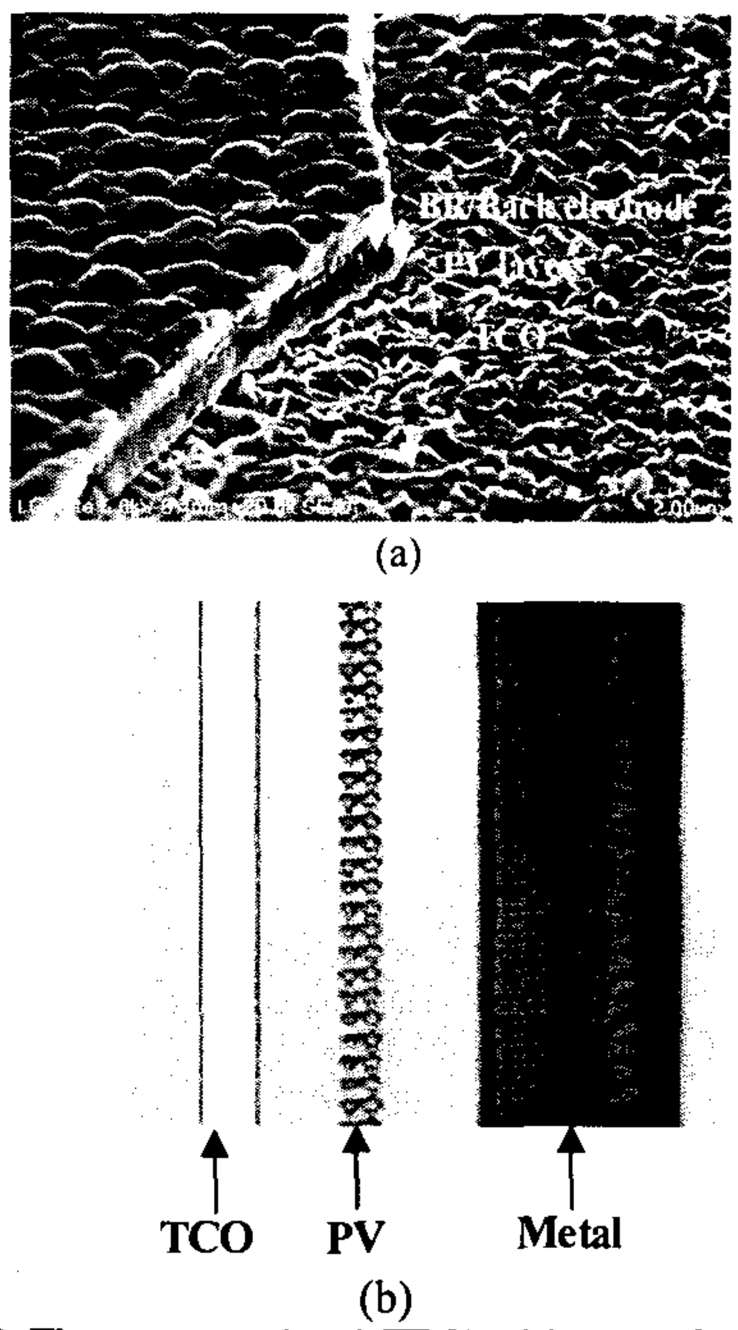


Fig. 2 The cross sectional FE-SEM image of scribed portion by the laser beam (a) and schematic illustration of scribed lines induced by the laser beam in a-Si:H thin film mini-module (b)

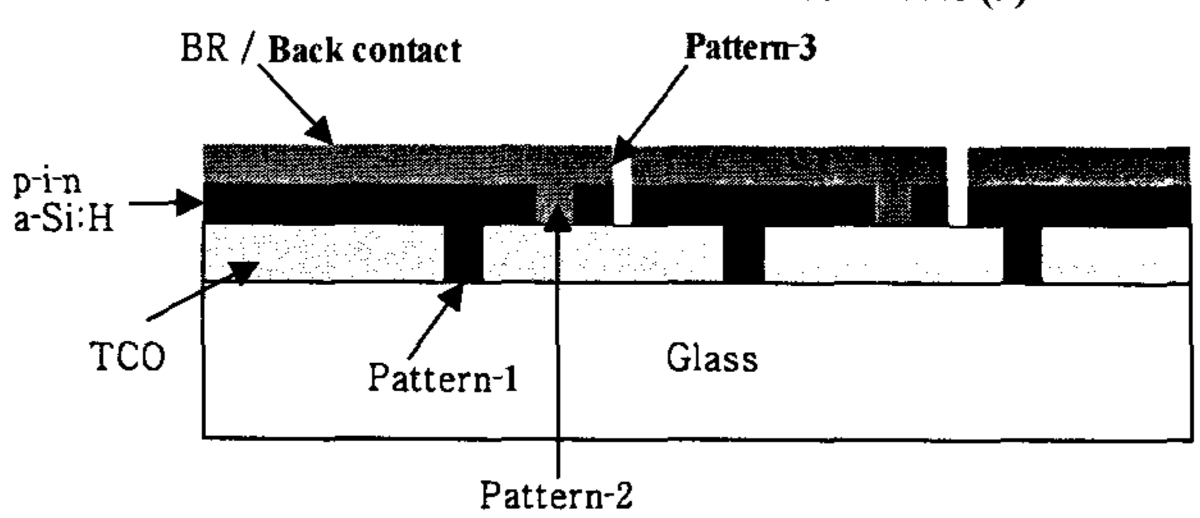


Fig. 3 The cross sectional structure of a-Si:H single junction thin film mini-module

the front TCO of pattern-1 was removed by SHG-YVO_4 laser of 0.532μm wavelength to isolate electrically the different segments of TCO, as the first step. In the next step, the pattern-2 and -3 were carried out in order with the same laser to make the series connection, as seen in Fig. 3. Here, the frequency used to scribe TCO layer (pattern-1), PV layer (pattern-2) and PV/BR/back electrode (pattern-3) were 20㎑, 15㎑ and 10㎑, respectively. The pulse width of the laser beam was about 40ns. The scribe line width of pattern-1, -2 and -3 were changed in the range of 30~50μm, 50~70μm and 50~100μm, to obtain the best performance in the mini-module, respectively.

On the other hand, the trimming process to form an outside isolation was carried out with YAG laser of 1.064μm wavelength.

3. Results and discussions

3.1 Re-deposition of front TCO by laser patterning

In this study, for the pattern-1 (front TCO), the scribed lines were isolated sufficiently with the result of resistance (> 30MΩ), and the pattern-2 was also isolated well. However, in the case of pattern-3, a high-energy part of laser shot damaged the textured surface of the front TCO, and consequently the re-deposition of SnOx on the sidewalls of pattern-3 scribe lines occurred. Here, a laser beam profile corresponds to a shape of Gaussian. Figure 4 shows a residual SnOx on the sidewall of scribed line at sample No. 138(~1 kΩ) observed by Field Emission-Auger Electron Spectroscopy (FE-AES) (a). Moreover, Zn (BR layer) and Al (back contact) elements also observed. These results imply that an incomplete isolation causes an increase of leakage current entirely, results in a low efficiency of module.

To improve an isolation resistance in metal-scribed lines (pattern-3), we have changed a laser beam profile at various conditions of laser patterning. As seen in Fig. 4(b), a residual SnOx, Al and Zn decreased at sample No.157 (> 400kΩ), where a laser beam profile is like a shape of flat beam (Fig. 4(b) inset). In conclusion, a laser beam profile affects significantly the re-deposition of front TCO, BR and back contact, so that it should be controlled to optimize the electrical series connection of multiple solar cells by laser patterning.

Figure 5 (a) and (b) show the surface morphology of TCO at sample No. 138 and No. 157 after laser patterning (pattern-3), respectively. At sample No. 138, morphology of the melted SnO_2 layer was observed, and this result is consistent with that in Fig. 4(a). On the other hand, more clear surface of TCO was observed at sample No. 157, and this result implies a low re-deposition of SnO_2 layer after laser patterning (pattern-3).

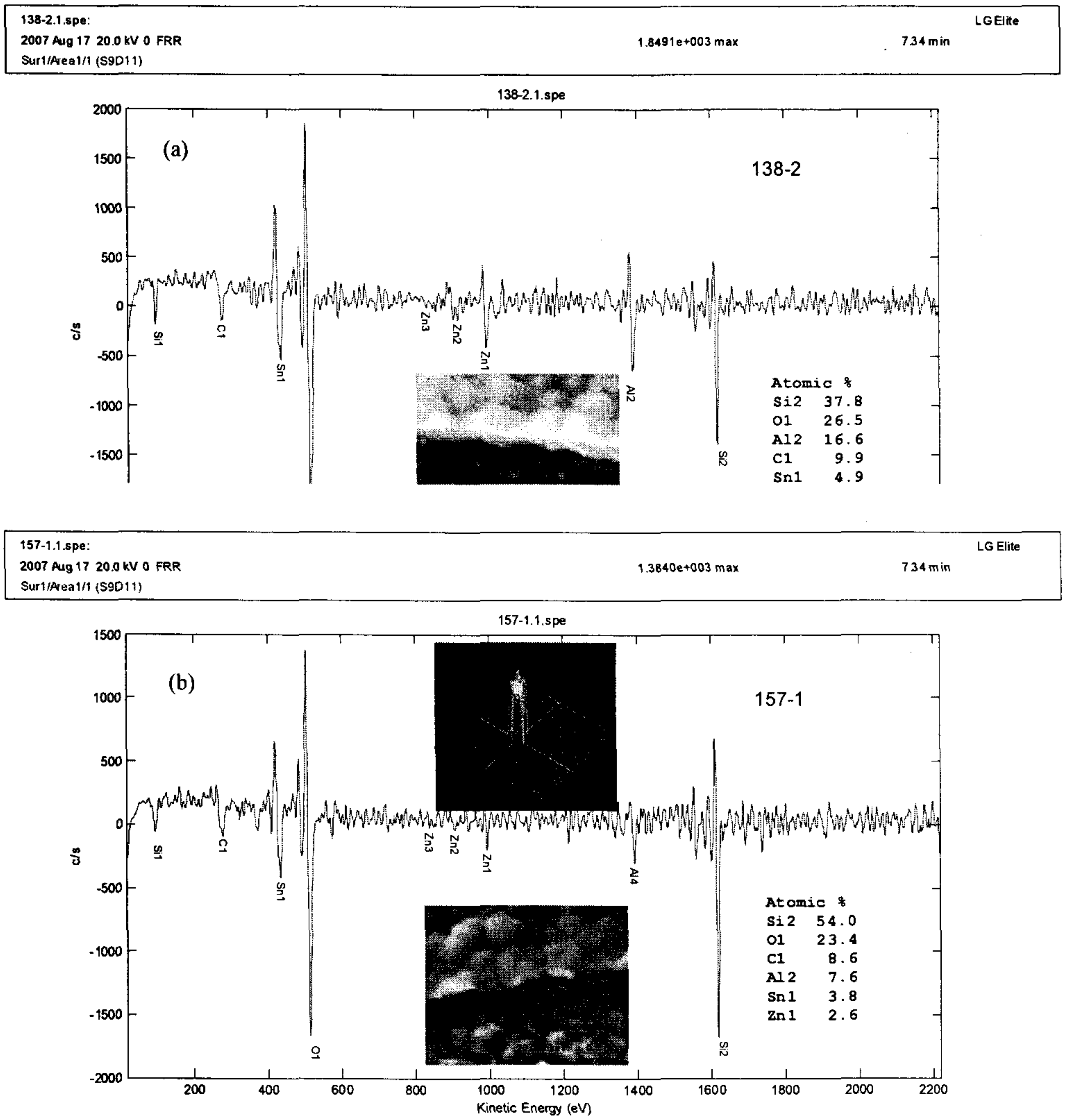
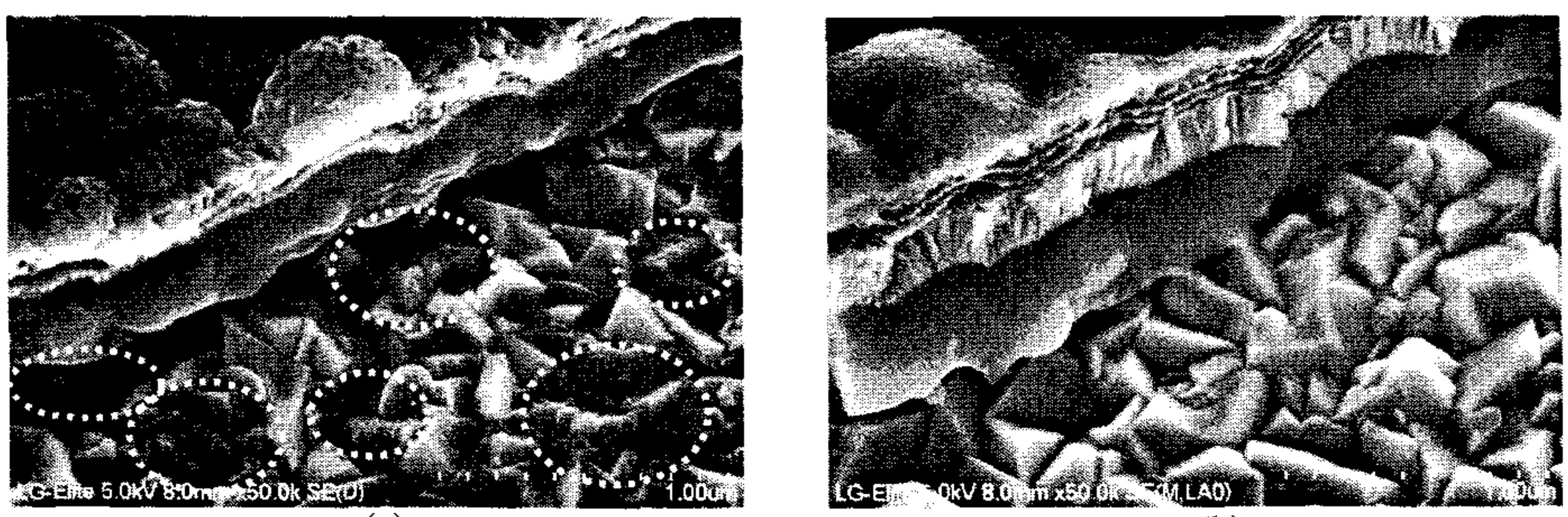


Fig. 4 Observation of a residual SnOx, Al and Zn on the sidewall of pattern-3 at sample No. 138(~1 kΩ) (a) and No.157 (> 400kΩ) (b) observed by Field Emission-Auger Electron Spectroscopy (FE-AES). (Inset : a beam profile)



(a) (b)

Fig. 5 FE-SEM image of the surface morphology of TCO at sample No. 138(~1 kΩ) (a) and No. 157 (> 400kΩ) (b) after laser patterning (pattern-3)

3.2 Re-crystallization of a-Si:H by laser patterning

As another reason for a low resistance value at isolated patterns of a-Si:H thin film module, the micro-structure change of a-Si:H layers due to thermal damage induced by laser patterning have been studied. Figure 6 shows the Raman spectrum of around scribed portion of pattern-3 at sample No. 138. The signal around the Raman shift at 520cm^{-1}, which corresponds to that of μc-Si:H, were observed. This is due to the H_2 decomposition from a heat remained around the removed portion by laser patterning, so that a-Si:H is changed to μc-Si:H. The mechanism of the pattern-3 is that (1) the laser beam is absorbed, (2) the decomposition of H_2 occurs, and (3) the PV layers are removed mechanically. In conclusion, a heat affected zone induces a high leakage current path at a poor isolation, resulting in a poor performance of a-Si:H thin film module. It is a key issue how to reduce thermal damage during the laser patterning process to fabricate a-Si:H thin film module. On the other hand, the signal around the Raman shift at 480cm^{-1}, which corresponds to that of a-Si:H, was observed at sample No. 157. It is thought to be due to a low thermal distribution by using a flat beam profile during laser patterning, result in a low leakage current path.

3.3 Optimization of a-Si:H single junction mini-module

Recently, we have successfully fabricated p-SiC/ i-Si/n-Si a-Si:H single junction thin film mini-module through the understanding of the optics of laser patterning equipment and the beam profile under the laser patterning conditions to avoid an incomplete isolation. The efficiencies of a mini-module developed by us were 7.4% (A=305cm^2, *Isc*=0.25A, *Voc*= 14.74V, FF=62%) measured with solar simulator under AM1.5G conditions, as seen Fig. 7. Here, the width of each cell is 9.75mm.

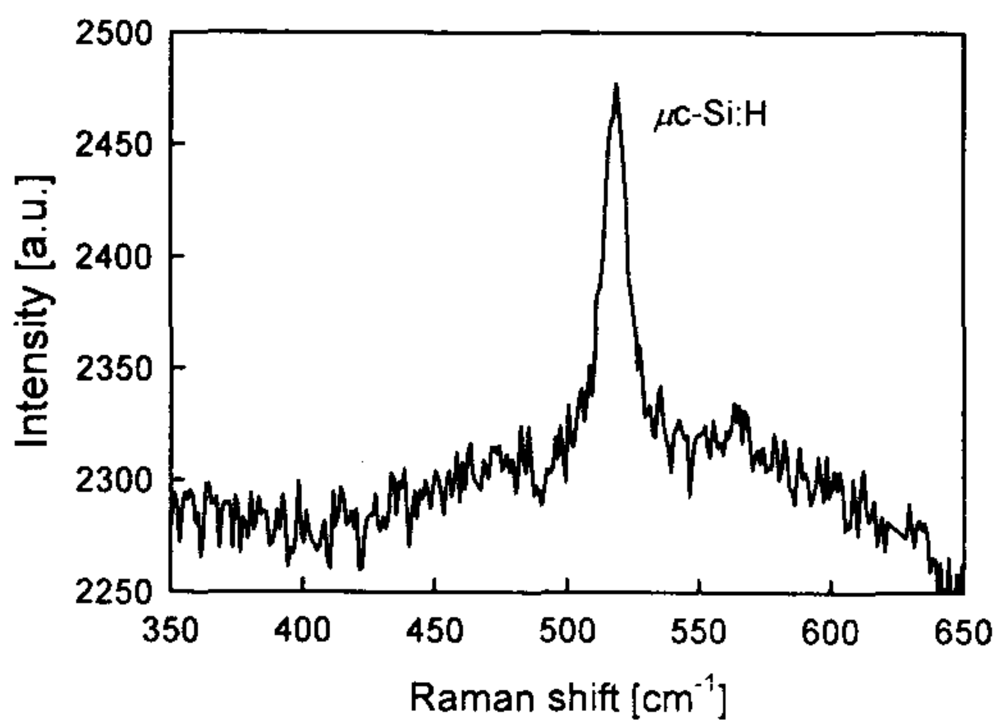


Fig. 6 Raman spectrum of around scribed portion of pattern-3 at sample No. 138 by laser patterning

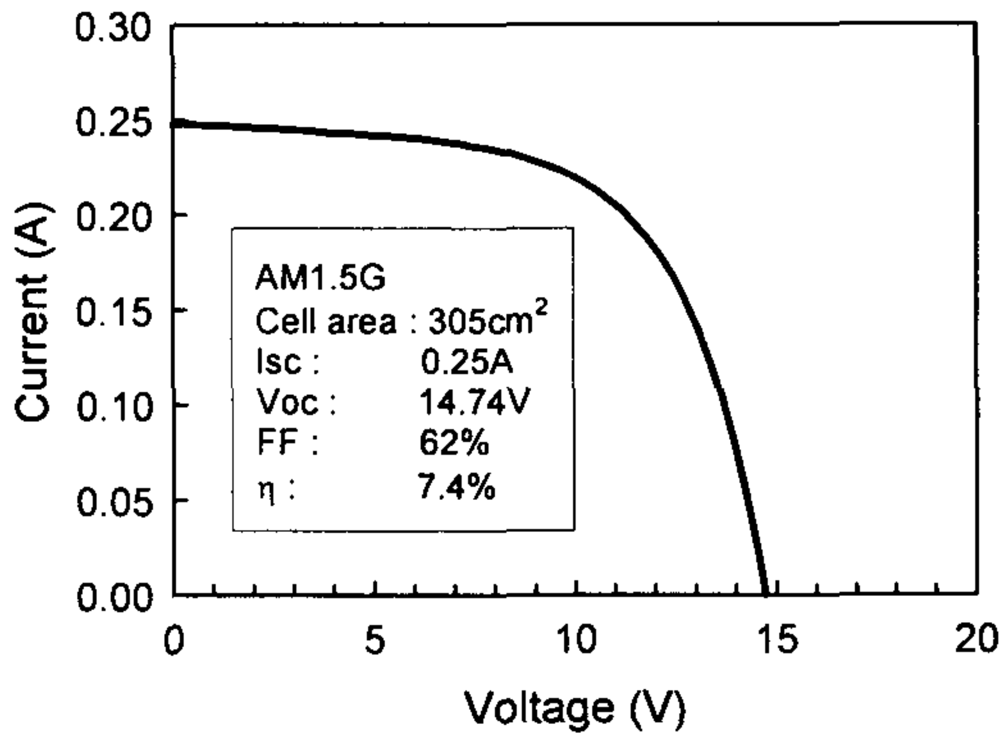


Fig. 7 I-V curve of a-Si:H single junction thin film mini-module measured with solar simulator under AM1.5G conditions

4. Conclusions

The laser patterning process to optimize hydrogenated a-Si single junction thin film modules is presented. The mini-modules are formed by an electrical series connection of multiple solar cells by using laser patterning such as pattern-1 (front TCO), pattern-2 (PV layer) and pattern-3 (BR/back contact). In the pattern-1 (front TCO), the scribe lines were isolated sufficiently with the result of resistance (> 30MΩ), and the pattern-2 was also isolated well. However, in the case of pattern-3, the re-deposition of SnOx, Zn and Al was observed with the result of resistance (~1 kΩ). Moreover, re-crystallization of a-Si:H layers due to a heat remained around the removed portion by laser patterning was observed with Raman spectrum. These induce a high leakage current, resulting in a poor performance of a-Si:H thin film module. To optimize a-Si:H single junction thin film modules, we have changed a laser beam profile at various conditions of laser patterning. A low re-deposition of SnOx, Zn, Al and re-crystallization of a-Si:H layers were obtained through a flat beam profile of laser.

As a result, the efficiency of a mini-module was recently obtained 7.4% (Area=305cm^2, *Isc*=0.25A , *Voc*= 14.74V, FF=62%). However, more study for laser patterning process to optimize the performance of a-Si:H or a-Si:H/μc-Si thin film modules is necessary.

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