Crystallization of Amorphous Silicon Films by Field-Aided Lateral Crystallization (FALC) technique at 350°C

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Abstract

The crystallization of amorphous silicon (a-Si) was achieved using a field aided lateral crystallization (FALC) process at 350 ℃. Under the influence of an electric field, Cu is found to drastically enhance the lateral crystallization velocity of a-Si. When an electric field was applied to the selectively Cu-deposited a-Si film during the heat treatment at temperature as low as 350 ℃, dendrite-shaped crystallization of a-Si progressed toward Cu-free region and the crystallization from negative electrode side toward positive electrode side was accelerated. We identified that 1000 Å thick a-Si film was completely crystallized by Cu-FALC process at 350 ℃ by TEM analysis.

1. Introduction

In the fabrication of polycrystalline silicon thin-film transistors (poly-Si TFTs), the major technological issue has been the growth of good quality of poly-Si thin film below 500℃ for being compatible with cheaper commercial glass substrate. Up to now, a number of low temperature poly-Si formation techniques have been suggested. A crystallization method that uses the effect of metal impurities on the low temperature crystallization of amorphous silicon (a-Si) has been studied extensively [1-3]. However, it takes a relatively long time to crystallize the a-Si since thermal diffusion process governs the crystallization velocity in the process. Also, for the crystallization in this method metal impurities can remain at the center of the transistor channel region.

Previously, we reported the effect of an electric field on the crystallization of a-Si films during thermal annealing. In such an attractive technology called field aided lateral crystallization (FALC), the enhanced crystallization is possible and, thus, the crystallization time can be shortened, together with the minimization of metal contaminant in the active area of the transistors. In addition, the applied field can induce the directional crystal growth, which is advantageous in fabrication of devices in terms of mobility [4, 5]. Also, we have applied Cu to the FALC process and as a result, Cu was found to induce the lateral crystallization at lower temperatures (<500℃) under the influence of the electric field. Furthermore, the velocity of Cu-FALC was faster than that of Ni-FALC [5].

In this study, we attempted to lower the crystallization temperature of a-Si films down to 350℃ and observe the microstructure of the crystallized Si films by using Cu-FALC process.

2. Experimental Procedure

Amorphous silicon film with a thickness of 1000 Å was deposited by plasma enhanced chemical vapor deposition (PECVD) on Corning 1737 glass substrate at 280℃ using disilane (Si_2H_6) as a source gas, which was followed by a sputter deposition of 1000Å silicon dioxide at room temperature. Windows were opened in the oxide using a patterned mask. 20Å thick Cu film was deposited on top of the patterned a-Si film by sputtering and the Cu on the oxide was removed using buffered HF. An electric field was applied to the specimen by a DC power supply through the electrodes formed at two opposite sides of the substrates during thermal annealing. The annealing was carried out in N_2 ambient at 350℃. The ramp-up rate to the annealing temperature was set to 5℃/min and annealing time varied from 2h to 15h at 350℃. The applied electric field was maintained in an electric field of 30V/cm for all specimens. The degree of crystallization was estimated by the relative peak intensity from micro-Raman spectroscopy. Also, the crystallization behavior and the microstructure of the crystallized area after the annealing were examined by Nomarski optical microscopy, scanning electron microscopy (SEM) and transmission electron microscopy (TEM).

3. Results and Discussion

Fig. 1 shows the Nomarski optical micrograph of partially crystallized a-Si using Cu in the presence of electric field of 30V/cm at 350℃. From Fig. 1, we observed that dendrite-shaped branches were formed at various annealing conditions. FALC-processed Si films reveal that the anisotropic nature in crystallization depends on the polarity of the electric field. Figs. 1(a) ~ 1(d) show dendrite-shaped branches growing from negative electrode side to positive electrode side. Russell *et al.* reported that the crystallization of a-Si/Cu films occurs above 485℃ in the form of dendrites with a fractal dimension [6].

Fig. 1(a) reveals that the dendrite-shaped branches can be formed for even 2hr annealing at 350℃. It is interesting to notice that the dendrites were formed at much lower temperature than the reported temperature under the influence of electric field during crystallization. The dendrite-shaped crystallization of a-Si occurred not only in the Cu deposited region outside of the pattern but also in the Cu-free region inside of the pattern during the heat treatment with an aid of electric field. Figs. 1(b) ~ 1(d) show the partially crystallized a-Si film annealed for a longer period at the identical temperature. From these Figures, we can understand how the dendrite branches grow and become thicker as the crystallization progresses. As shown in Fig. 1(e) the completion of overlapping of each dendrite-shaped branch enabled to fully crystallize a-Si, inside of 30㎛ pattern for 15h annealing.

From these results, it is judged that the applied electric field can play a significant role in enhancing the migration of Cu ion, which is thought as a crucial diffusion species for the FALC. Under the influence of an electric field, the local electric field can be built up in silicide mediator (Cu silicide in this case) because the electrons in the silicide are readily pulled to the interface between Cu silicide and a-Si by the electric field. Then the positively charged metal ions left behind could migrate faster due to the attractive force by electrons, and they react with a-Si to form a silicide leaving crystalline silicon (c-Si) behind [5, 7]. Hence, the interface of silicide/a-Si proceeds into the uncrystallized a-Si region. As a result, the lateral crystallization by FALC process happens much faster than that by other processes, which are dependent solely on the thermal diffusion.

In order to investigate the degree of crystallization of poly-Si crystallized by Cu-FALC, Raman beam was focused on the inside of the pattern as shown Fig. 1. It is known that single c-Si has a sharp peak around 521cm^{-1} and a-Si has a broad peak around 480cm^{-1} in Raman spectra. Fig. 2 represents the Raman peak intensity of Cu-FALC processed film at various experimental conditions. Although the intensity of Raman spectra measured from the crystallized region by Cu-FALC does not reach the intensity of c-Si but it shows the obvious evidence of crystallization. Also, the enhanced Raman spectra intensity depended on the annealing time. The characteristic peak of c-Si was observed in all regions where the dendrite-shaped branches formed. However, the characteristic peak of c-Si was not detected at positive electrode side of Fig. 1(a) where the dendrite shaped branches were not formed. From the Raman results, it was confirmed again that Cu induced dendrite-shaped lateral crystallization and the crystallization was successfully accomplished by applying 30V/cm electric field at 350℃.

SEM images of crystallized area by increasing an annealing time during Cu-FALC process at 350℃ were shown in Fig. 3. From SEM images (Figs. 3(a) ~ 3(d)), a dendrite-shaped crystallization seems to remarkably progress from negative electrode side toward positive electrode side under the influence of electric field with annealing time. From plan-view image (Fig. 3(e)), we can observe that the crystallite is roughly 300~500Å in diameter and the grain with nearly same size is uniformly distributed.

Fig. 4 is a cross-sectional TEM image showing the microstructure of crystallized film by Cu-FALC at 350℃ for 10hrs with an electric field of 30V/cm. From this figures, it was identified that the bottom as well as the surface a-Si film was completely crystallized by Cu-FALC process.

4. Conclusions

Under the influence of the electric field, Cu rapidly induced lateral crystallization of a-Si, exhibiting the directionality in crystallization behavior from negative electrode side toward the positive electrode side. Because the lateral crystallization by the electric field may mainly depend on the diffusion of metal ions rather than that of neutral Si atoms, the crystallization velocity can be more enhanced by accelerating the diffusion of metal ions in the presence of an electric field. When an electric field of 30V/cm was applied to the specimen at 350℃, the large dendrite-shaped branches were formed in the crystallized region and the lateral crystallization progressed from negative electrode side toward positive electrode side. Cross sectional TEM image showed that 1000Å-thick a-Si film was fully crystallized by Cu-FALC. Consequently, we could successfully form the poly-Si film when the electric field of 30V/cm was applied to the specimen at temperature as low as 350℃.

5. References

[1] R. S. Wagner and W. C. Ellis: Appl. Phys. Lett. 4, 8900 (1964).

[2] C. Hayzelden and J. L. L. Bastone: J. Appl. Phys. 73, 8279 (1993).

[3] S. W. Lee and S. K. Joo: IEEE Electron Dev. Lett. 17, 160 (1996).

[4] S. H. Park, S. I. Jun, C. K. Kim and D. K. Choi: Jpn. J. Appl. Phys. 38, L 108 (1999).

[5] C. J. Lee, J. B. Lee, Y. C. Chung and D. K. Choi: Jpn. J. Appl. Phys. 39, 6191-6193 (2000).

[6] S. W. Russell, J. Li and J. W. Mayer: J. Appl. Phys. 70, 5153 (1991).

[7] J. B. Lee, C. J. Lee, J and D. K Choi: Jpn. J. Appl. Phys. 40, 6181 (2001)

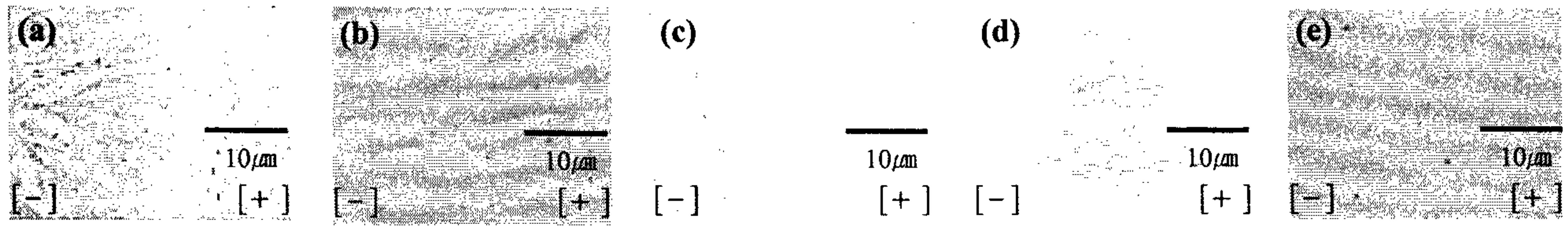

Fig. 1. Nomarski optical micrographs showing the partially crystallized a-Si at 350℃ with an electric field of 30V/cm after annealing for (a) 2h (b) 5h (c) 7h (d) 10h and (e) 15h.

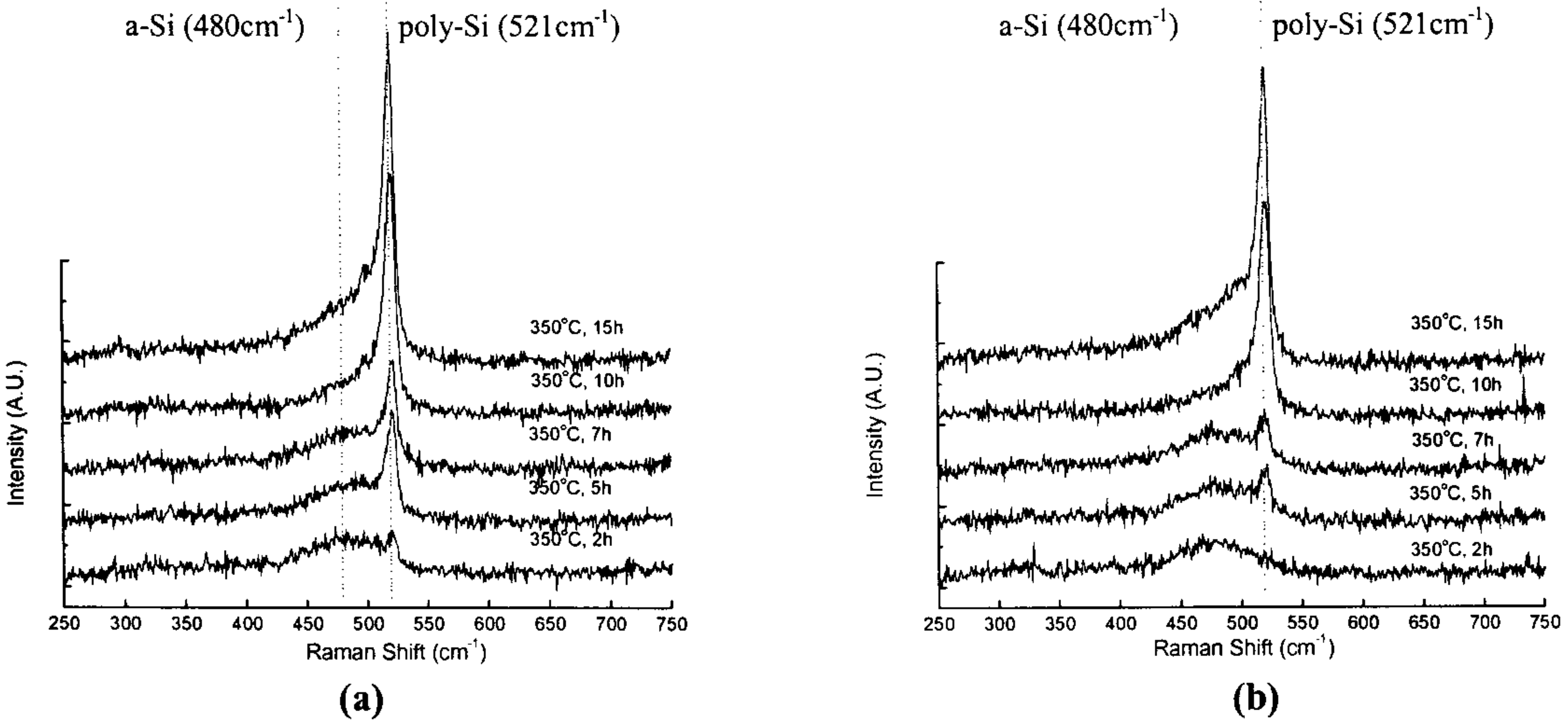

Fig. 2. Raman spectra results of (a) negative electrode side of Fig. 1 and (b) positive electrode side of Fig. 1.

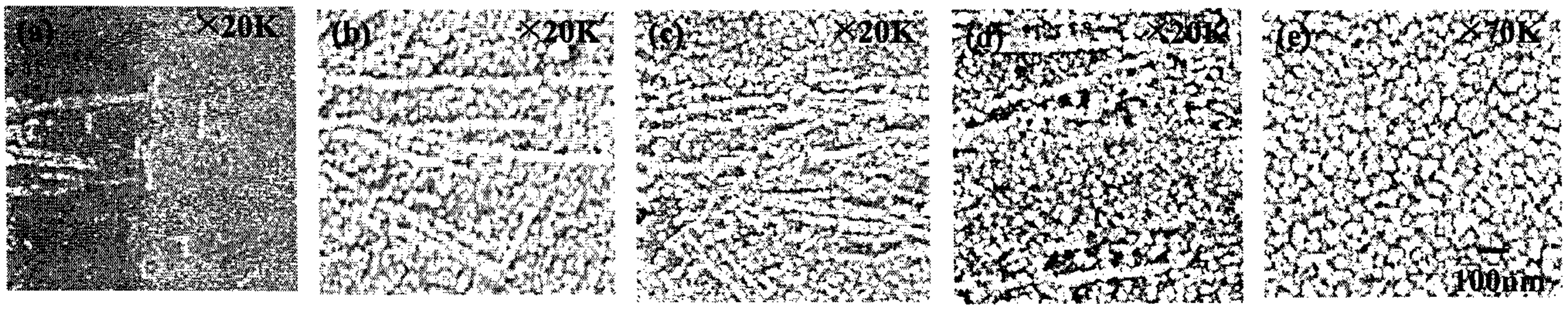

Fig. 3. Plan-view SEM images showing the microstructure of crystallized region by Cu-FALC (350 , 30V/cm). Annealed for (a) 2h (b) 5h (c) 7h (d) 10h and (e) 15h.

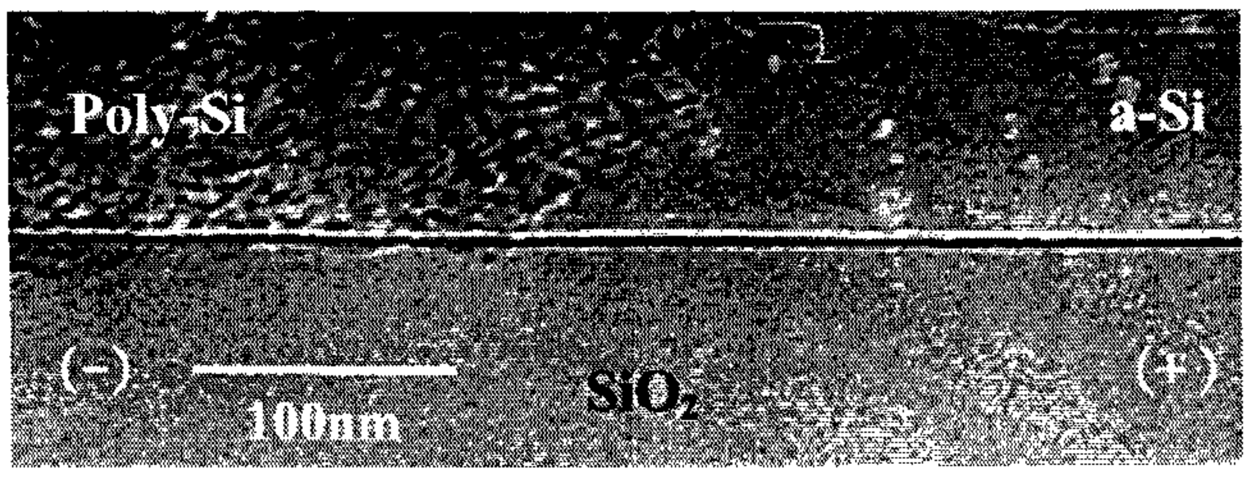

Fig. 4 Cross-sectional TEM image of the microstructure of the partially crystallized Cu-FALC processed film (350℃, 10h, 30V/cm). Boundary between poly-Si and a-Si.