Characterization of Local Electrical Properties of Poly-Si Thin Films Exposed to Atomic Hydrogen by Conductive Atomic Force Microscopy

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Abstract. In this study, we analyzed local electrical defects in polycrystalline silicon (poly-Si) thin films. We observed local electrical properties of poly-Si thin films by conductive atomic force microscopy (C-AFM). Moreover, we observed local electrical properties poly-Si thin films exposed to atomic hydrogen. Before the atomic hydrogen exposures, conductive regions in grains disappeared with the repeated scanning of the cantilever, suggesting that the trapping sites in grains were charged by the injection of holes from the cantilever. On the other hand, conductive regions in grain boundaries remained while the increased number of scans. Therefore, it is thought that current flowed continuously without the hole trapping at these electrical defects in grain boundaries. After the atomic hydrogen exposures for 20 min, electrical defects were inactivated, and the conduction mechanism of device became similar to semiconductor conduction mechanism behavior.

Introduction

Thin film transistors (TFTs) are widely used in switching devices for display [1~3], and it is well known that their performance is significantly affected by field-effect mobility of the channel material. In recent years, polycrystalline silicon (poly-Si) TFTs have attracted much attention because their field-effect mobility (10~150 $\mathrm{cm^2/V{\cdot}s}$) is greater than that of amorphous silicon (a-Si) TFTs (<1 $\mathrm{cm^2/V{\cdot}s}$). However, the poly-Si films have many electrical defects at the oxide interface and/or grain boundary. These electrical defects cause marked reduction in field effect mobility or increase in threshold voltage [4~6]. Therefore, the investigation of the location of electrical defects in poly-Si films is very important in order to improve the electrical properties of poly-Si TFTs.

In this study, we observed local current images of poly-Si films by conductive atomic force microscopy (C-AFM), and analyzed them. In the use of C-AFM, the density and the regions of formation of these electrical defects can be observed, because local current images and surface topography can be simultaneously obtained by this method [7]. We observed local current images and measured current-voltage (I-V) characteristics of the poly-Si films before and after the atomic hydrogen exposures, and investigated their local electrical properties.

Experimental

The poly-Si thin films were formed by the crystallization of a-Si by XeCl excimer laser annealing (λ = 308 nm). The a-Si film (50 nm) was deposited on a glass substrate by plasma enhanced chemical vapor deposition (PECVD), and the structure of the sample is a-Si (50 nm)/ SiO_2 (100 nm)/ SiN (50 nm)/ non-alkali glass substrate. Prior to laser annealing, the a-Si film was annealed in a vacuum chamber at 400℃ for the dehydrogenation. The grain size of the poly-Si thin films was estimated by scanning electron microscopy (SEM) image taken after Secco etching. The microstructure of the poly-Si films was observed by cross-sectional transmission electron microscopy (TEM).

Before C-AFM measurements, native oxide on the poly-Si films was removed using a HF solution (5%) at room temperature. C-AFM measurements were performed using Shimadzu SPM-9600 with a platinum-coated cantilever at a constant sample voltage of -1.0 V or -2.0 V. Surface topography and current images were simultaneously measured by C-AFM at room temperature in air ambient. The sample holder, to which the sample voltage was applied, was electrically connected to the poly-Si film surface by an electrode. Thus, the sample voltage was applied between the cantilever and the poly-Si film surface. The atomic hydrogen exposures of poly-Si films was performed for 5 min or 20 min (5 min x 4) by a hot-wire method [8]. Atomic hydrogen was generated by the thermal separation of H_2 gas due to contact with a high-temperature tungsten filament in a vacuum chamber. The poly-Si film surface was exposed to the atomic hydrogen in a vacuum chamber to terminate the poly-Si surface. The base pressure of the chamber was 3.0×10^{-5} Pa, and the H_2 gas pressure was 1.0×10^{-1} Pa. The substrate temperature of poly-Si films was 300℃. Before and after the atomic hydrogen exposures, native oxide on the poly-Si films was removed using a HF solution (5%) at room temperature.

Results and discussion

Figure 1 shows SEM image of Secco etched poly-Si film formed by ELA. Grain boundaries can be clearly observed in SEM image. The average grain size was about 300 nm. From AFM measurement of poly-Si film surface, the root mean square (rms) of surface roughness was estimated 10.5 nm. Figure 2 shows cross-sectional TEM image of poly-Si film formed by ELA. As shown in Fig.2, there is a prominent ridge at grain boundary.

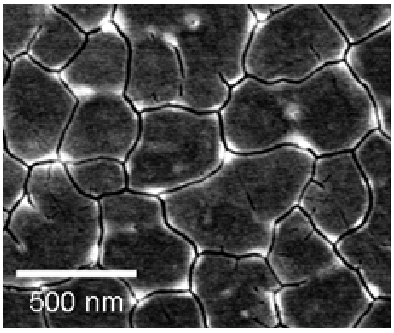


Fig.1 SEM image of a poly-Si film. Average grain size = 300 nm.

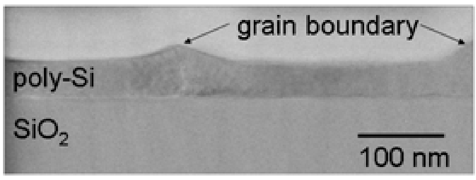
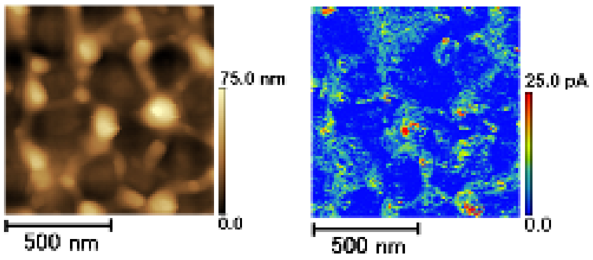


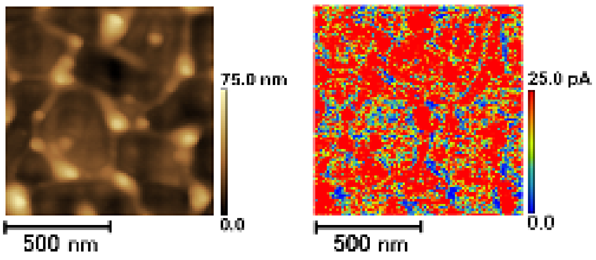
Fig. 2 Cross-sectional TEM image of a poly-Si film.

Figure 3 shows C-AFM images of (a) the surface topography and (b) the current image of poly-Si thin film before the atomic hydrogen exposures taken at a sample voltage (V_{sub}) of -1.0 V. Surface topography and current images were simultaneously measured. As shown in Fig. 3(b), conductive regions correspond to circled region by prominent ridge in Fig. 3(a). As shown in Fig. 2, the poly-Si films crystallized by ELA have a ridge at grain boundaries. In addition, as shown in Fig. 3(a), the size of circled region by prominent ridge is almost equal to grain size in Fig. 1. Therefore, we concluded that the conductive regions correspond to grain boundaries. Figure 4 shows C-AFM images of (a) the surface topography and (b) the current image of the poly-Si thin film before the atomic hydrogen exposures taken at V_{sub} of -2.0 V. As shown in Fig.4 (b), conductive regions covered whole surface of the poly-Si film.



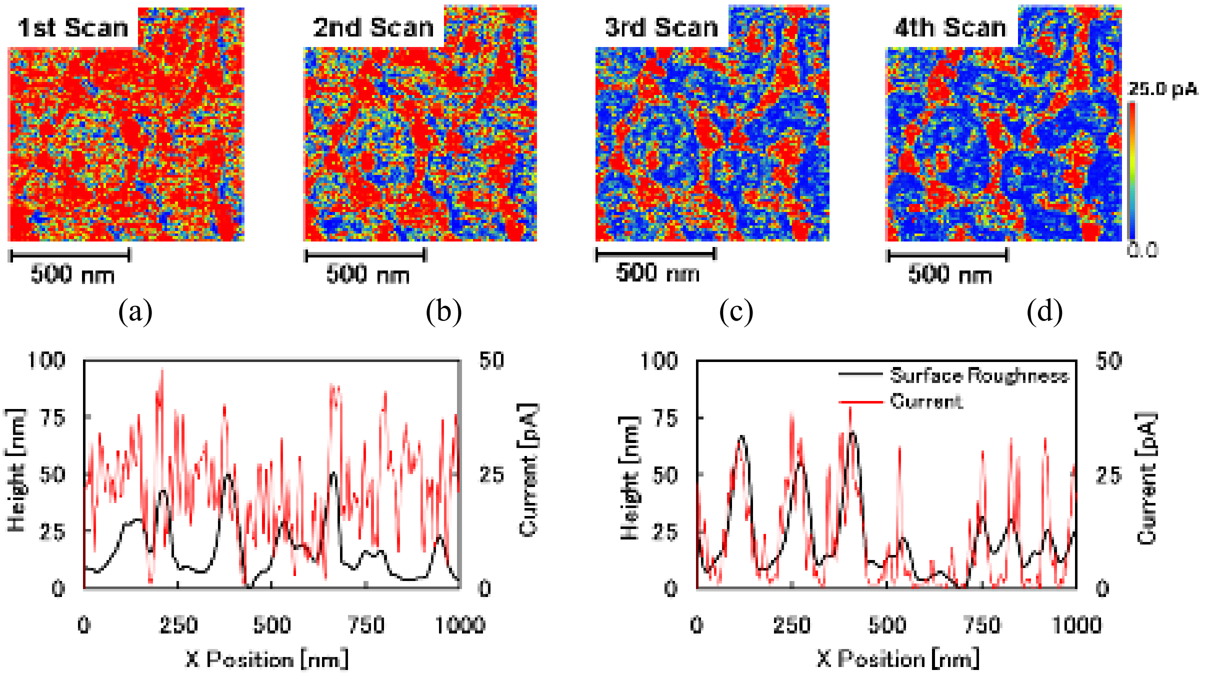
(a) (b)

Fig. 3 C-AFM images of (a) surface topography and (b) corresponding current image of a poly-Si film at a V_{sub} of -1.0 V.



(a) (b)

Fig. 4 C-AFM images of (a) surface topography and (b) corresponding current image of a poly-Si film at a V_{sub} of -2.0 V.

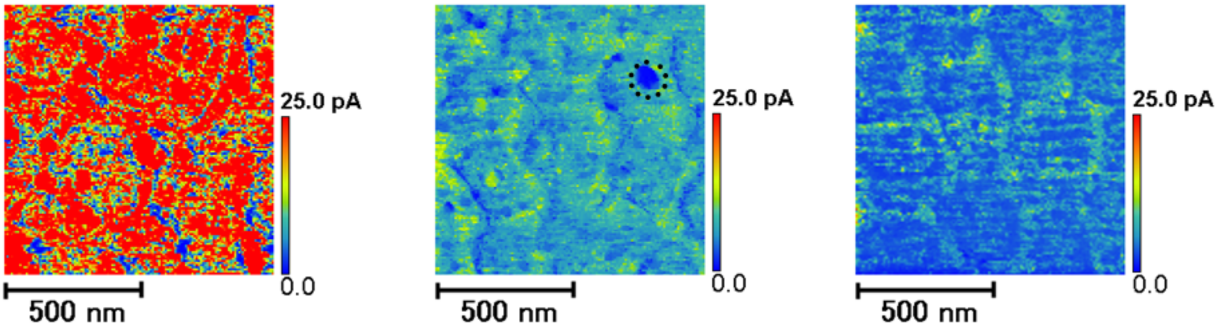


(a) (b) (c) (d)

(e) (f)

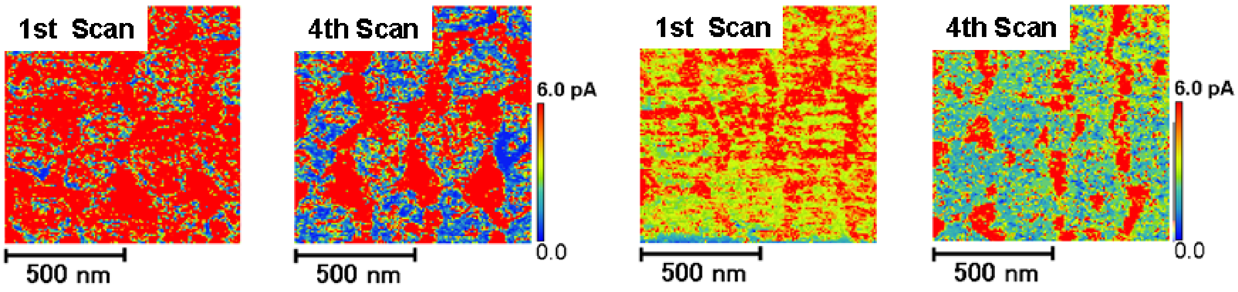
Fig. 5 (a) ~ (d) Current images of an identical area of the poly-Si film taken at V_{sub} of -2.0 V. (a) first, (b) second, (c) third, (d) fourth scans. (e), (f) Line profiles of surface topography and corresponding current image of (e) first scan, (f) fourth scan.

Figure 5(a) ~ 5(d) show current images of the poly-Si films before the atomic hydrogen exposures (V_{sub} = -2.0 V) and Fig. 5(e) ~ 5(f) show line profiles of surface topography and corresponding current images. These current images are of the same area, which underwent repeated scanning using a Pt-coated cantilever. Figure 5 shows (a) first, (b) second, (c) third and (d) fourth scanning image. The surface roughness of the poly-Si film had little change owing to repeated scanning. As shown in Fig. 5(a) ~ (d), conductive regions in grains significantly decrease in area with increasing number of scans. However, conductive region in grain boundaries does not change while scanning. As shown in Fig. 5(e) and (f), current of about 30 pA flows continuously through grain boundaries. After changing the measurement region to obtain a new first scanning image, we observed new conductive regions, similar to those shown in Fig. 5(a). From these results, we concluded that the decrease in the area of the conductive regions does not occur due to the degradation of the cantilever. These results indicate that many conductive regions correspond to low-resistance region. It is well known that there are many electrical defects in grain boundaries. Therefore, it can be thought that these conductive regions correspond to electrical defects in grain boundaries. Conductive regions in grains disappear with repeated scanning of the cantilever, and thus, it is thought that trapping sites in grains were charged by the hole injection from cantilever. On the other hand, it is well known that there are many electrical defects such as dangling-bond in grain boundary. So, it is thought that current flowed continuously without the hole trapping at these electrical defects in grain boundaries.



(a) (b) (c)

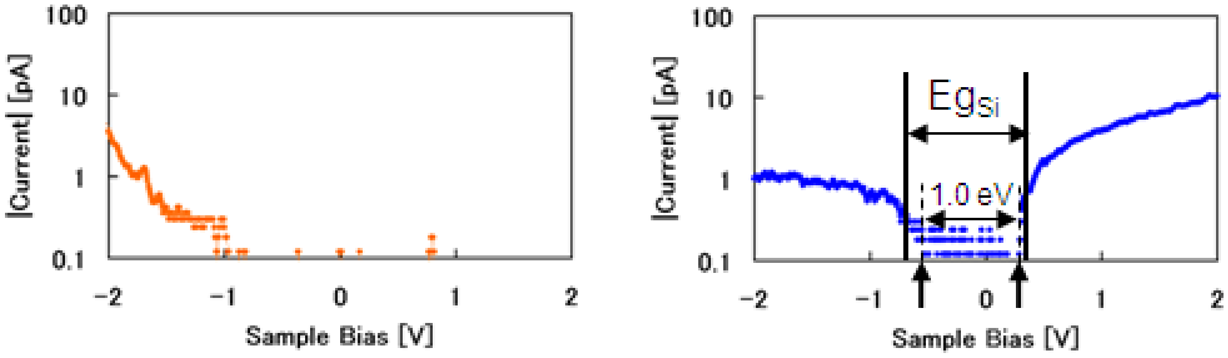
Fig. 6 Current images of the poly-Si films (V_{sub} = -2.0 V). (a) Before hydrogen termination. (b) After 5 min hydrogen termination. (c) After 20 min hydrogen termination.



(a) (b) (c) (d)

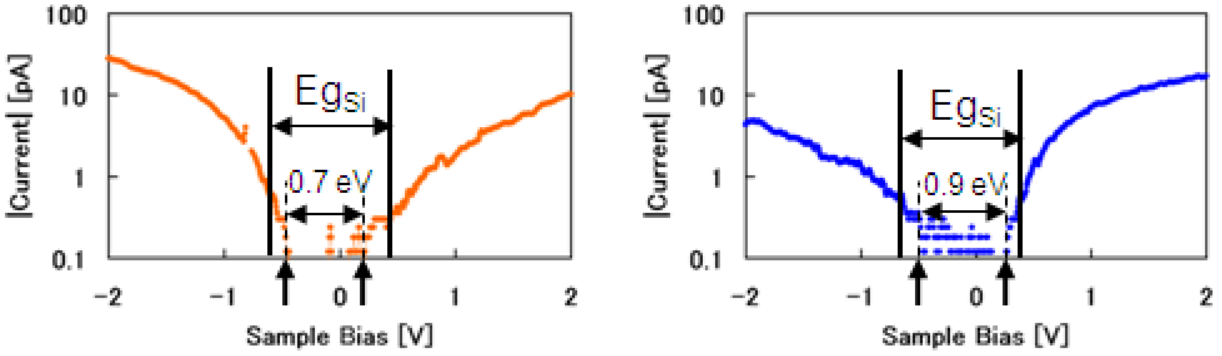
Fig. 7 Current images of the poly-Si films (V_{sub} = -2.0 V). (a) and (b) Before the atomic hydrogen exposures. (c) and (d) After the atomic hydrogen exposures for 20 min.(a) and (c) First scanning image. (b) and (d) Fourth scanning image.

Figure 6 shows current images of the poly-Si films before and after the atomic hydrogen exposures. Figure 6(a) shows current image of non-treatment poly-Si film, (b) shows current image of the atomic hydrogen exposures for 5 min poly-Si film and (c) shows current image of the atomic hydrogen exposures for 20 min poly-Si film. As shown in Fig. 6, conductive regions in the poly-Si film disappear with the atomic hydrogen exposures. Therefore it can be concluded that electrical defects were inactivated by the atomic hydrogen exposures. Figure 7 shows local current images of poly-Si films before and after the atomic hydrogen exposures. To clarify change of conductive regions in grains, current range of local current images was set to 6.0 pA. Figure 7(a) and (b) show current images of non-treatment poly-Si film, and (c) and (d) show current images of the atomic hydrogen exposures for 20 min poly-Si film. Figure 7(a) and (c) are first scanning image, and (b) and (d) are fourth scanning image. As shown in Fig. 7(a) and (c), electrical defects in grains were also inactivated by the atomic hydrogen exposures as in the case of grain boundaries. However, there is considerable difference in change of conductive regions due to increase of number of scans. In Fig. 7(a) and (b), conductive regions in grains significantly decrease in area with increasing number of scans. On the other hand, in Fig. 7(c) and (d) conductive regions in grains remained in spite of increasing in scanning number. From these results, it can be concluded that electrical defects in grain are inactivated by the atomic hydrogen exposures, and the charge up in trapping sites does not occur by the hole injection from the cantilever. In addition, as shown in Fig. 6(b), there is locally non-terminated region (circled region with dot-line in Fig. 6(b)) near grain boundary in the case of the atomic hydrogen exposures for 5 min. Thus, it is thought that there are partially-non-terminated regions such as point defect in poly-Si films.



(a) (b)

Fig. 8 I-V curves in grain region of poly-Si film. (a) Before hydrogen termination. (b) After 20 min hydrogen termination.



(a) (b)

Fig. 9 I-V curves at grain boundary of poly-Si film. (a) Before hydrogen termination. (b) After 20 min hydrogen termination.

Figure 8 shows current-voltage (I-V) curves in grain region of poly-Si films (a) before and (b) after the atomic hydrogen exposures. As shown in Fig. 8(a), the current edge was very unstable and current does not flow until high gate voltage. On the other hand, after the atomic hydrogen exposures, I-V curve indicates asymmetric rising and the edge was very stable, as shown in Fig. 8(b). Moreover, width of the edge (1.0 eV) was almost equal to the band gap of Si (1.1 eV) and thus, the conduction mechanism of device shown in Fig.8 is similar to semiconductor conduction mechanism behavior. Figure 9 shows I-V curves at grain boundaries of the poly-Si films (a) before and (b) after the atomic hydrogen exposures. As shown in Fig. 9(a), the edge was nearly symmetrical and width of the edge (0.7 eV) was smaller than band gap of Si. In addition, conductive mechanism of device of Fig. 9(a) is similar to metallic conductive mechanism behavior. However, the I-V characteristic does not show complete ohmic characteristics, so it is suggested that major conduction mechanism are hopping conduction mediated by electrical defects in grain boundary[9, 10]. In Fig. 9(b), the current edge of I-V curve is asymmetrical and width of the edge (0.9 eV) is close to band gap of Si. Therefore, we concluded that electrical defects in grains and grain boundaries of the poly-Si film are inactivated by the atomic hydrogen exposures, and the conduction mechanism becomes similar to semiconductor conduction mechanism behavior.

Summary

We analyzed local electrical properties in the poly-Si thin films formed by ELA. The poly-Si thin films (50 nm) were crystallized of a-Si by XeCl excimer laser annealing. We simultaneously observed surface topography and current images of the poly-Si thin films before and after the atomic hydrogen exposures by conductive atomic force microscopy (C-AFM). Before the atomic hydrogen exposures, conductive regions in grains disappeared with repeated scanning of the cantilever. Thus, it is thought that trapping sites of grains were charged by the hole injection from cantilever. On the other hand, conductive regions in grain boundaries unchanged while the increasing number of scanning. Therefore, it is thought that current flowed continuously without the charge up of trapping sites in grain boundaries. In the case of after the atomic hydrogen exposures for 20 min, electrical defects were almost inactivated, and the conduction mechanism of device became similar to semiconductor conduction mechanism behavior.

Acknowledgments

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