Room Temperature Preparation of Poly-Si Thin Films by IBE with Substrate Bias Method

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Using intense pulsed ion beam evaporation technique, we have succeeded in the preparation of poly crystalline silicon thin films without impurities on silicon substrate. Good crystallinity and high deposition rate have been achieved without heating the substrate by using IBE. The crystallinity of poly-Si film has been improved with the high density of the ablation plasma. The intense diffraction peaks of poly-Si thin films could be obtained by using the substrate bias system. The crystallinity and the deposition rate of poly-Si thin films were increased by applying (-) bias voltage for the substrate.

Keywords : Poly-Si, Intense pulsed ion beam evaporation, Bias voltage, Crystallinity, High deposition rate

1. INTRODUCTION

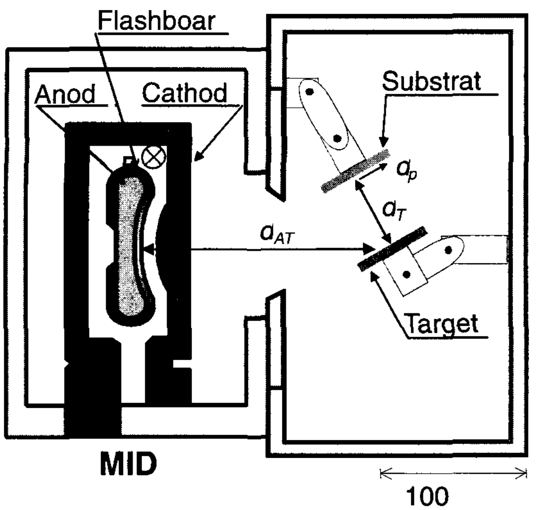
The preparation of polycrystalline silicon (poly-Si) thin films has received much attention due to their wide application potential for semiconductors such as thin film transistors (TFTs), solar cells, peripheral circuits of liquid-crystal displays, and electrodes in Si-integrated circuits. Conventionally, poly-Si films were prepared by using a plasma-enhanced chemical vapor deposition (PECVD) method with post annealing (~800 ℃) of a-Si:H films or substrate heating (200~400 ℃)[1-3]. However, this technique requires high processing temperature and a long processing time. Since such a high processing temperature limits the selection of the substrate materials or fabrication process, the deposition of poly-Si films at low temperatures, which leads to the improvement of the throughput and feasibility, is preferred.

In addition, for practical engineering applications, the very low deposition rate has been a serious problem to achieve higher throughput of electronic devices such as solar cells. For this purpose, several types of low-pressure and high-density plasma sources have been applied to increase the crystallinity and the deposition rate of poly-Si thin films such as inductively coupled plasma (ICP), surface wave plasma (SWP), ultra high-frequency (UHF) plasma, and electron cyclotron resonance (ECR) plasma[2-5].

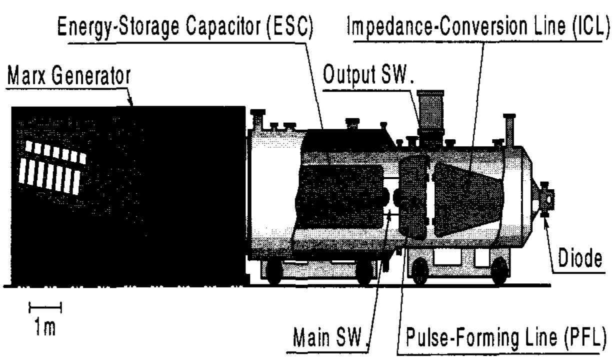
In this paper, we report the characteristics of poly-Si thin films prepared at room temperature, i.e., without heating the substrate, by using a high-density ablation plasma formed by the intense, pulsed, ion beam, which is named as pulsed ion-beam evaporation (IBE). The crystallization and the deposition rate of poly-Si thin films prepared at different substrate positions were investigated. Furthermore, to improve their crystallinity, the bias voltage was applied to the substrate.

2. EXPERIMENTAL APPARATUS AND METHOD

If the pulsed proton beam irradiates solid targets, high-density ablation plasma can be produced due to short rage of protons in targets. This high density ablation plasma has been reported to prepare thin films very efficiently. After the first demonstration of the preparation of thin films of ZnS in 1988[6], various kinds of thin films, e.g., YBCO, ITO, $BaTiO_3$, BN, SiC



(a) Experimental setup(Diode and deposition room)



(b) Pulsed ion-beam generation machine

Fig. 1. Experimental setup and pulsed ion-beam generation machine.

TiO_2, ZrO_2, AlN, have been successfully prepared by IBE [7-9].

Figure 1 shows the schematic diagram of the experimental arrangement. The light ion beam (LIB) was produced by a geometrically focused and magnetically insulated diode (MID). A polyethylene sheet (flashboard) was attached on the anode (aluminum), which acted as the ion source. It was found from the measurement by energy spectrometer, that the ion consisted of the proton (approximately 75 %) and the rest carbons.

The energy density of the ion beam was observed up to be ~100 J/cm^2 at the geometrically focusing point. The beam spot size on the target was 20 mm diameter. As a target, a single crystal silicon with 50x50 mm in diameter and 10 mm in thickness was used. As a substrate, we used Si wafer(100). The substrate (20x80 mm) was kept at room temperature and was directly hit the substrate by the ablation plasma.

Table 1. Typical experimental conditions.

Experimental parameters	Value	Unit
Main component of ion	Proton(H^+)	
Beam voltage	1	MV
Beam current	70	kA
Energy density on target	50	J/cm^2
z (anode-target distance)	180	mm
d_{TS} (target-subst. distance)	70	mm
Target angle	45	°
Substrate	Si (100)	
Pressure	10^{-4}	Torr
Substrate temperature	R. T.	
Number of shots	5	Shot

The chamber pressure was ~10^{-4} Torr. Typical experimental conditions are listed in Table 1.

The crystal structures and the properties were investigated through X-ray diffraction (XRD) and scanning electron microscope (SEM). The grain size for a certain crystal plane (nkl) was estimated from the full width at half-maximum (FWHM) of the XRD spectra by using Scherrer's formula. The film thickness was measured by a roughness meter and SEM.

3. EXPERIMENTAL RESULTS AND DISCUSSION

In our previous paper [10], we had investigated the behavior of the ablation plasma by high-speed camera. It was found that the ablation plasma was generated by the irradiation of the ion beam, and that the plasma expanded in the direction perpendicular to the target surface. The substrate was surrounded by the ablation plasma for 20 μs, after the beam irradiation started.

Figure 2 shows XRD spectra of poly-Si films according to d_p. From Fig. 2, diffraction peaks of (111), (220) and (311) axes could be observed at d_p =20 mm, d_p is the distance from the plasma center. The most intense XRD peak appeared for the (111) axis, followed by (220) and (311) axes. However, any diffraction peaks could not be observed at d_p = 60 mm. These results show that by using IBE, we can fabricate the polycrystalline silicon thin films without both the substrate heating and post annealing. From Fig. 2, the crystallinity of the film was significantly improved near the center because the plasma density was much higher than that at the periphery.

Figure 3 shows dependence of the beam shot in deposited films. From Fig. 3, the intensity of XRD peaks increased as the beam shot increased.

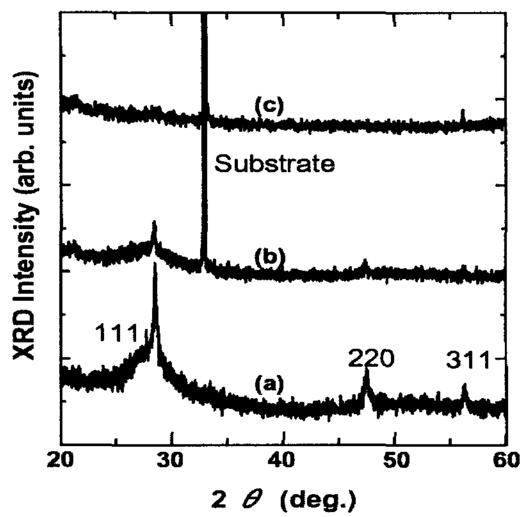


Fig. 2. XRD data with d_p as a parameter; (a) $d_p = 20$ mm, (b) $d_p = 40$ mm, (c) $d_p = 60$ mm.

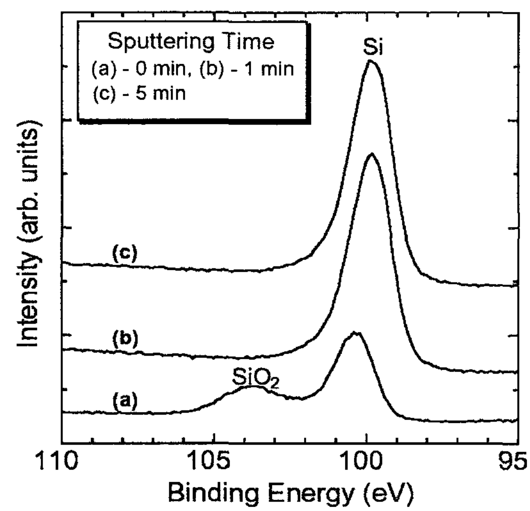


Fig. 4. XPS Analysis of the thin films with sputtering time; (a) 0 minute, (b) 1minute, (c) 5 minute.

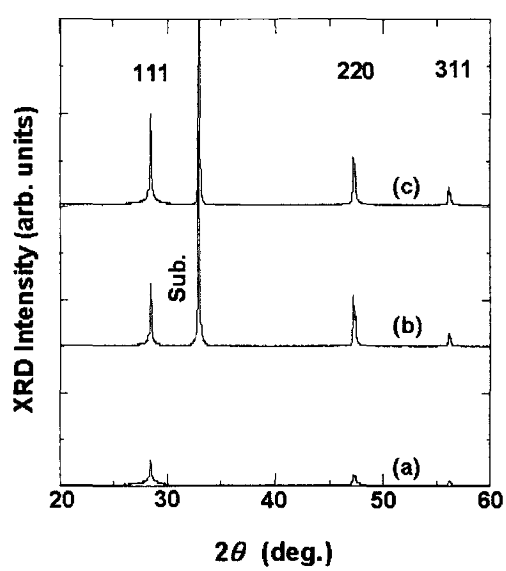


Fig. 3. Dependence of the beam shot on deposited films; (a) 5 shot, (b) 10 shot, (c) 15 shot.

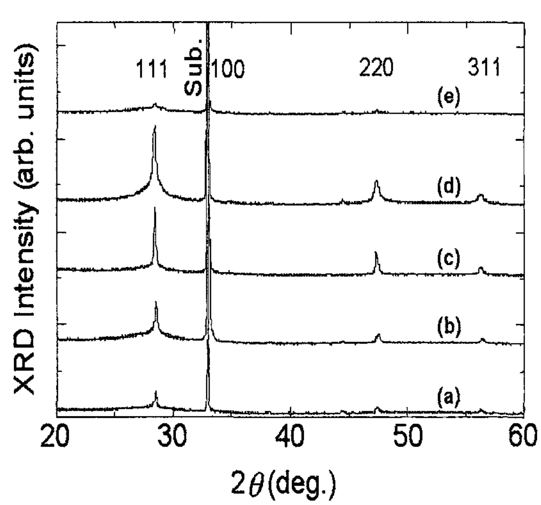


Fig. 5. XRD patterns of the thin films prepared by the substrate bias according to bias voltage; (a) V_{bias}=0 V, (b) -25 V, (c) -50 V, (d) -75 V, (e) -100 V.

Figure 4 shows X-ray photoelectron spectrometer (XPS) analysis of the prepared thin films. From Fig. 4, it was found that Si and SiO_2 peak appeared at the same time on the thin film surfaces. However, after Ar Ion etching (at 10 nm dept during the 1min), it was found that Si peak appeared and that SiO_2 disappeared. After during the 3 minutes etching, it was found that Si peak only appeared. This result means that surface of the film is oxidized but the inner parts of the thin film does not conclude an oxygen. From above analysis, it was confirmed that the high-quality Si thin thin films could be obtained by using IBE.

Figure 5 shows XRD spectra of poly-Si films at 5 beam shot where the bias voltage is applied to the substrate. From Fig. 5, diffraction peaks of (111), (220) and (311) axes could be observed at all substrates. The most intense XRD peak appeared at (111) axis and diffraction peaks of (100) was the peak of the Si substrate. The intensity of these peaks increased with the increase of the substrate bias voltage. This results suggest that it is possible to prepare poly-Si thin films with high crystallinity by applying the (-) bias voltage for the substrate, which means that the ion bombardment affects the crystallization of poly-Si. The diffraction peak of (111) at V_{bias}=-100 V, however, was considerably smaller.

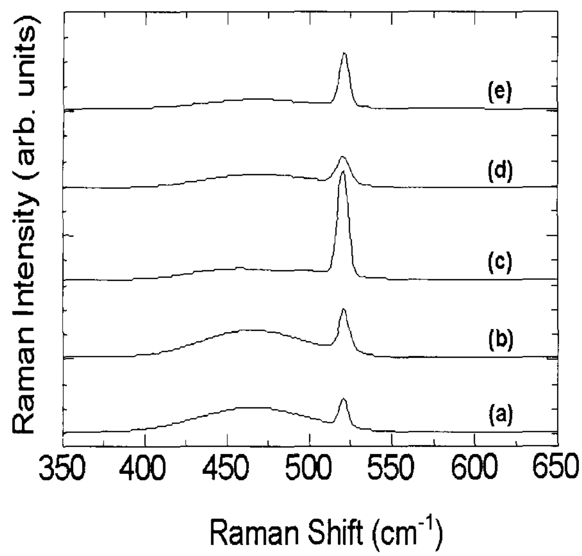


Fig. 6. Raman spectra of the thin films prepared by substrate bias; (a) V_{bias}=0 V, (b) -25 V, (c) -50 V, (d) -75 V, (e) -100 V.

From the XRD data, the grain size of the nanocrystalline silicon films was calculated using Scherrer's formular:

$$d = \frac{0.9\lambda}{\beta \cos\theta} \quad (1)$$

Where d is the grain size, λ is the X-ray wave length, β is the FWHM, and θ is the Bragg angle. Using equation. (1), the grain size of poly-Si films deposited under the conditions of Fig. 5 was estimated to be 38, 40, 100, 36 and 24 nm at V_{bias}=0, -25, -50, -75, and 100 V, respectively. From Fig. 5, the XRD peak intensity increased at a low bias voltage region(~ -50 V). However, it decreased at a high bias voltage region(above -70 V) because of the by high-energy ion bombardment.

Figure 6 shows the Raman scattering spectra, which reinforces the XRD data. These results also showed similar results for the XRD data. The sharp peak near 520 cm^{-1} and the broad peak near 480 cm^{-1} appeared at V_{bias}=0 V. The former indicates that the Si material is microcrystalline. On the other hand, the latter indicates that the Si material is amorphous. At V_{bias}=-50 V, it was observed that the amorphous component disappeared and that the microcrystalline component enhanced. on the other hand, the crystalline component decreased largely at V_{bias}=-75 V, because the film thickness was reduced by high-energy ion bombardment.

Figure 7 shows Crystallinity obtained from Fig. 5 of the XRD pattern and Fig. 6 of the Raman spectra. In case

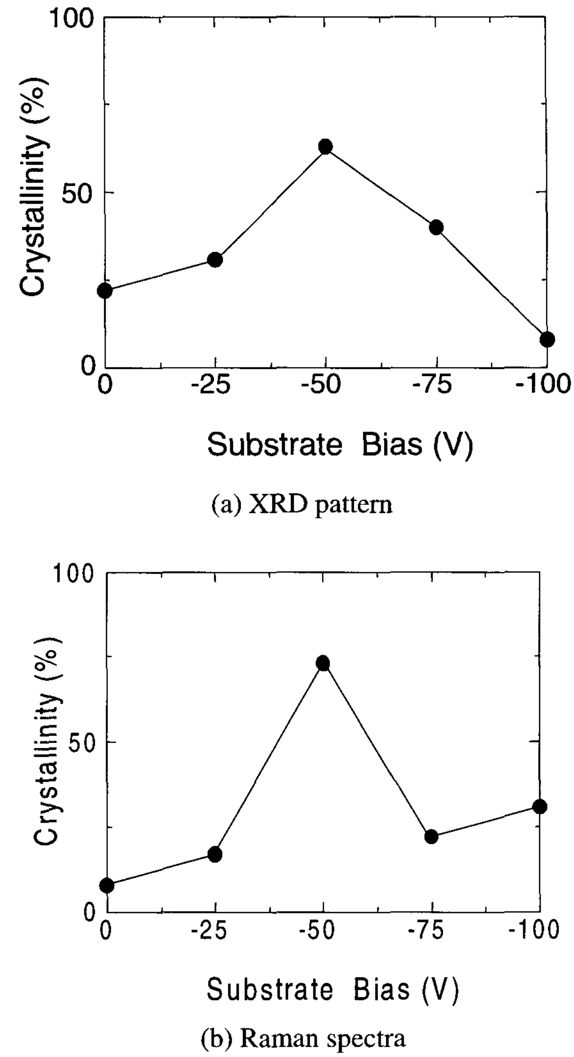


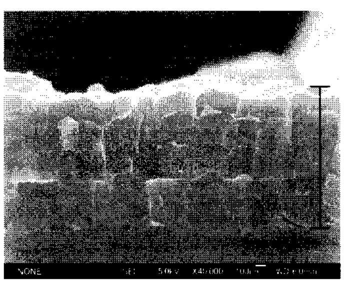
Fig. 7. Crystallinity from (a) the XRD pattern and (b) the Raman spectra.

of Fig. 7(a) XRD pattern, about 25 % high crystallinity was obtained at V_{bias}=0 V. Moreover the crystallinity increased with the increase of the substrate bias voltage. But decreased at V_{bias}=-75 V. From Fig. 7(b) the Raman spectra, also increased with increasing the substrate bias voltage. But decreased at V_{bias}=-75 V. This results indicate that about 70 % high crystallinity can be obtained at V_{bias}=-50 V by the IBE method and applying the substrate bias voltage.

Figure 8 shows cross-sectional SEM images of the films deposited under the conditions of (a) V_{bias} = 0, (b) -25 V, (c) -50 V, (d) -75 V, and (e) -100 V at d_p=10 mm. The deposition rate of poly-Si film was estimated to be about 210, 230, 260, 380 and 210 nm/shot, respectively. From Fig. 8, the deposition rate of the film increased with the increase of the substrate bias voltage until V_{bias} approached -50 V. We found that high deposition rate could be obtained at V_{bias}=-75 V, but we suggest that the

(a) V_{bias}=0 V, 1.06 μm

(b) V_{bias}=-25 V, 1.17 μm



(c) V_{bias}=-50 V, 1.33 μm

(d) V_{bias}=-75 V, 1.93 μm

(e) V_{bias}=-100 V, 1.06 μm

Fig. 8. Cross-sectional SEM images of the thin films by the bias variation; (a) V_{bias}=0 V, (b) -25 V, (c) -50 V, (d) -75 V, (e) -100 V at d_p=10 mm.

high deposition rate is the image of before re-sputtering because of the high ion bombardment and that is low density film. While the deposition rate was decreased at V_{bias}=-100 V. It suggest that the deposition rate decreases at a high bias voltage region because the film thickness is reduced by high-energy ion bombardment. From Fig. 7 and Fig. 8, we obtained good crystallinity and high deposition rate of the poly-Si thin film at V_{bias}=-50 V.

4. CONCLUSION

By intense pulsed ion beam evaporation, we succeeded in the preparation of polycrystalline silicon thin films on silicon substrate. Good crystallinity and high deposition rate achieved without heating the substrate and post annealing. The crystallinity of the poly-Si film improved with increasing the density of the ablation plasma where the grain size of the film was to be smaller than that at the periphery.

To enhance the crystallinity and density of poly-Si thin film, bias voltage was applied to the substrate, where the quality of poly-Si film has been improved by the ion bombardment. The film thickness increases to a maximum value at V_{bias}=-50 V and decreases at V_{bias}=-100 V because the film thickness is reduced by high-energy ion bombardment.

From this results, using IBE and substrate bias voltage we achieved good crystallinity, high deposition rate of the poly-Si thin film at V_{bias}=-50 V.

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