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PAPER

Role of Hydrogen in Polycrystalline Si by Excimer Laser Annealing

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SUMMARY The role of hydrogen in the Si film during excimer laser annealing (ELA) has been successfully studied by using a novel sample structure, which is stacked by a-Si film and SiN film. Hydrogen contents in the Si films during ELA are changed by preparing samples with hydrogen content of 2.3–8.2 at.% in the SiN films with a use of catalytic (Cat)-CVD method. For the low concentration of hydrogens in the Si film, the grain size increases by decreasing hydrogen concentration in the Si film, and the internal stress of the film decreases as increasing the shot number. For the high concentration of hydrogens in the Si film, hydrogen burst was observed at 500 mJ/cm² and the dependence of the internal stress on the shot number becomes weak even at 318 mJ/cm². These phenomena can be understood basically using the secondary grain growth mechanism, which we have proposed.

key words: polycrystalline Si, excimer laser annealing, hydrogen, secondary grain growth, stress relaxation, Cat-CVD

1. Introduction

Polycrystalline Si (poly-Si) film recrystallized by excimer laser annealing (ELA) has been studied intensively focusing both on the nucleation and crystal growth mechanisms because it is attractive for application to thin film transistors (TFTs) [1]–[4].

We have studied the crystal growth mechanism of the poly-Si film prepared by ELA [5]–[12]. The electron spin resonance (ESR) measurement for ELA poly-Si film indicated that the density of the defects at the grain boundary such as the dangling bonds is much larger than that of the in-grain defects [5]. The hydrogen in the amorphous Si (a-Si) film strongly affects the spin density even after the recrystallization of the poly-Si film by ELA [6]. To clarify the hydrogen role further, we investigated the characteristics of the recrystallized poly-Si film on SiO₂/SiN/glass. Here, the SiN films are deposited by plasma-enhanced chemical vapor deposition (PECVD), and the hydrogen concentration of a

SiN film is large. Then, we inferred the nucleation model related to the hydrogen supplied from the SiO₂/SiN/glass [10]–[12]. It was found that hydrogen supply from the substrate was the dominant factor to determine the morphology and grain size of poly-Si.

Considering our experimental results, it is thought that the difference in grain size of the poly-Si film between on a SiN film and on a glass substrate is attributed to hydrogen in the SiN film and the thermal conductivity of the substrate. Therefore, a quantitative supply of the hydrogens to the melt-Si from the SiN film is necessary to understand what role the hydrogens have during the crystallization by ELA.

In this study, we clarify the influence of hydrogen concentration in the Si film on morphology, defect density and internal stress of poly-Si experimentally, and verify the crystallization model [8] which were presented by our group. The hydrogens are introduced in the melt-Si film from the catalytic chemical vapor deposition (Cat-CVD) SiN films including hydrogens of 2.3, 4.2 and 8.2 at.%.

2. Experimental

An a-Si film was deposited on the SiN/quartz substrate by low-pressure chemical vapor deposition (LPCVD) method using Si₂H₆ at 450°C. The thickness of a-Si film was 50 nm. SiN film was deposited by Cat-CVD method [13]. The following deposition conditions were employed. The flow rates of SiH₄ and NH₃ were 2 and 200 sccm. The pressure in the deposition chamber was 4 Pa. The catalyzer temperature was kept at 1650°C. The hydrogen concentration of SiN film was controlled by changing the substrate temperature during the deposition: The hydrogen concentrations of 2.3, 4.2 and 8.2 at.% correspond to substrate temperature of 400, 300 and 200°C, respectively. The hydrogen concentration is given by measuring the signal intensity of Si-N stretching mode with a use of the Fourier Transform Infra-Red spectrometer (FTIR). The refractive index of SiN film for 2.3 and 4.2 at.% hydrogen was 2.0 and that for 8.2 at.% was 1.95. The thickness of SiN film was 42 nm. The KrF multi-pulse excimer laser was irradiated to the a-Si film at 1 Hz and at room temperature under approximately 10⁻⁴ Pa. The irradiation time was 23 ns at full width at half maximum (FWHM). The energy density and shot number were 318 to 500 mJ/cm² and 8 to 300 shots, respectively. The hydrogens are introduced into the melt-Si from the SiN film during the ELA [12]. The concentration of hydrogens in the poly-Si film are

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close and proportional to that in the SiN film, although they are not measured precisely. The crystallinity and surface morphology of the poly-Si film were measured by Raman spectroscopy, scanning electron microscopy (SEM), transmission electron microscopy (TEM) and electron spin resonance (ESR). Raman spectroscopy was carried out with backscattering geometry and a 514.5 nm Ar ion laser with a spot size of 0.8 μm . The FWHM of the transverse optical (TO) Raman peak of Si(100) wafer was 4.2 cm^{-1} . Secco etching was performed before observing the poly-Si surface by SEM to clarify the film structure and the morphology. The temperature of ESR measurement, the center and range of the magnetic field and power were 10 K, 3367 G, 100 G and 40 μW , respectively.

3. Results and Discussion

3.1 Influence of Hydrogen Concentration on Morphology, Defect Density and Internal Stress of Poly-Si Film

Figure 1 shows the relationship between the FWHM of the Raman peak and the energy density at 8 shots. The FWHM values are nearly constant for the energy density of 318 to 500 mJ/cm^2 and hydrogen concentration of 2.3 and 4.2 at.%. FWHM of Raman peak is related to the defects in the Si [14]. The crystal defect density is nearly constant at 2.3 and 4.2 at.% of hydrogens. The reason why it drastically increases at 500 mJ/cm^2 and hydrogen concentration of 8.2 at.% is due to the hydrogen burst, which we have examined by cross section TEM. It is found that the hydrogen behavior introduced in the melt-Si is very sensitive to the hydrogen concentration and the energy density.

Figure 2 shows the cross section TEM image of the poly-Si at 500 mJ/cm^2 and 8 shots for hydrogen concentration of 2.3 at.%. The poly-Si film is formed uniformly. It is indicated that the poly-Si is formed uniformly at the ELA conditions of present experiment except for 500 mJ/cm^2 and 8.2 at.%.

Figure 3 shows the relationship between $\Delta\omega$ and shot number. This experiment was conducted at 318 mJ/cm^2 to eliminate the hydrogen burst during the ELA. $\Delta\omega$ is the dif-

ference of the Raman peaks between the c-Si (521 cm^{-1}) and poly-Si. $\Delta\omega$ corresponds to the tensile stress τ in the poly-Si grains as shown by eq.(1) [14].

$$\tau [\text{dyn}/\text{cm}^2] = 2.49 \times 10^9 \times \Delta\omega [\text{cm}^{-1}] \quad (1)$$

Although $\Delta\omega$ decreases drastically with increasing the shot number for 2.3 and 4.2 at.%, it decreases gently with the shot number for 8.2 at.%. This result shows that the stress relaxation of poly-Si with hydrogen concentration of 8.2 at.% in SiN film is smaller than that of 2.3 and 4.2 at.%. The phenomenon that the stress relaxation proceeds with increasing the shot number for 2.3 and 4.2 at.% also indicates that the secondary grain growth proceeds with the shot number.

Figures 4(a) and (b) show the SEM images of 2.3 and 4.2 at.% for 318 mJ/cm^2 and 8 shots, respectively. The grain size of poly-Si with 2.3 and 4.2 at.% are estimated to be 575 and 252 nm, respectively. The grain size of 2.3 at.% is larger than that of 4.2 at.%. It is found that the secondary grain growth activates the stress relaxation.

Figure 5 shows the ESR result at 500 mJ/cm^2 for 2.3 at.%. The signal of $g=2.0055$ and that of $g=2.0007$ correspond to the dangling bond in the poly-Si film and that in the quartz substrate, respectively. The spin density in the poly-Si film for hydrogen concentration of 2.3 at.% in SiN film is $2.1 \times 10^{19}/\text{cm}^3$. It is thought that the origin of the spin density is the crystal defects at the grain boundary, as we already pointed at [5].

3.2 Crystallization Model

The results shown in the previous section are clearly un-

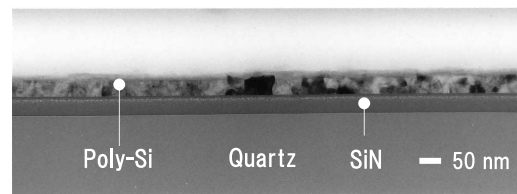


Fig. 2 Cross section TEM image of the poly-Si at 500 mJ/cm^2 and 8 shots for H concentration of 2.3 at.%.

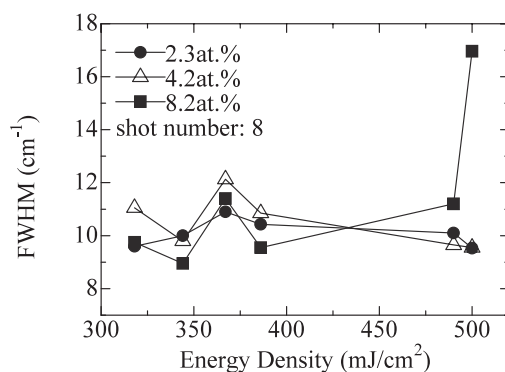


Fig. 1 Relationship between the FWHM of the Raman peak and the energy density at the shot number of 8.

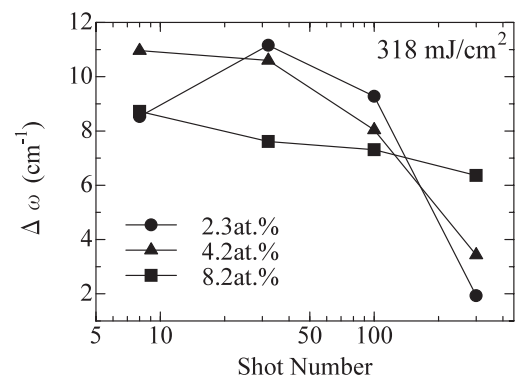


Fig. 3 Relationship between the $\Delta\omega$ and shot number. $\Delta\omega$ is the difference of the Raman peak between the c-Si (521 cm^{-1}) and poly-Si.

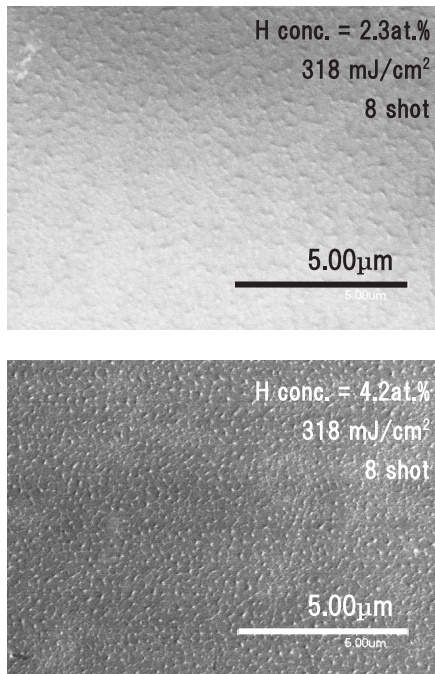


Fig. 4 SEM images of 2.3 at.% (a) and 4.2 at.% (b) for 318 mJ/cm² and 8 shots, respectively.

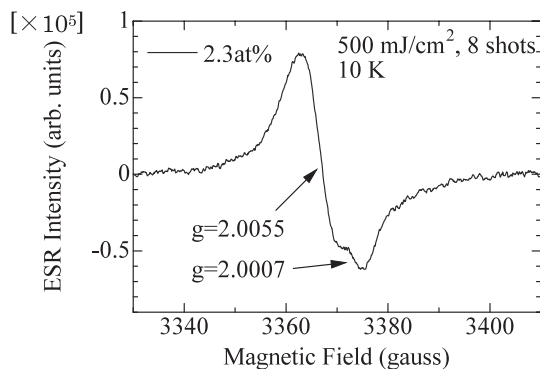


Fig. 5 ESR result at 500 mJ/cm² for 2.3 at.%.

derstood by using following the model. Figure 6 shows the model of the secondary grain growth under the solid phase crystallization (SPC). We already reported that the grain enlargement of poly-Si under the solid phase occurs by carrying out the multi-pulse laser irradiation at low energy density [3]. The theory of the secondary grain growth by the SPC was studied by Thompson [15], and our proposed model also assumes the SPC process [4], [5]. The present model was constructed by taking into considerations of the following experimental results. First, in-grain defects disappear under the laser irradiation because of the defects movement to the grain boundary [5]. Second, the rapid secondary grain growth occurs when the laser energy density and shot number reach critical values [6]. These phenomena indicate that the secondary grain growth occurs when the sum of the laser energy density and the crystal defects energy

Critical condition for secondary grain growth:

Laser energy density

+ Crystal defect energy at grain boundary = Critical value
(=strain energy)

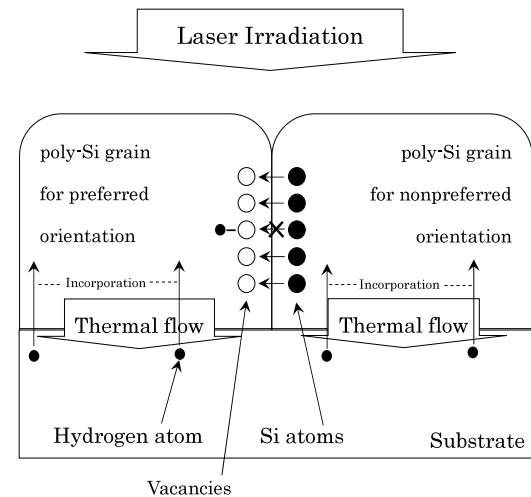


Fig. 6 SPC model considering the incorporation of the hydrogen.

per unit area becomes a critical value. Si atoms in the grain with non-preferred orientation move to the grain with preferred orientation via the grain boundary. The grain boundary movement from the left to right occurs. The secondary grain growth and the internal-stress relaxation, which proceeds through the secondary grain growth, occur simultaneously. The present model assumes that the strain energy, which is generated by the crystal defect at the grain boundary, is released at the start of the secondary grain growth. The hydrogen atoms incorporated in the Si during the ELA form the hydrogen-vacancy pair at the grain boundary and it prevents the secondary grain growth. Therefore, the grain size increases with decreasing the hydrogen concentration. Our experimental results support the present growth model as follows. First, the internal stress of the poly-Si film decreases as increasing the shot number as explained in Fig. 3. The grain enlargement is observed as increasing the shot number. This phenomenon fits to the model in the point that the secondary grain growth leads to the internal-stress relaxation. Second, the grain size of poly-Si secondary grain with 2.3 at.% is larger than that with 4.2 at.% as shown in Fig. 4. This phenomenon also fits to the present model from a viewpoint of the effect of hydrogen on the grain growth[†]. It was also reported that the grain sizes of poly-Si with hydrogen concentrations of 1.3 and 2.8 at.% are 500 and 150 nm, respectively [16]. It seems to be right that the hydrogen concentration in the Si film influences the grain size.

The present model does not apply to high concentration of hydrogen, such as 8.2 at.%. The stress relaxation

[†]Details will be appeared elsewhere.

also has a close relationship with the hydrogen concentration. Thus, it is important for the secondary grain growth utilizing ELA to decrease the hydrogen concentration in the Si film. The formation of SiN film on the glass substrate is also necessary from a viewpoint of suppressing the diffusion of contaminations such as K or Na into the a-Si layer. The advantage of Cat-CVD method comparing with thermal CVD and PECVD method to prepare SiN film with low hydrogen concentration was shown in ref 13. The formation of SiN film with low H concentration by Cat-CVD process is necessary to realize high reliability of the TFTs.

4. Conclusions

The influence of hydrogens, which was introduced from the Cat-CVD SiN film into the melt-Si film, on the laser crystallization of Si was examined. For the poly-Si film with a low hydrogen concentration crystallized on the SiN film from 2.3 to 4.2 at.% hydrogens, the stress relaxation of poly-Si proceeded with increasing the shot number and the grain size increased as decreasing the hydrogen concentration. The defect density at the grain boundary deduced from the spin density was $2.1 \times 10^{19}/\text{cm}^3$. For the poly-Si film with a high hydrogen concentration crystallized on the SiN film of 8.2 at.% hydrogens, the hydrogen burst occurred at $500 \text{ mJ}/\text{cm}^2$ and the dependence of the internal stress of the poly-Si film on the shot number becomes weak even at $318 \text{ mJ}/\text{cm}^2$. These results dependent on hydrogen concentration support the crystallization model which we have already proposed. The present model is effective to clarify precisely the laser crystallization phenomenon of the Si film including hydrogens with low concentration. And also Si/SiN film structure is very useful to obtain large grain sized poly-Si films using Si/SiN film structure.

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