Crystal Growth of Low-Temperature Processed Poly-Si by Excimer Laser Annealing —Dependences of Poly-Si Grain on Energy Density and Shot Number—

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This paper examines the characteristics of the poly-Si grains formed by ELA with the energy density from 75 mJ/cm² to 400 mJ/cm², and discusses the change of the crystal growth mechanism of the recrystallized poly-Si dependent on the energy density. For the energy density from 250 mJ/cm² to 350 mJ/cm², the disk-shaped grains are observed. The dependences of the area ratio of disk-shaped grain both on the energy density and on the shot number are examined. From these results, the role of the disk-shaped grains for the change of the crystal growth mechanism dependent on the energy density is clarified.

Keywords: poly-Si grains, ELA, disk-shaped grains, crystal growth mechanism

1. Introduction

The characteristics of the recrystallized poly-Si film prepared by excimer laser annealing (ELA) and that of the thin film transistors (TFTs) fabricated on the film have been examined^{1,2)}. The growth model of the recrystallized poly-Si under the high energy density has been presented from a viewpoint of the nucleation from the super cooled liquid (SCL)³⁾. However, considering the fact that the entire irradiated amorphous Si (a-Si) becomes poly-Si grains after a certain shot number for multi-pulse laser irradiation under a low energy density, smaller than 250 mJ/cm² and the melting point of the poly-Si is higher than that of a-Si, the super cooled liquid is not thought to be formed in the range above the shot number. We have examined the characteristics of the low-temperature processed poly-Si formed at the energy density of 75~250 mJ/cm², and presented a new crystal growth model based on the solid phase crystallization (SPC) which proceeds during low-energy density ELA. The crystal growth mechanism is understood through the dislocation movement⁴⁾.

This paper examines the characteristics of the poly-Si grains formed by ELA with the energy density from 75 mJ/cm² to 400 mJ/cm², and discusses the crystal growth mechanism of the recrystallized

poly-Si. For the energy density from 250 mJ/cm² to 350 mJ/cm², the disk-shaped grains are observed. First, the dependence of the ratio of disk-shaped grain on the energy density is examined. Secondly, the dependence of that of the disk-shaped grains on the shot number is examined. From these results, the change of the crystal growth mechanism depending on the energy density and shot number is discussed.

2. Growth and Analysis Methods

An a-Si film is deposited on the quartz substrate by the low pressure chemical vapour deposition (LPCVD) method using Si₂H₆ for the film with the hydrogen concentration (H₂ conc.) of 4E20. The film thickness is 100 nm. The KrF multi-pulse excimer laser is irradiated after the a-Si formation at 1 Hz and at room temperature under approximately 10⁻⁴ Pa. The irradiation time is 23 nS at full width at half maximum (FWHM). The energy density and the shot number are 200~400 mJ/cm² and 8~100, respectively. The crystallinity and surface morphology of the poly-Si film are measured by the Raman spectroscopy and scanning electron microscopy (SEM), respectively. Secco etching was performed before observing the poly-Si surface by SEM to clarify the film structure and the morphology.

Fig. 1 Relationship between the Raman intensity and shot number for 175 ~ 225 mJ/cm².

3. Results and Discussion

3.1 Influence of energy density on the grain morphology

Figure 1 shows the relationship between the Raman intensity and shot number for 175 ~ 225 mJ/cm². The crystallinity of poly-Si increases at the critical laser irradiation condition, 225 mJ/cm² and 100 shots. Although it is difficult to identify the recovery and primary recrystallization process, the secondary recrystallization is identified as the condition of 225 mJ/cm² and 100 shots and 200 shots. Fig. 2(a) and 2(b) show the SEM photographs of the poly-Si surface for the condition of 225 mJ/cm² and 32 shots and 225 mJ/cm² and 100 shots, respectively. The poly-Si grains become large as increasing the shot number, and the SPC occurs under the low energy density.

Figures 3(a) ~ 3(d) show the SEM photographs of the poly-Si surface for the energy densities of 250 mJ/cm², 300 mJ/cm², 350 mJ/cm² with the shot numbers of 8, and the schematic illustration of the SEM photograph of poly-Si surface, respectively. It is found that both the disk-shaped grains and the small size grains by the SPC grow and the area of the disk-shaped grains becomes large as increasing the energy density. It is considered that there is a nucleus in the center of the disk-shaped grains. Although they are observed at the energy density larger than 250 mJ/cm² in the present experiment, it is also reported that the disk-shaped grains are formed by the ELA at the energy density of 178 mJ/cm² followed by SPC⁹. Fig. 4 shows the relationship between the area ratio of the disk-shaped grain and energy density. The area ratio of the disk-shaped grains becomes large as increasing the energy density. Fig. 5 shows the SEM photographs of the poly-Si surface for the condition of

(a)

(b)

Fig. 2(a), (b) SEM photographs of the poly-Si surface for the condition of 225 mJ/cm² and 32 shots and 225 mJ/cm² and 100 shots, respectively.

400 mJ/cm² and 8 shots. It is found that the disk-shaped grains are not observed at the large energy density, and the grains with the size of approximately 40 nm grow.

3.2 Influence of shot number on the grain morphology

Fig. 6(a) ~ 6(c) show the SEM photographs of the poly-Si surface for the shot numbers of 8, 32 and 100 with the energy density of 250 mJ/cm², respectively. Fig. 7(a) ~ 7(c) show the SEM photographs of the poly-Si surface for the shot numbers of 8, 32 and 100 with the energy density of 300 mJ/cm², respectively. Fig. 8(a) ~ 8(c) show the SEM photographs of the poly-Si surface for the shot numbers of 8, 32 and 100 with the energy density of 350 mJ/cm², respectively. It is found that the disk-shaped grains grow and the area of them becomes large as increasing the shot numbers. Although the disk-shaped grains are observed almost entire area for 350 mJ/cm², the gatherings of the small grains which are due to the SPC are observed. Fig. 9 shows the relationship between the

(a)

(b)

(c)

area ratio of the disk-shaped grain and shot numbers for the energy densities of 250 ~ 350 mJ/cm². For 300 mJ/cm², the dispersion of the area ratio of the disk-shaped grains is observed. This may be because of the fluctuation of laser energy density at the Si surface. The area ratio of disk-shaped grains becomes large as increasing the shot numbers at the condition of 250 and 350 mJ/cm².

3.3 Change of the crystal growth mechanism from low to high energy density

From the experimental results, the change of the crystal growth mechanism dependent on the energy density is discussed. Fig. 10 summarizes the present experimental results. For the low energy density

SPC

(d)

Fig. 3(a) ~ (d) SEM photographs of the poly-Si surface for the energy densities of 250 mJ/cm², 300 mJ/cm² and 350 mJ/cm² with the shot numbers of 8, and schematic illustration of the SEM photograph of poly-Si surface, respectively.

Fig. 4 Relationship between the area ratio of the disk-shaped grain and energy density.

Fig. 5 SEM photographs of the poly-Si surface for the condition of 400 mJ/cm² and 8 shots.

(a)

(a)

(b)

(b)

(c)

Fig. 6(a) ~ (c) SEM photographs of the poly-Si surface for the shot numbers of 8, 32 and 100 with the energy density of 250 mJ/cm², respectively.

(c)

Fig. 7(a) ~ (c) SEM photographs of the poly-Si surface for the shot numbers of 8, 32 and 100 with the energy density of 300 mJ/cm², respectively.

smaller than 250 mJ/cm², the SPC occurs⁴⁾. For the high energy density larger than 400 mJ/cm², crystallization from the super cooled liquid occurs. The conditions of the crystal growth by SPC are painted and those by SCL are not painted. The transient condition between the SPC and the SCL correspond to the area with a tone of color. For a certain energy density, the area ratio by the SCL increases with increasing the shot number and at a

certain shot numbers the area ratio equals to 1. For the shot number, the same phenomenon occurs.

The relationship between the critical grain size r^* and the super cooled rate ΔT is given by eq. (1).

$$r^* = \frac{2vT_E}{L\Delta T} \quad (1)$$

Here, v , T_E , L are the surface free energy per unit area, the melting temperature and the latent heat,

(a)

(b)

(c)

Fig. 8(a) ~ (c) SEM photographs of the poly-Si surface for the shot numbers of 8, 32 and 100 with the energy density of 350 mJ/cm², respectively.

respectively. For the high energy density, the super cooled rate ΔT is large and the critical grain size r^* becomes small: The generation of the nucleus is accelerated. This leads to a decrease of the grain size at the energy density of 400 mJ/cm². In the transient energy density, the formation of both the disk-shaped grains and the small grains by the SPC occurs. Fig. 11 shows the schematic model of the crystal growth during the transient stage. The dis-

Fig. 9 Relationship between the area ratio of the disk-shaped grain and shot numbers for the energy densities of 250 ~ 350 mJ/cm².

Fig. 10 Summary of the present experimental results.

persion of the surface temperature due to the fluctuation of the energy density during the stage is around the melting temperature of the poly-Si. In the surface area which temperature is higher than the melting temperature, the poly-Si becomes the super cooled liquid and the nuclei of the disk-shaped grains are formed in the super cooled liquid. In the surface area which temperature is smaller than the melting temperature, the SPC proceeds. The total energy irradiated to the Si surface is shown by product of the energy density and the shot number. As increasing the total energy, the area ratio of the SCL becomes large due to the increase of the fluctuation. Therefore, the area ratio of the disk-shaped grain becomes large, as increasing the energy density or the shot number.

Fig. 11 Schematic model of the crystal growth in the transient area.

4. Conclusions

In the range from low to high energy densities, the change of the crystal growth mechanism of recrystallized poly-Si film was examined. In the energy density smaller than 250 mJ/cm², the SPC proceeds. In the energy density larger than 400 mJ/cm², the crystal growth from the super cooled liquid proceeds. In the transient stage of the energy density from 250 mJ/cm² to 400 mJ/cm², the dispersion of the surface temperature is around the melting temperature of the poly-Si and both crystal

growth mechanisms occur simultaneously: The disk-shaped grains are observed at the melted area and the number of them increases as increasing the energy density and shot number.

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