Influence of the beam irradiation condition with oblique incidence on crystallization of an Si film by a linearly polarized pulse laser

Yasunori Nakata, Hirokazu Kaki and Susumu Horita
JAIST (Japan Advanced Institute of Science and Technology), Ishikawa, JAPAN

ABSTRACT

We investigated influence of the beam irradiation conditions with oblique incidence on crystallization of an Si film by a linearly polarized pulse laser in order to enlarge the periodic width of grain boundary. The irradiation conditions are fluence, pulse number and film thickness. We can obtain the periodic width of about 900 nm by increasing the incident angle to 25^o. The experimental results suggest that the pulse number and the film thickness should be controlled properly as well as fluence in order to produce large grain stably for the oblique incidence. The detail of these conditions was discussed.

INTRODUCTION

Poly-Si films have been widely applied to thin film transistors (TFTs) for liquid crystal display. Among several methods to fabricate the poly-Si film, the pulse laser annealing (PLA) method is effective to produce large grains with high carrier mobility. In order to control the location of the grain boundary which reduces the mobility, several modulated PLA methods have been proposed using an absorption layer [1], a pre-patterned poly-Si layer [2] and so on [3]. Also, interference PLA methods have been introduced by some authors using a beam-splitter [4] and a phase-shift mask [5]. However, these methods need the additional process of deposition and patterning or additional optical components.

On the other hand, it has been reported that linearly polarized laser irradiation induces periodic structures on the surfaces of semiconductors [6] and metals [7]. This means that the

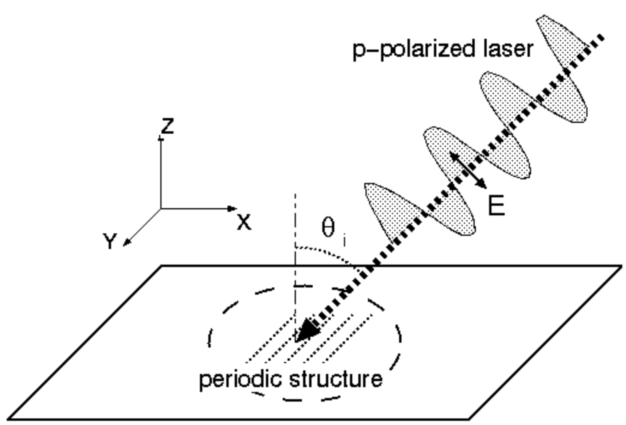


Figure 1. Schematic diagram of periodic structure produced by a linearly polarized laser beam.

laser irradiation produces the periodic temperature distribution on the surface. This grating or ripple spacing of the surface structure is formulated as $\lambda/[n_0(1 \pm \sin\theta_i)]$ for the p-polarized beam according to Raylegh's diffraction condition, where λ is the incident laser wavelength and θ_i is the incident angle. The direction of the stripe is perpendicular to that of the electric field of the incident beam as shown in Fig. 1.

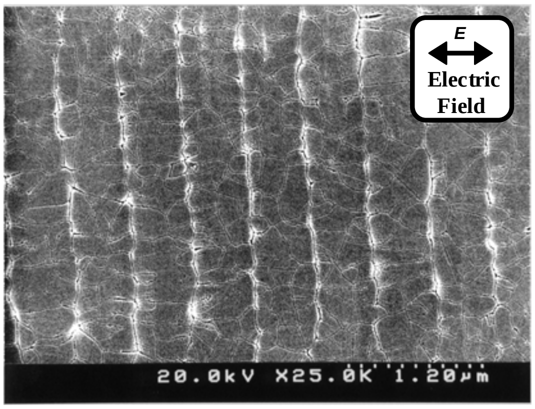
By applying this phenomenon to PLA methods, we made the grain boundaries align in parallel one another with the width of the laser beam wavelength and obtained stripe large grains on a glass substrate for the almost normal incident $\theta_i \fallingdotseq 0$ [8]. In order to enlarge the periodic width of the crystallized stripe, we increased the incident angle θ_i to 25^o, where the larger periodic width is calculated to be 920 nm from the Rayleigh's diffraction condition. In this paper, we present the influence of the beam irradiation conditions with the oblique incidence $\theta_i = 25^o$ on melting-crystallization of an Si film on a glass substrate.

EXPERIMENTAL

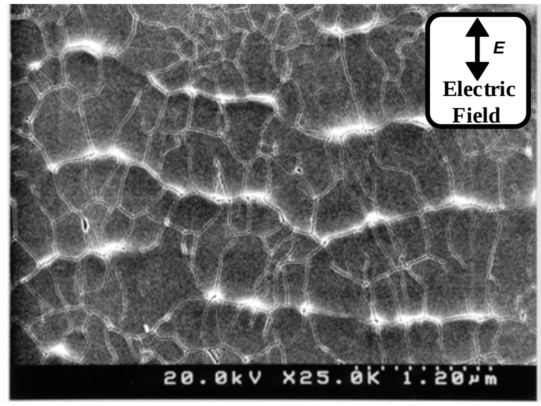
A 55- to 120-nm-thick a-Si film deposited on a Pyrex glass substrate at 350 ^oC was irradiated by an Nd:YAG pulse laser beam at 220^oC with θ_i of 25^o in the ultra high vacuum chamber. The wavelength, the repetition frequency and the pulse width of the laser beam were 532 nm, 10 Hz and 6-7 nsec, respectively. The laser fluence was 100 to 225 mJ/cm^2 and the number of the pulse was 1 to 100. After melting-crystallization, some samples are Secco-etched in order to reveal the grain boundaries.

RESULTS AND DISCUSSION

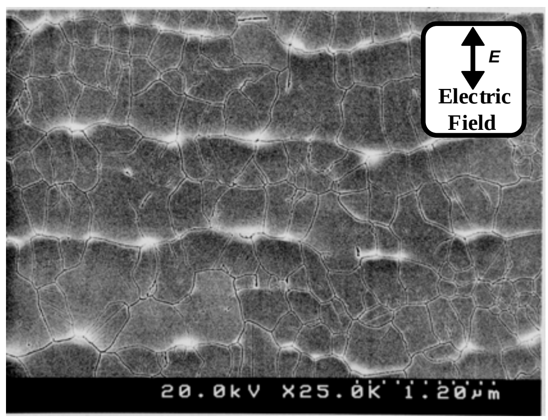
Figures 2 (a), (b) and (c) show SEM images of the Secco etched Si films crystallized at the beam fluences of 90, 110 and 110 mJ/cm^2, respectively, where the thickness of the a-Si is 60 nm and the pulse numbers for (a), (b) and (c) are 5, 5 and 30, respectively. In these figures, the arrows indicate the electric field directions of the incident laser beam. We can recognize from Figs. 1 (a) and (b) that the periodic boundaries in both melting-crystallized Si films are aligned perpendicularly to the electric field and that the widths of grain boundary in (a) and (b) are 550 and 650-960 nm, respectively. Although the width of crystallized grain in Fig. 1 (b) is surely enlarged by increasing the incident angle, the width and direction of grain boundary are unstable or fluctuated. This means that the periodic temperature distribution induced with the oblique incidence is more unstable than with normal incidence or the amplitude of the periodic temperature distribution with the oblique incidence is smaller than with the normal incidence. On the other hand, by means of increasing the pulse number to 30, even with oblique incidence, the fluctuation of the width and direction of the periodic grain boundary in the crystallized Si film is further reduced as shown in Fig. 2 (c). It can be considered from this result that increasing the pulse number enhances the amplitude of the periodic temperature distribution. Also, comparison of the results between Figs. 2 (b) and (c) suggests that the formation of the periodic grain boundary strongly depends on the pulse number. Although it is necessary to check the formation of the grain boundary in every sample for study, Secco-etching process destroys the sample and it takes much longer time to observe them. So, from the next experiment, we observed the periodic surface roughness by Nomarsky optical microscope without Secco-etching because the periodic surface roughness is resulted from collision between solidification fronts of the lateral



(a) Normal incidence
F=90 mJ/cm^2 and pulse number=5.



(b) Oblique incidence (θ_i=25^o)
F=110 mJ/ cm^2 and pulse number=5.



(c) Oblique incidence (θ_i=25^o)
F=110 mJ/ cm^2 and pulse number=30.

Figure 2. SEM images of the Secco-etched Si films crystallized at 220^{o}C. The arrow lines indicate the electric field directions of the irradiation beam.

growth of Si film so that it indicates the location of the grain boundary.

We investigated the influence of pulse number on the periodic surface roughness of the crystallized Si film. Figure 3 shows the dependences of the periodic surface roughness area ratio on the pulse number at the laser fluences of 110 to 225 mJ/cm^2, where the pulse numbers in (a) and (b) are 0 to 20 and 0 to 100, respectively. The periodic surface roughness area ratio of 100% means that the whole observed area (0.1 mm$\times$0.1 mm) of the sample has the periodic surface roughness. When the fluence was less than 90 mJ/cm^2, the periodic roughness was not formed or the Si film was not enough molten. In the cases of 110, 135 and 150 mJ/cm^2, the periodic area ratios approach the saturation value of 100% with the pulse number more than 40. However, in the case of more than or 180 mJ/cm^2, the periodic roughness ratio achieves a maximum less than 70% at some pulse number smaller than 10 and decreases with increasing the pulse number further. This is because the crystallized film is easily damaged or ablated even with small pulse

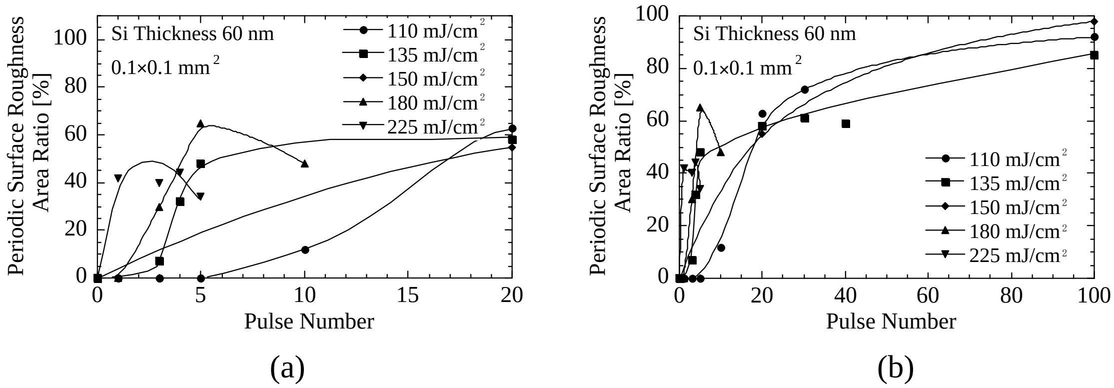


Figure 3. Dependences of periodic boundary area ratio on the substrate temperature at 220°C and various laser fluences. Pulse numbers are (a) less than 20 and (b) from 0 to 100.

number due to its high fluence and the surface becomes too rough to induce the periodic temperature profile in the film. Also, we can explain the phenomenon that the periodic surface roughness area ratio is increased with the pulse number at the initial stage as follows; According to Siegman's report [9], the amplitude of the periodic temperature distribution induced by a linearly polarized laser beam is increased with the periodic surface roughness. Though the surface of an as-deposited Si film has the random roughness with very small height, it maybe has a spatial periodic component that produces the diffracted light progressing the surface. The surface roughness with the spatial component is slightly increased by the first pulse. An increased surface roughness leads the diffracted light intensity to increase, which leads modulation of the incident beam to increase, so that the amplitude of the periodic temperature distribution is increased. Therefore, the periodic surface roughness area ratio is increased with the pulse number.

Figure 4 shows the dependences of the periodic surface roughness area ratio on the pulse number to 30 for various thicknesses of a-Si film from 55 to 120 nm. In this case, the laser fluence was 135 mJ/cm^2. We can see from this figure that the periodic surface roughness area ratio is increased with the pulse number except for the 55 nm thickness and that the film thickness dependence seems complicated. However, this result is roughly explained as follows; According to calculation of the optical absorptivity of a poly-Si film on an SiO_2 substrate considering multiple reflection, the absorptivity has maxima periodically by each about 60 nm. Also, numerical thermal analysis shows that the amplitude of the induced periodic temperature distribution is enhanced with the fluence or the absorption of beam power in the irradiated film. So, the amplitude of the induced periodic temperature distribution has the maxima by each 60 nm, which means that the formation of periodic surface roughness is promoted periodically by each 60 nm. However, increasing the film thickness increases lateral thermal conduction of the molten film to reduce the amplitude of the periodic temperature profile. Therefore, for 55- and 60-nm-thick film thicknesses whose optical absorption is maximum, the amplitudes or the periodic surface roughness area ratios increase with the pulse number faster than other film thickness. However, the irradiated film with 55 nm thickness is easily evaporated and ablated due to its high absorption and thinner thickness. So, the maximum of the periodic surface roughness area ratio is small, less than 30%. However, the 60-nm-thick film is hardly damaged although the thickness is a little larger and comparable to 55 nm. We do not well understand the reason of this difference in phenomenon at present. On the other hand, for thicker thickness more than or equal to 72 nm, the amplitude is increased with the pulse number slowly compared to the cases of 55 and 60 nm. Also, increment of the periodic surface roughness area ratio to the pulse number is decreased roughly with the film thickness. However, because the film with 120 nm thickness has the second maximal optical absorptivity, the periodic surface roughness area ratio at 10 pulse numbers is larger than that of 98 nm thickness. Therefore, in order to optimize the laser condition to produce the periodic grain boundary stably, we must take account of film thickness and control it properly as well as fluence, in particular, for oblique incidence.

CONCLUSION

We can enlarge the periodic grain boundary to about 900 nm by linear polarized laser irradiation with the oblique incidence of $\theta_i = 25^o$. In case of the oblique incidence, in order to produce the large width of the grain boundary stably, the irradiation conditions of the film thickness and pulse number should be controlled properly as well as the fluence. The film thickness should be set to have a maximum optical absorptivity for the wavelength of the pulse laser. The pulse number should be decided to make the amplitude of the periodic temperature distribution so that the lateral growth of crystallized Si film occurs smoothly. The pulse number is too small to make enough amplitude and too large to produce a continuous film, in particular, a thinner film. From a viewpoint of mass-productivity, the pulse number should be reduced as well as possible.

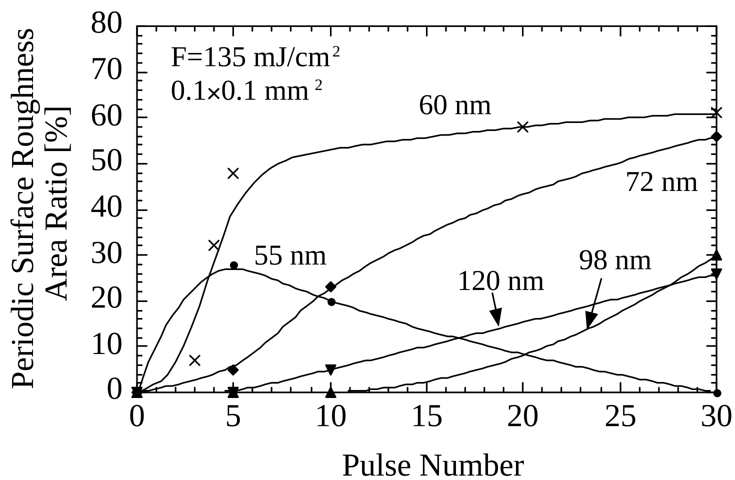


Figure 4. Dependences of periodic surface area ratio on pulse number at 135 mJ/cm^2 for various a-Si thicknesses.

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