Crystallization behavior of a-Si film using UV pulsed laser

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Abstract

We studied the crystallization behavior of LP-CVD a-Si film using UV pulsed laser. With increase in the shot number of irradiation by fixing its energy density, poly-Si film having a large grain size of 0.5 μm was obtained. By analyzing the crystallized Si films using optical analysis such as Raman spectroscopy or AFM technique etc., conspicuous correlation between the grain size and the resultant film properties such as the stress or the roughness has been found. With the increase in the energy density or the shots number of laser, remarkable grain growth occurred following to the roughness formation corresponding to the increase in the tensile stress.

1. Introduction

The Active Matrix Liquid Crystal Display using a-Si:H TFT became already the main stream in display industry. The TFT-LCD using a-Si:H TFT has, up to now, conquered the markets of a laptop computer and a PC monitor, respectively and is presently extending the markets to the field of a TV and a mobile phone. However, because of the physical limitation of a-Si:H TFT (low mobility ; $\mu_n < 1$ cm^2/Vs, $\mu_p < 10^{-2}$ cm^2/Vs), the many people have concentrated on research and development of low temperature poly-Si TFT and the many institutes have a big concern [1], [2].

For the formation of LTPS films using crystallization of a-Si films, the various methods have been tried so far. The two main streams among them are the method of MIC (Metal Induced Crystallization) and ELA (Excimer Laser Annealing) [3], [4]. However, in current FPD field, there are attempts changing the substrate from glass to plastic. In that case, it becomes more important to crystallize a-Si films using laser annealing [5], [6], [7]. The many researches are studying crystallization of a-Si films based on laser annealing technique.

So far, the some previous researchers had already tried the multi shot effect of poly-Si film using the UV pulsed laser annealing. Almost 10 years ago, Kuriyama et al. had attempted to crystallize a-Si film by performing various laser shots up to 128 shots at the constant laser energy density [8]. They reported the experimental result that the grain sizes are increased by increased laser shots, and the films with large grains shows the preferred crystal orientation in (111) direction. The other research group attained the similar results. [9] Meanwhile, Matsuo et al. attained some notable result. [10] They irradiated the multiple laser between 8 and 200 shots at the various energy density from 175 to 225 mJ/cm^2. In the case of comparatively low laser energy density of 175 mJ/cm^2, they found that the grain size does not change by increasing the number of shots. Such a grain-growth mechanism should be studied in more detail.

In this paper, we analyzed the mutual relation between a film stress, a surface roughness and a grain size of poly-Si films. The result would give us a help to understand the multi-shot effect for the grain growth and the optimized ELA condition, which can control the giant grains.

2. Experimental

The SiO_2 films with the thickness of 200 nm were deposited on a corning 1737 glass for suppressing a diffusion of impurities from glass into a-Si film during laser annealing. The a-Si films were deposited on the glass substrate by using Low Pressure Chemical Vapor Deposition (LP-CVD). The thickness of a-Si films was 50 nm. The a-Si films were crystallized by UV pulsed ELA. The used UV pulsed laser is the XeCl excimer laser with a wavelength of 308 nm. The laser energy density was chosen between 100 mJ/cm^2 and 400 mJ/cm^2. The number of shots was increased from 1 to 200 shots. The ELA were done at an atmospheric pressure and a room temperature, respectively. The degree of crystallization was examined by using Raman spectroscopy and UV reflectance spectroscopy [11]. The grain size was measured by using a Scanning Electron Microscopy

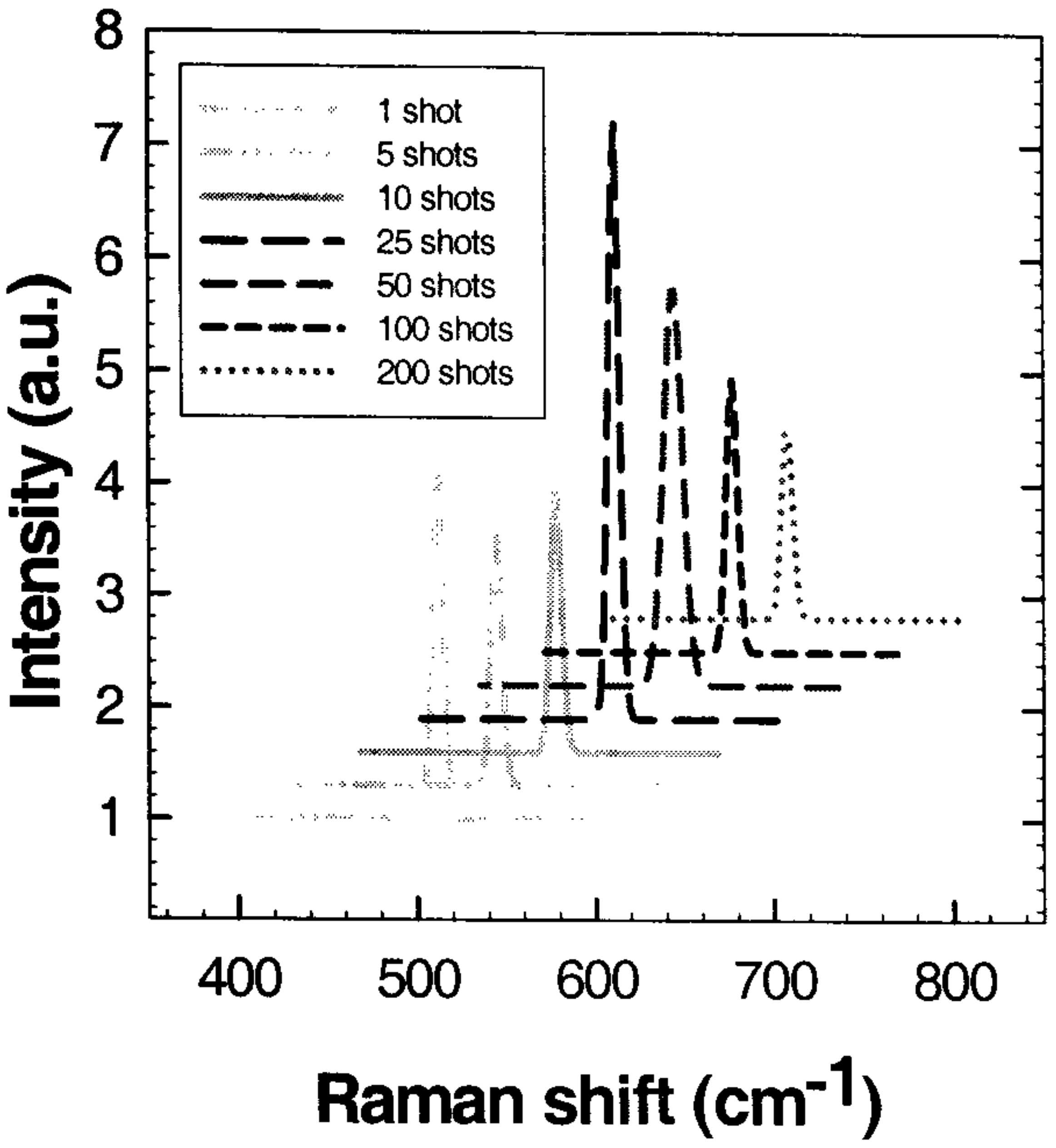

Figure 1 The intensity of Raman shift as a function of multiple shots ; 1, 5, 10, 25, 50, 100 and 200 shots (energy density : 240 mJ/cm^2).

(SEM). The Secco Etching method was performed before observing the surface images of poly-Si films (SEM). By the Secco Etching, both a part of the a-Si and the grain boundary are selectively removed and the crystallized part in total Si region is remained. The surface roughness was measured by using Atomic Force Microscopy (AFM) and UV reflectance spectroscopy. Finally, the film stress is examined by Raman spectroscopy. In the c-Si film, the peak position of the Raman shift by LO-TO phonon stays a 520 cm^{-1} [12], [13]. Normally, the peak position of poly-Si films crystallized by UV pulsed laser annealing exhibits the smaller wavenumber than 520 cm^{-1} by receiving a tensile stress.

3. Results and discussion

Figure 1 shows the variation of the peak intensity at Raman spectroscopy. The peak of degenerated LO-TO phonon mode by c-Si appears at the wavenumber of 520 cm^{-1}. Generally, the stronger peak intensity means that the Si film has the larger portion of poly-Si in a whole film [14], [15]. In figure 1, the crystallization ratio increases with increasing the number of shots from 1 shot up to 25 shots. But the crystallization ratio decreases conversely with increased shots from 25 shots up to 200 shots. These results are supported by SEM images of figure 2. The grain size of the poly-Si

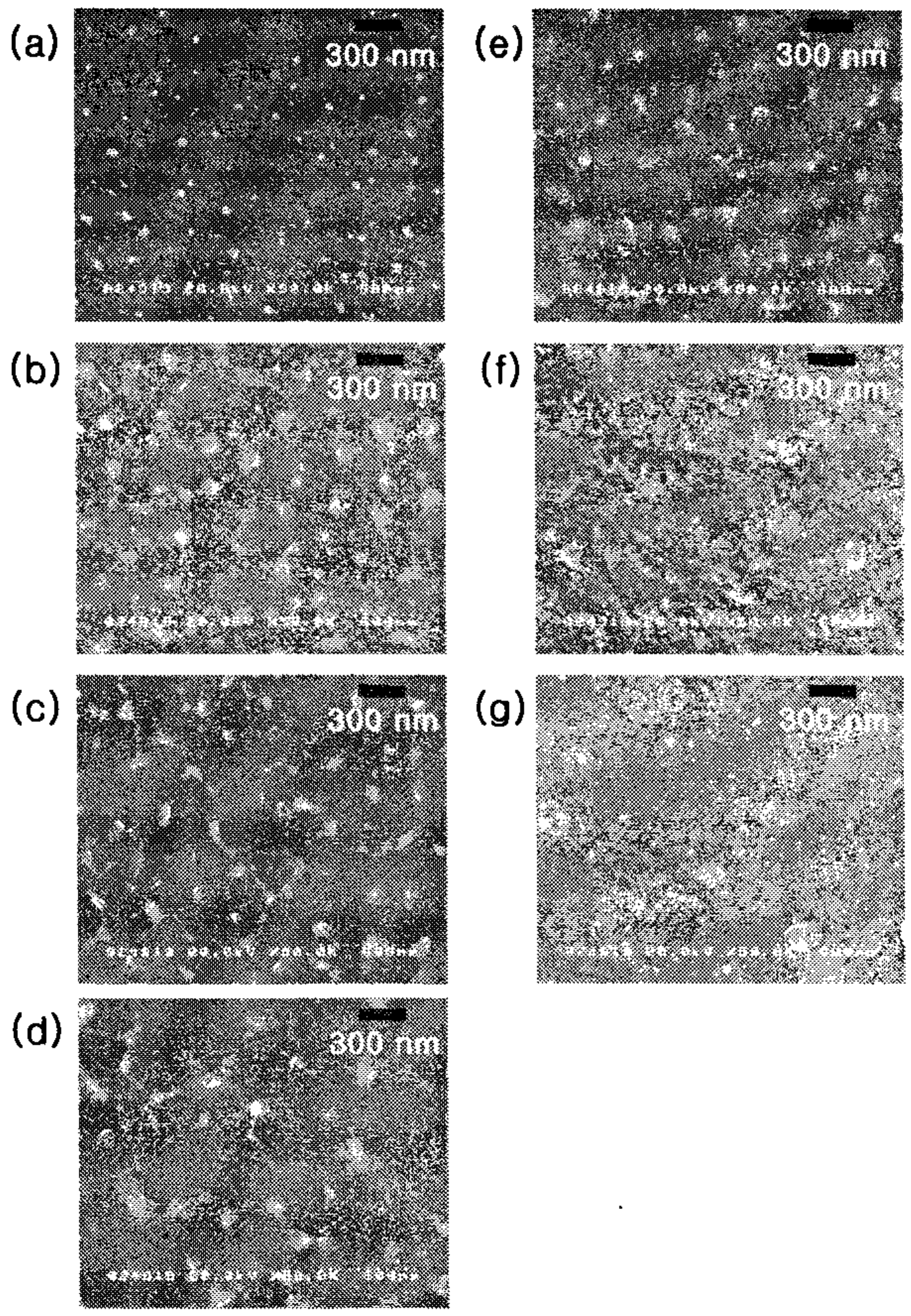

Figure 2 The SEM images as a function of multiple shots ; (a) 1 shot, (b) 5 shots, (c) 10 shots, (d) 25 shots, (e) 50 shots, (f) 100 shots and (g) 200 shots (energy density : 240 mJ/cm^2)

film by 1 shot irradiation of UV pulsed laser is about 150 nm (fig. 2 (a)). The grain size increases with the increased number up to 25 shots. The maximum grain size at 25 shots is about 500 nm (fig. 2 (b)). The grain size at 50 shots decreases to about 300 nm (fig. 2 (b)). In the case of 100 and 200 shots, the grain size decreased rapidly. Such a behavior after multi shots has not studied in details [8], [9], [10]. In order to examine the macroscopic crystallinity of the poly-Si films, we measured the reflectance of poly-Si film at UV region between 200 nm and 400 nm. Figure 3 shows UV reflectance of the same sample. The result of UV reflectance exhibits the similar trend as the results appeared at Raman spectroscopy and SEM images.

In order to understand the grain growth mechanism of Si film for the laser annealing of multiple shots, we summarize the results of the surface rroughness, the shifts of Raman peaks and the grain size as a function

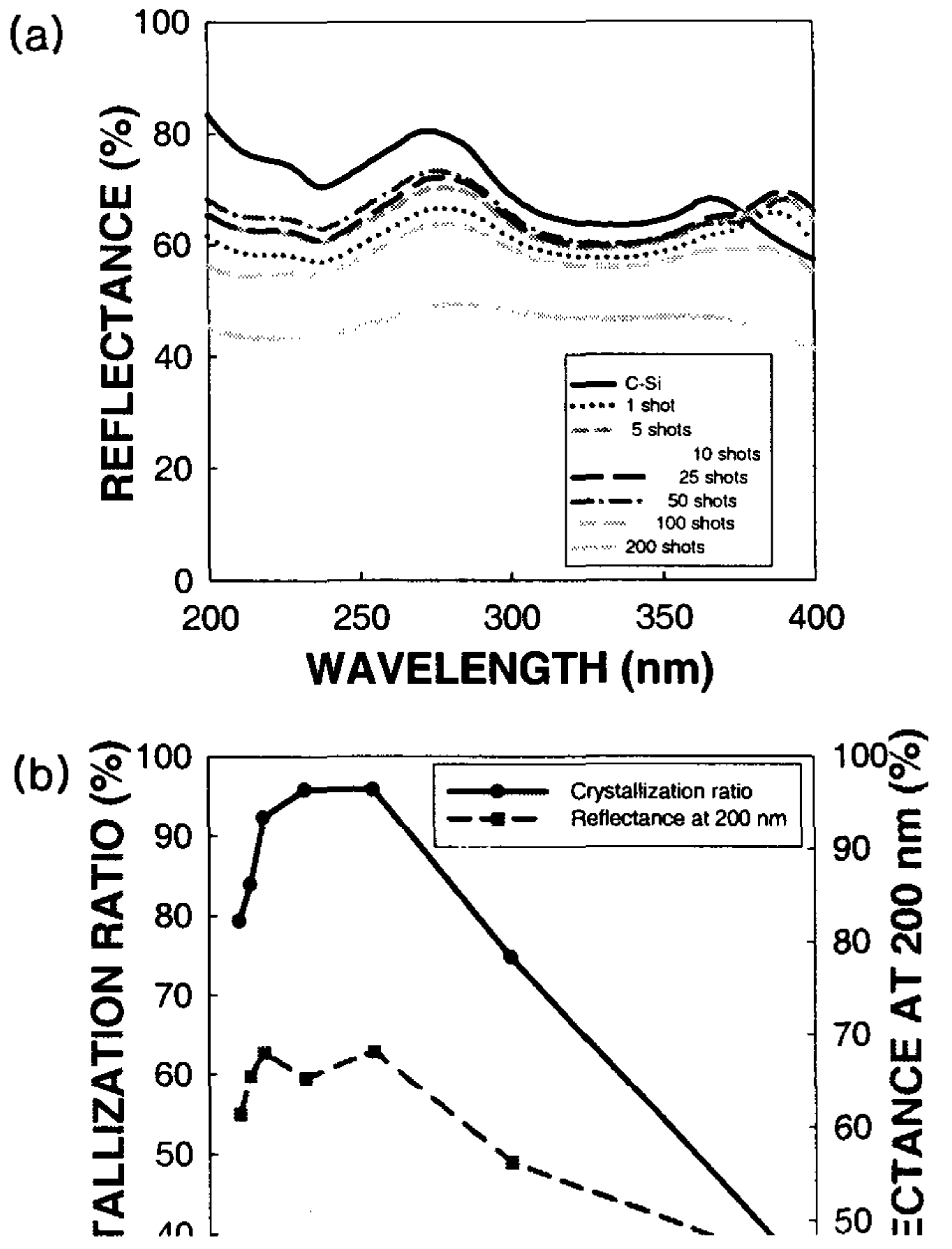

Figure 3 (a) The UV reflectance as a function of the multiple shots (b) The crystallization ratio and the reflectance at 200 nm wavelength.

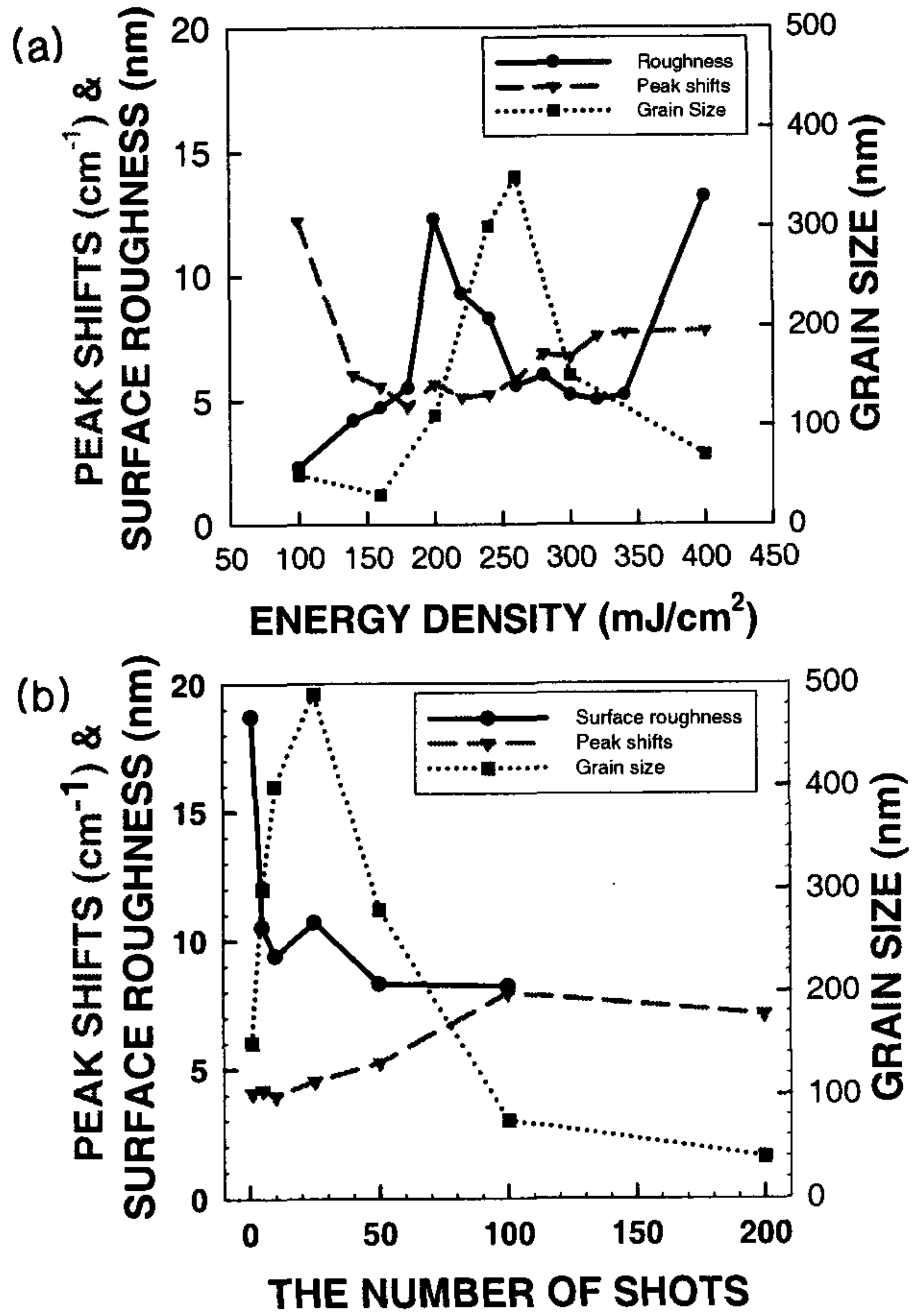

Figure 4 The shift of a peak position at Raman spectroscopy, the surface roughness and the grain size as a function of (a) laser energy density at 50 shots and (b) the multiple shots at 240 mJ/cm^2.

f laser energy density and the number of shots, respectively, as shown in figure 4. In figure 4 (a), at lowest laser energy density of 100 mJ/cm^2, the grain size is about 50 nm close to the film thickness, the surface roughness is smallest and the stress of poly-Si film shows the maximum. Generally, the poly-Si films have a tensile stress by the densification of films during crystallization from an a-Si film to a poly-Si film and generate the minus shifts of the LO-TO phonon mode at Raman spectroscopy [12], [13]. At energy density of 200 mJ/cm^2, the grain size increases to about 150 nm, the surface roughness is highest and the film stress decreases rapidly and increases slowly till the energy density of 400 mJ/cm^2. In the rage of energy density below 260 mJ/cm^2, the grain size increased drastically with the increase in the pulse energy density and became the maximum. Correspondingly, the surface roughness deceases drastically and remains almost constant value. The grain size of the poly-Si film decreases at energy density over 260 mJ/cm^2.

This means that before starting the lateral grain growth by low laser energy density, the surface roughness of the poly-Si film is low similar to that of the initial a-Si film and the film stress by the densification of a Si film is not reduced, yet and became maximum. When the grain size becomes larger than the film thickness, the film stress become smaller. In other words, as starting lateral grain growth, the film stress is dissolved by lateral grain growth.

Meanwhile, in figure 4 (a), the trend of increase and decrease in the surface roughness is not consisted exactly with the grain size. This also means that as the lateral grain growth starts, the protrusions at the grain boundary generated by the impingement of adjacent grains increases the surface roughness rapidly. The formation of the larger grains at higher energy density decreases the number of the grain boundary and thus reduces surface roughness again.

The film stress, the surface roughness and grain size exhibits very similar result as a function of the number of shots (figure 4 (b)). If we ignore the data less than 200 mJ/cm^2 at the plot of figure 4 (a), the plots are similar as that of Figure 4 (b). This means that the lateral grain growth has already started in spite of 1 shot at the energy density of 240 mJ/cm^2.

In the previous researches, an explanation for the grain growth phenomena by multiple laser shots has been tried. The secondary grain growth phenomenon progressed to the direction of a (111) crystallographic orientation has been explained by adopting the lowest surface free energy [8], [16]. Our result attained at partial-melting regime can be explained as the similar model of the phenomenon. The preferred orientation analysis in our films is under study. Also, in order to explain the larger energy regions, in which the grain size is reduced, further study is required with considering the surface roughness.

4. Conclusion

The a-Si films deposited by LP-CVD were crystallized using UV pulsed laser. The large grain size of 0.5 μm has been observed in the poly-Si films. We found a fact that the grain size once increases by the increase in shots number and decreases by further increase of shot number. Up to the critical number of laser shots (25 times), both the grain size and the crystallization ratio increased by the increase of laser shot. However, above 50 shots, both the grain size and crystallization ratio reduced by the increase of the laser shots. Remarkable lateral grain growth with decreasing the surface roughness has been seen. The smaller laser energy density region with the increased grain size by multi shots might be explained by the secondary grain growth phenomenon [16]. However, the higher laser energy density region with the reduced grain size by multiple shots requires more precise study including the stress behavior.

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6. References

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