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Roughness Reduction Technique for High Performance Poly-Si TFTs by CW Laser Lateral Crystallization with Cap SiO_2 Thin Films

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1. Introduction

Low temperature polycrystalline silicon (poly-Si) thin film transistors (TFTs) are widely used in system on glass (SOG) application. To enlarge grain size and improve mobility, laser crystallization process is performed. However, excimer laser annealing (ELA) induces the surface roughness [1]. From the viewpoint of gate insulator reliability, smooth surface is desirable [2]. Although the surface formed by continuous wave (CW) laser lateral crystallization is smoother than that formed by ELA, the roughness should be more suppressed [3].

In this work, cap SiO_2 thin films were introduced to CW laser lateral crystallization to reduce the roughness for the first time. The cap SiO_2 thin film effects were investigated.

2. Experiments

Figure 1 shows a schematic diagram of the sample structure for CW laser lateral crystallization. An undoped amorphous Si (a-Si) thin film was deposited by PECVD at 430°C using SiH_4 gas on a 1 μm thick SiO_2 film/quartz substrate. After annealing in N_2 ambient at 490°C for 20 min to reduce the hydrogen content in the a-Si thin film, a cap SiO_2 thin film with a thickness of 10 nm was deposited. The samples were irradiated by diode pumped solid state (DPSS) CW laser with a wavelength of λ=532 nm. The spot shape was ellipse, and the intensity profile was Gaussian with dimensions of 90×20 μm^2 (FWHM).

3. Results and Discussions

Figure 2 shows optical microscope images of CW laser annealed Si thin films, at a laser power and a scanning speed of 10 W and 40 cm/s, respectively. In the both cases of without and with a cap SiO_2 thin film, Si grains were laterally grown. It seemed that the smooth surface was realized at the Si thin film crystallized with the cap film, as compared with that without the cap film. In addition, the lateral crystallized area formed with the cap thin film was larger than that without the cap film.

Figure 3 shows the lateral crystallized area ratio as a function of scanning speed. Lateral crystallized area ratio was defined by a ratio between lateral crystallized area and total crystallized area. Lateral crystallized area ratio was increased by the cap film. It was thought that back diffused heat from the cap SiO_2 films spread in the Si thin films perpendicularly to scanning direction because thermal conductivity of melting Si is larger than that of SiO_2 [4]. The lateral crystallized area ratio was 1.5 times increased by the cap SiO_2 thin films.

Figure 4 shows the conditions of lateral crystallization as a function of laser power and scanning speed. With a cap SiO_2 thin film, an available region to form lateral crystallized Si thin film was enlarged. The cap SiO_2 thin film has an effect of longer duration time at high temperature due to the back diffused heat from the cap films [4]. Upper limits in scanning speed for lateral crystallization were shifted to a faster scanning speed region by the longer duration time at high temperature. Lower limits in scanning speed for lateral crystallization was shifted to a slower scanning speed region by the introduction of the cap SiO_2 thin film. It was thought that the shift of lower limits was induced by the surface free energy (γ) reduction. It is reported that γ of Si is 1.2 J/m^2 [5], and that of SiO_2 ranges from 0.4 to 1.0 J/m^2 [6]. By using Fowkes theory, γ of the interface between the Si thin film and the cap SiO_2 thin film was roughly estimated at from 0.2 to 0.01 J/m^2. Due to the reduction of γ, the wettability of Si thin films was increased and it became difficult to form void.

Figure 5(a) shows the average surface roughness (R_a) as a function of scanning speed. As scanning speed became smaller, the melting time was increased and R_a was reduced. By using the cap SiO_2 thin film, R_a was dramatically reduced. This reason was also explained by reduction of γ. Figures 5(b) and (c) show the typical Atomic Force Microscopy (AFM) images. R_a was decreased from 6.7 nm to 1.3 nm by using the cap SiO_2 thin films.

Figure 6 shows Raman spectra of lateral crystallized Si thin films. The crystallinity wasn't degraded even if the cap SiO_2 thin films were introduced to CW laser lateral crystallization. Back diffused heat from the cap SiO_2 thin films didn't harmfully interfere the temperature slope along the scanning direction, resulting in lateral growth of Si grains.

Figure 7 shows a schematic image of the cap SiO_2 thin film effects on CW laser lateral crystallization of Si thin films. Lateral crystallized area enhancement will be useful to integrate TFT devices. Surface roughness decrease will enhance gate insulator reliability in TFTs.

4. Conclusion

It has been found that the cap SiO_2 thin films have the effects to CW laser lateral crystallization of Si thin films. Using the cap SiO_2 thin films with a thickness of 10 nm, lateral crystallized area was enhanced and the surface roughness was decreased without degrading the crystallinity. These effects are useful to TFT device integration and reliability enhancement.

5. Acknowledgment

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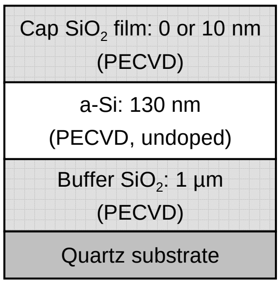

Fig. 1 Schematic diagram of sample structure for CW laser lateral crystallization.

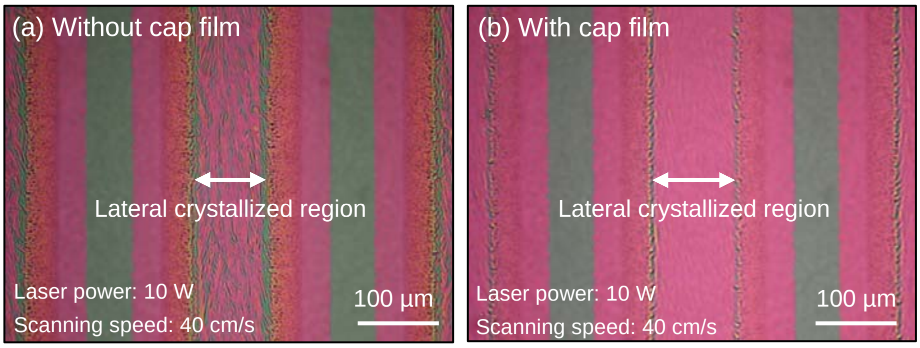

Fig. 2 Optical microscope images of the lateral crystallized Si thin film. (a) Without cap film. (b) With cap film.

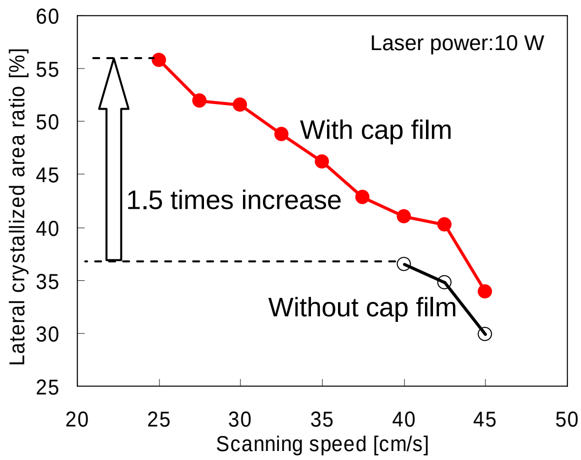

Fig. 3 Lateral crystallized area ratio as a function of scanning speed.

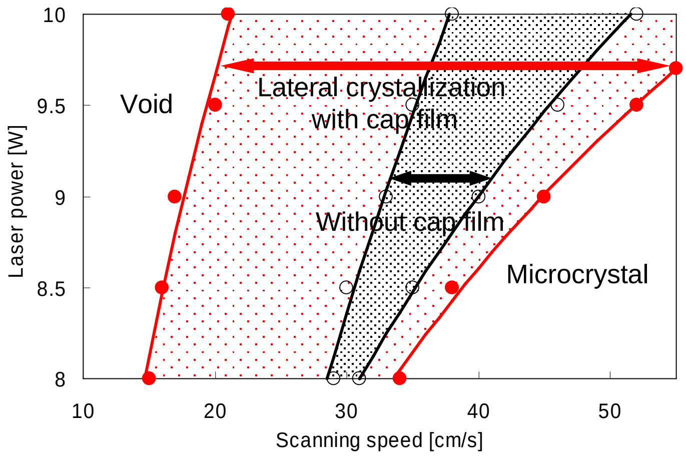

Fig. 4 Conditions for lateral crystallization as a function of laser power and scanning speed.

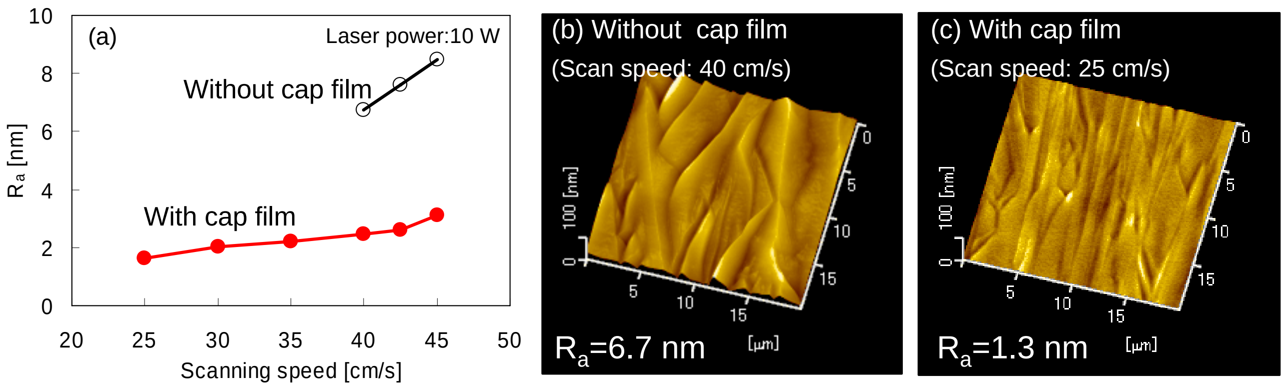

Fig. 5 Surface roughness in the lateral crystallized Si thin films. (a) Dependencies of R_a on scanning speed. (b) and (c) are typical AFM images.

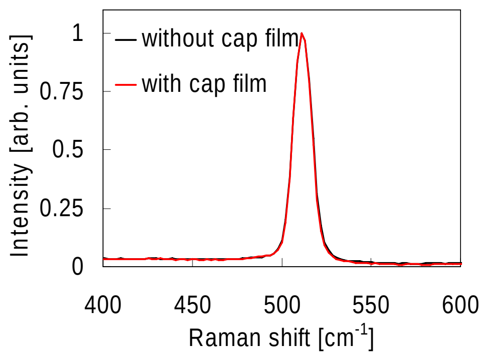

Fig. 6 Raman spectra of the lateral crystallized Si thin films.

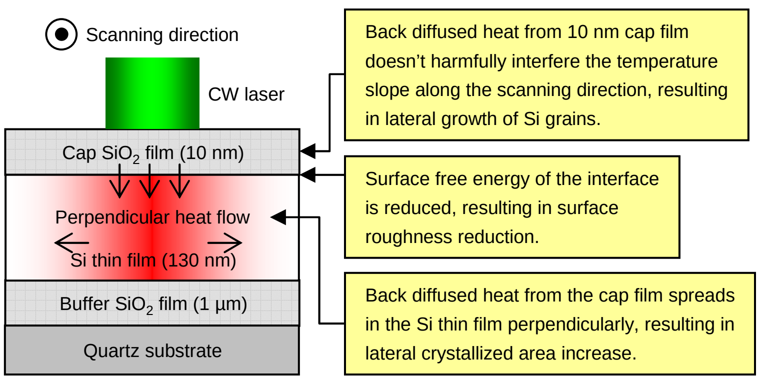

Fig. 7 Schematic image of the cap film effects on CW laser lateral crystallization. Arrows (→) mean heat flow direction in cross sectional plane perpendicular to scanning direction.