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Influence of different gas environments on the formation of thin film polysilicon by excimer laser annealing

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Excimer laser annealing (ELA) amorphous silicon (a:Si) to poly-silicon (poly-Si) in different gas environments, i.e. N_2 or N_2 mixed with O_2:2%, for the fabrication of thin film transistors (TFTs) is studied. Influence of laser power on the surface morphology, grain size and height of gibbous grain is also investigated. The variations of threshold laser power for the generation of surface ablation in pure N_2 only and the mixture of N_2:98% and O_2:2% environments are also discussed respectively. From experiment, it is found the combination of N_2:98% and O_2:2% can enhance the threshold laser power for the generation of surface ablation from 320mJ/cm^2 to 390 mJ/cm^2. In the condition of average grain over 0.25 μm, the process window (i.e. laser power for processing ability) is 30mJ/cm^2 for pure N_2 only, but is 50mJ/cm^2 for the combination of N_2:98% and O_2:2%.

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1. Introduction

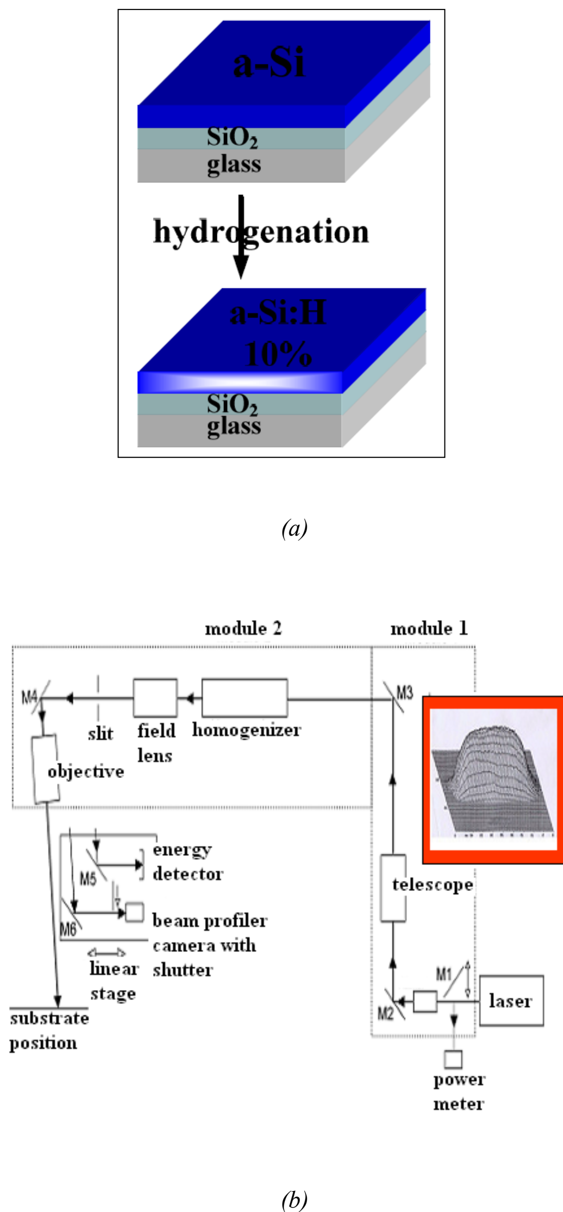
Recently, pulse-induced crystallization using excimer laser has shown potential on the LPCVD a:Si films[1] that a small experimental process window exists within which exceedingly large grains can be obtained. The attainable grain size is determined by the on set of copious nucleation in the continuously cooling ahead of the ELA crystallization interface [2]. The technological significance of the super lateral growth (SLG) phenomenon is outward as the result of large-grained poly-Si films address one of the major drawback associated with the ELA crystallization of a:Si [3]. The SLG phenomenon is important because it provides a fresh experimental environment for the investigation of not well-known conditions in the field of solidification from a:Si to poly-Si. Now, the ELA crystallization of a:Si films bring attractive processing characteristics, which are suitable for forming poly-Si thin films during the fabrication of thin film transistors [4].

For traditional FET transistors, they can not supply enough mobility, high current and high resolution in TFT application. To improve both film uniformity and the device performance for future use, the formed poly-Si films with controlled grain sizes and high process window are required. The investigations of the influence of N_2 gas mixing with other gas on the poly-silicon growth are still limited.

In this study, the PECVD prepared a:Si films are crystallized through ELA at different gas environments of pure N_2 or the mixture of N_2:98% and O_2:2%. The formations of poly-Si thin films are investigated for different gas environments and laser powers. The experimental images of grain sizes are captured by optical morphology (OM) and scanning electron microscope (SEM) for different gas environments. From the results, for the case with the gas environment of N_2:98% with O_2:2%, the process window can be improved and threshold laser power has an optimal value.

2. Experiment

First, the PECVD-grown SiO_2 film is first deposited on the no. Eagle 2000 corning glass and followed by the a:Si. The thickness of glass, SiO_2 and a:Si are 0.7 mm, 300 nm and 90 nm, respectively. The aim of SiO_2 film is used as a buffer and prevents the out-diffusion into the a:Si film. Next, the sample is put into the H_2-contained chamber for hydrogenation under vacuum of 10-6 torr to form the a:Si, as shown in Fig. 1 *(a).* In Fig. 2, the poor surface of hydrogenation is depicted under the conditions of H_2 flow rate of 10 sccm, reaction time of 1hr and temperature of 1500 ^{0}C. The optimization of hydrogenation to form the a:Si can be well controlled by varying the flow rate, pressure, heater temperature and reaction time.



(a)

(b)

Fig. 1. (a)The schematic diagram of the a-Si/SiO_2/glass structure after hydrogenation in this study; (b) The ELA measurement system.

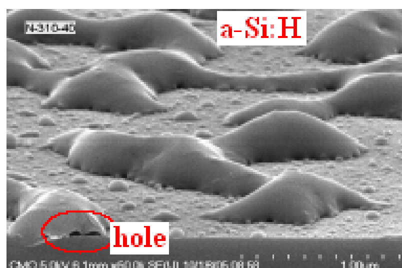
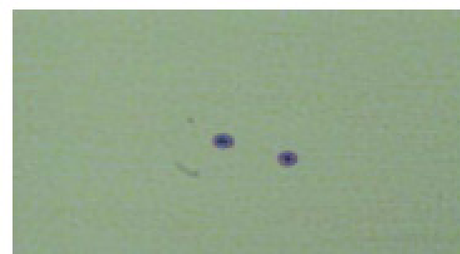


Fig. 2. The formation of gibbous surface and hole after hydrogenation.

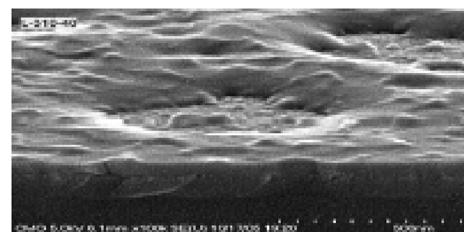
The 308nm excimer pulsed XeCl gas laser is used in this study. The scheme of the set-up optical laser measurement is shown in Fig. 1 *(b)*. The optical laser is with 315W maximum stable power, 300Hz maximum frequency and 370 mm x 400 um laser beam size, respectively.

3. Results and discussion

A series of laser power for investigating the surface quality during ELA crystallization are studied. The corresponding image captured by optical morphology (OM) under N_2 360 mJ/cm^2 ELA is shown in Fig. 3(a). Two obvious blue spots are observed in the figure. The corresponding image captured by SEM is also shown in Fig. 3(b). It is clear found that the a-Si:H disappears around the center hole. The resultant center hole is resulted from the ablation phenomenon after ELA heating. The ablation phenomenon is happened at about 320 mJ/cm^2 and increases with the increase in laser power. The origin of ablation is formation SiN_x during ELA which suppresses the air out-diffusion and then the suppressed air is finally exploded.



(a) OM



(b) SEM

Fig. 3. The images captured by (a) OM and (b) SEM under the pure N_2 gas environment at the laser power of 360mJ/cm^2 ELA.

For the case with the gas environment of N_2:98% with O_2:2%, the ablation energy during ELA crystallization is as high as 390 mJ/cm^2. This phenomenon indicates the additional O_2:2% will enhance the threshold ELA power. This improvement results from the formation of SiO_x during ELA, but the out-diffusion for gas inside ablation bubble in the condition of SiO_x is much easier than that in the condition of SiN_x. Thus, the threshold ELA power for ablation is higher with the gas environment of N_2:98%

with O_2:2%.

Fig. 4 depicts the relationship of laser power versus grain size and average ablation numbers. For average grain size over 0.25 μm, the measured process windows are 320~370 mJ/cm^2 for the case of N_2:98% with O_2:2% and 360~390 mJ/cm^2 for pure N_2. The corresponding process window ranges are 50 mJ/cm^2 and 30 mJ/cm^2, respectively. Obviously, for the case of N_2:98% with O_2:2%, the variation of grain size versus laser power is much smoother than that for the case of pure N_2. The observed ablation phenomena happen at the 320mJ/cm^2 laser power under the gas environment of pure N_2, but at 390mJ/cm^2 laser power under the gas environment of N_2:98% and O_2:2%. The average ablation number for the case of pure N_2 is much larger than that for the case of N_2:98%with O_2:2%N_2.

Fig. 5 shows the RMS and the maximum to minimum R-max values of the gibbous grains versus laser power. At N_2 320 mJ/cm^2, the RMS values reduce from 12 nm to 9 nm with the increase in laser power, but the R-max ranges between 70 nm to 90 nm. The phenomenon of the decrease of RMS mainly results from the larger grain size and the decreasing grain boundary area with the increase in power. The resultant gibbous grains will decrease the device breakdown voltage and are harmful to the circuit. For the case of N_2:98% with O_2:2%, the insensitive RMS and R-max are 2~3 nm and 20~35 nm which corresponding to 1/3~1/4 times then that for pure N_2 condition.

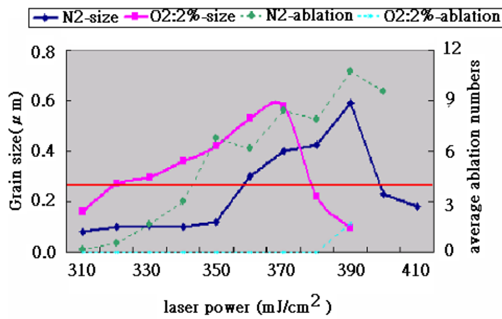


Fig. 4. The relationship of laser power versus grain size and average ablation number.

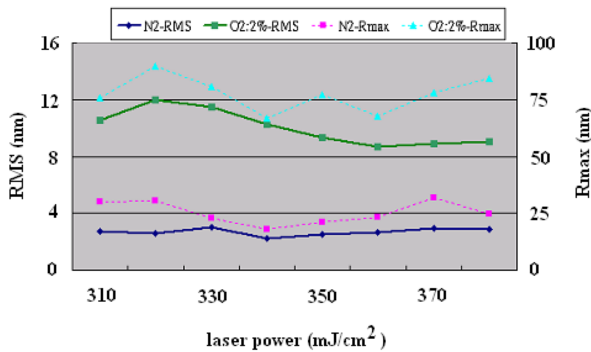


Fig. 5 . The RMS and R-max height of gibbous grains versus laser power.

Fig. 6 shows the images captured by SEM under the gas environments with pure N_2 or N_2:98% with O_2:2%N_2 at laser power from 310 mJ/cm^2 to 380 mJ/cm^2. It is clear found that the trap numbers (grain size) between grain boundaries are much higher in the gas environment of pure N_2, but are greatly reduced in the gas environment with N_2:98% and O_2:2%N_2. It is noted that for laser power from 310 mJ/cm^2 to 360 mJ/cm^2, the numbers of grain size are obviously reduced for the case of N_2:98% with O_2:2%N_2 under ELA recrystallization.

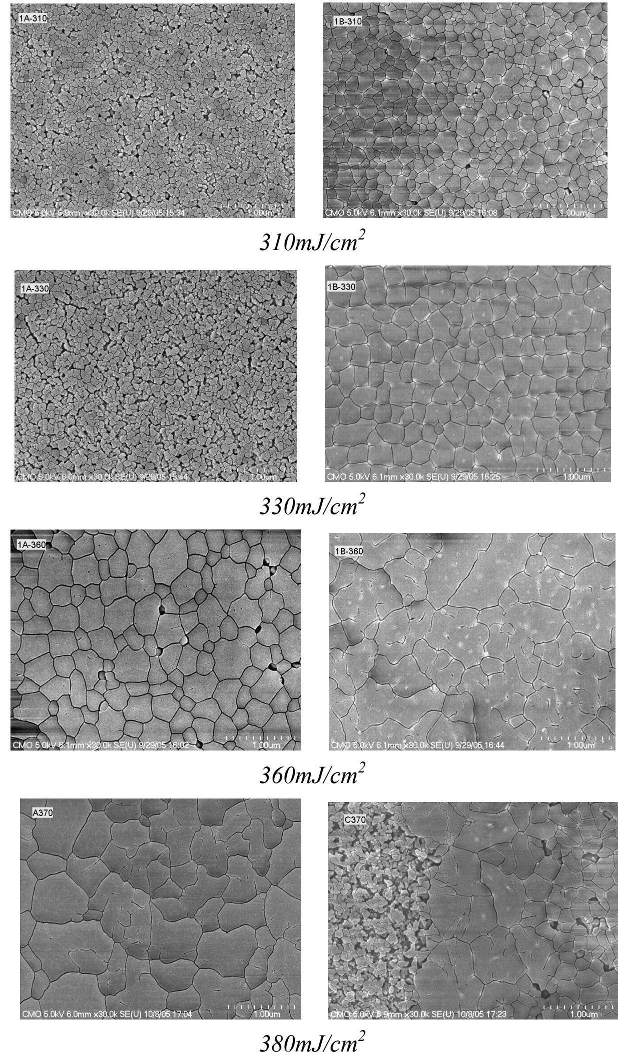


Fig. 6. The SEM images under the gas environment of pure N_2 (left images) and N_2:98% with O_2:2% (right images) at different ELA powers ranging from 310mJ/cm^2 to 380mJ/cm^2.

On the contrary, the numbers of grain size are increased while the laser power is over 380 mJ/cm^2. This phenomenon might be resulted from the over-heated energy breaking up the covalence bonds and increasing the grain boundaries. From the bottom of Fig. 6, it is obvious that the higher laser power up to 380 mJ/cm^2 will finally result in the increase of surface temperature and also increase the surface grains. Thus, the transition of ELA

power is about at 360 mJ/cm^2 in this study.

4. Summary

Experimental observations and analysis of ELA on low temperature PECVD-grown poly-Si are reported. Hydrogenated Si films during ELA under the gas environment with the combination of N_2:98% and O_2:2%N_2 are investigated. From the experimental results, the better process window, less traps and small gibbous grains can be achieved under the gas environment of N_2:98% and O_2:2%. From the controllable ELA crystallization in reducing grain size, high mobility and high resolution in scaled down TFT application is possible. Because the out-diffusion for gas inside ablation bubble in the condition of SiO_x is much easier, the better surface morphology can be obtained under the gas environment of N_2:98% with O_2:2%. The influence of the mixing ratio of the oxygen in the mixture gas on the poly-silicon growth will be further investigated in the future.

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