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Low temperature solid phase crystallization of amorphous silicon thin film by crystalline activation

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Abstract – We have investigated the effects of crystalline activation on solid phase crystallization (SPC) of amorphous silicon (a-Si) thin films. Wet blasting and self ion implantation were employed as the activation treatments to induce macro or micro crystalline damages on deposited a-Si films. Low temperature and larger grain crystallization were obtained by the applied two-step activation. High degree of crystallinity was also observed on both furnace and rapid SPC. Crystalline activations showed the promotion of nucleation on the activated regions and the retardation of growth in an amorphous matrix in SPC. The observed behavior of two-step SPC was strongly dependent on the applied activation and annealing processes. It was also found that the diversified effects by macro and micro activations on the SPC were virtually diminished as the annealing temperature increased.

I. Introduction

Considerable works in polycrystallization of hydrogenated amorphous silicon(a-Si:H) thin films have been accomplished during the last decade. The major thrust of these efforts was to enhance the electrical properties of a-Si films for the applications of flat panel displays (FPD) [1-5]. Primary approach of these works was based on the low temperature crystallization of a-Si films on Corning glass. Reported crystallization process was mostly restrained to the furnace solid phase crystallization (SPC), pulsed-laser liquid phase crystallization (LPC), and metal induced SPC. Among them, the laser LPC process showed the relatively superior characteristics in crystallizations. But, there still exists some problems such as uniformity and degree of crystallinity in large FPD applications [6, 7]. Here, we discuss the two-step low temperature SPC with large grain growth and high degree of crystallinity. The speculated mechanism on the presented two-step activation is schematically drawn in Fig. 1.

Some of the free energy required on SPC was partially provided as the crystalline activation energy on deposited a-Si films. Applying the crystalline activations on a-Si films, the minimum level of thermal-free-energy for crystallization was expected to be decreased. High nuclei generation and low growth rates expected to be induced on activated regions in following SPC. The investigated characteristics of crystallization was based on the employed macro and micro activation treatments on a-Si films. We tried to obtain the characteristics of low temperature crystallization, large grain growth, and high degree of crystallinity by the two-step SPC. The behavior of SPC was characterized by x-ray diffraction (XRD) and Raman spectroscopy. We also discuss the influence the activation and annealing methods on the characteristics of the SPC.

II. Experimental

The low temperature (485°C) chemical vapor deposited (LPCVD) a-Si films of 2500Å thickness were prepared. The films were grown on Corning 7059 glass and silicon wafer under the

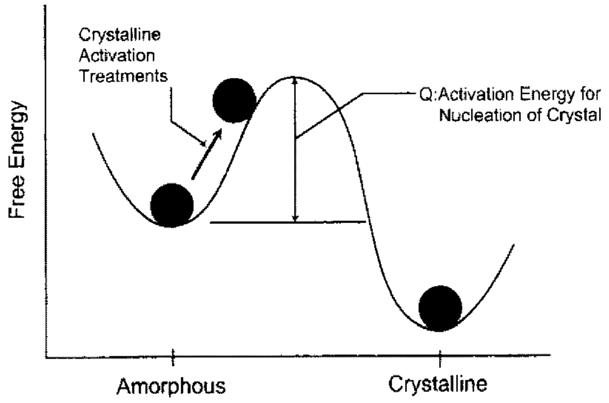

Fig. 1. Nucleation energy level for crystallization.

optimum deposition conditions established experimentally [8]. Macro and micro crystalline activation were induced on a-Si films as mechanical damages by silica blasting and low energy self ion implantation. Wet blasting used to metal impurity gettering in silicon wafer was employed as the macro activation. Approximately 1 μm silica slurry was blasted to create the activated stress in the lattice. The density of the blasting silica was controlled to induce the desired level of activations. The optimum degree of activation intensities in wet blasting was determined by trial and errors. The degree of crystalline activation was controlled to hard and soft blasting. Induced stacking fault densities on a-Si films were estimated about 5×10^4~10^5 cm^{-2}. Low energy (350 keV) self-ion (Si$^+$) implantation was also implemented to derive the micro activation. The dose of the implanted ions was varied from 1.2×10^{14} to 1.2×10^{16} cm^{-2}. And, the current density of implanted ions was controlled about 136 μC cm^{-2}. Tube furnace and halogen lamp rapid SPC annealing were accomplished under the argon atmosphere. Based on the softening temperature (595°C) of Corning glass and the film sample's substrate, furnace and rapid annealing temperatures were ranged in 540~750°C. The annealing temperatures and times were controlled to observe the initialization, fraction of crystallization and the degree of crystalline orderness.

III. Results and Discussions

Substantial variation of the x-ray signal intensity for the Si <111> peak was observed as the function of crystallized fraction. The <220> and <311> peaks showed virtually negligible change in intensity over the observed SPC conditions. The <111> peak was observed as major XRD peak and its intensity variation was monitored as the characteristics of SPC. Figures 2 and 3 show the intensity variation on Si <111> peak of furnace annealed films. Higher peak intensity was observed on blasting films than the self implanted ones. The characteristics of low temperature crystallization was attained from the activation effects on a-Si films. The noticed saturation temperature of crystallization was dependent upon the applied activation methods and annealing times. Lower saturation temperature on blasting films represented the higher nuclei generation and growth rate due to the macro activation effects compared to the self implantation. As increasing the annealing temperature and time, the grain size was more rapidly saturated, and even decreased in wet blasting films. High density grains with small diameters due to the higher nuclei generation rates was expected at high temperature. As the annealing time increased, larger grains were attained at lower temperature. The desirable crystallized fraction was observed in annealing period around 1 hour

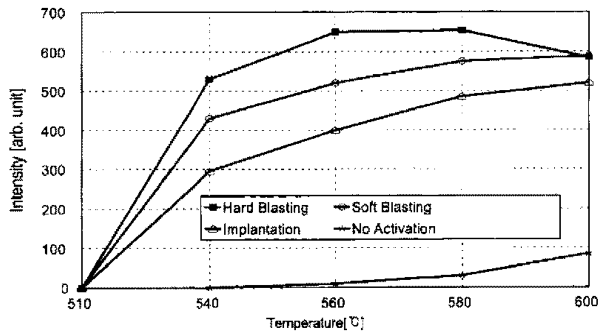

Fig. 2. Average intensity of Si <111> peak versus furnace SPC temperatures (1h annealing).

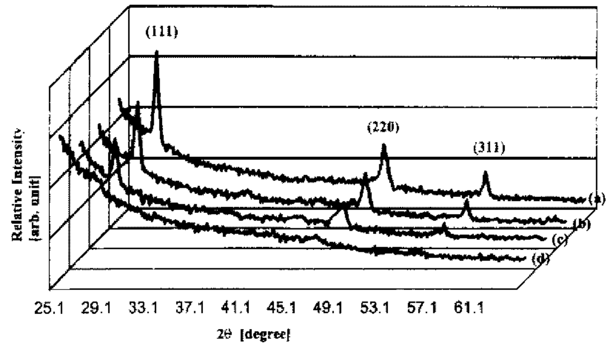

Fig. 3. X-ray diffraction patterns of the film samples (a) hard blasting (b) soft blasting (c) implantatiion (d) no activation [furnace annealing at 580 C for 1 hr].

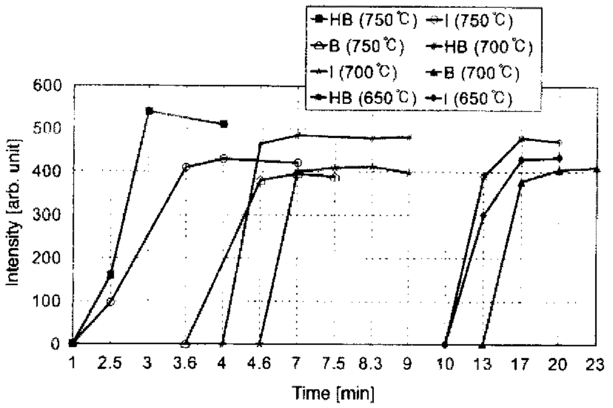

Fig. 4. Average intensity of Si<111> peak versus rapid annealing times (HB: hard blasting, I: implantation, B: bare-no activation).

in the range of annealing temperatures. The more rapid SPC behavior than that of the reported work was observed on the self ion implanted films [9]. About 12 hours was reported as the minimum crystallization annealing period for the self ion implanted film at 600°C. Observed difference in the crystallization annealing time could be explained as the effects due to the variation of implantation and film deposition conditions. The higher energy and dose of self ion implantation showed the short annealing time for SPC. Employed micro activation treatment on LPCVD a-Si film with disilane (Si_2H_6) source gas showed the promising effects on the behavior of SPC. Without activation treatments, films showed no noticeable crystallization over the probed SPC conditions. The increase in the <111> peak diffraction intensity was associated with the estimated average grain size of films. The average grain size of SPC was determined by applying Scherrer's formula to the x-ray diffraction of the Si <111> peak. It should be noticed that the used XRD system allows the determination of the grain size normal to the film surface only. Mechanical activation induced by wet blasting showed more desirable effects on the grain growth. Larger grain size (about 2300Å) than that of the reported laser crystallization was estimated [10].

In rapid SPC, the activated films started to crystallize within 2.5 min at 750°C. Fig. 4 illustrated the <111> peak intensity changes versus rapid thermal annealing (RTA) times. Effects of activation was not substantial on rapid SPC. Surface RTA temperature plays a major role to the initializations of rapid SPC. Full growth and saturation within minutes was observed as expected. General behavior of rapid SPC was obtained at the temperature above 700°C. CVD films with no activation showed the initial crystalline growth at 700°C for 17 minutes. Blasting activation also showed the more desirable degree of crystallinity in RTA. Smaller grains (about 1600Å) compared to furnace SPC were obtained in rapid SPC. Full growth in a minute due to high temperature resulted in the small grain size in RTA. No noticeable variations in the implanted and bare films indicates the temperature is a major effect in RTA annealing. The degree of crystallinity analyzed by the Raman phonon peaks are plotted in Figs 5, 6 and 7. Lorentz fitting was performed to determine the center wave number of phonon peaks [11]. The peak broadness was also normalized and analyzed. Due to the difference in absorption coefficients, the variation of peak intensity could not be directly estimated. The observed phonon peak shift showed the fairly high crystallinity of activated films on the both of furnace and rapid SPC. As the temperature

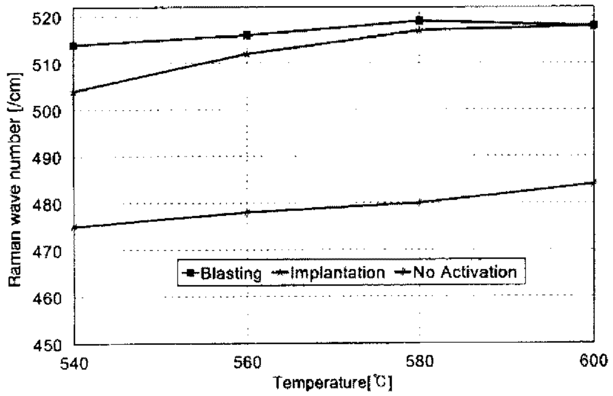

Fig. 5. Raman peak shift versus furnace SPC temperatures (1 h annealing).

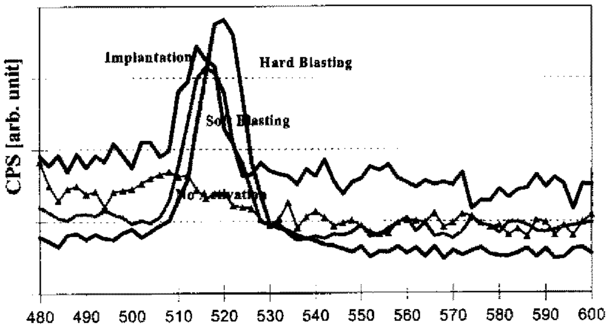

Fig. 6. Raman spectra of the films after furnace SPC at 580C for 1 hr.

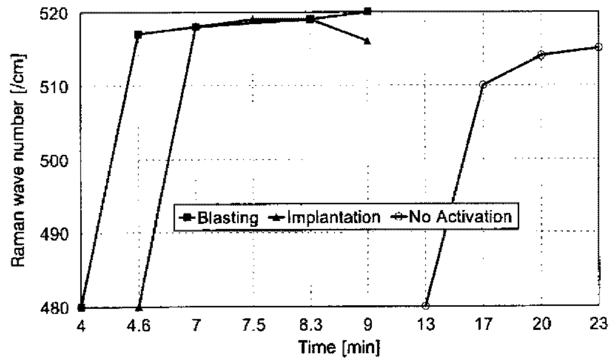

Fig. 7. Raman peak shift versus RTA (700°C) times.

increased, the fraction and quality of crystallinity on implanted films was slightly improved in the furnace SPC. Concerned with the degree of crystalline fraction, the activation treatments showed virtually significant effects on the SPC.

IV. Conclusions

We found the crystalline activation treatment on a-Si films enhanced the nucleation and restrained the growth on SPC. By inducing the macro and micro activations in an amorphous matrix, low temperature (540°C) crystallization with the applicable degree of crystallinity was obtained. Wet blasting treatment showed the more desirable activation effects on larger grain growth. As the SPC temperature increased, the activation effects were virtually diminished due to the higher growth rate. In RTA process, the full growth within a minute was observed by the activation effects. But, the estimated grain size was smaller than that of the furnace SPC. Both furnace and halogen SPC showed the similar high degree of crystallinity regardless of the mactivation treatments.

Acknowledgment

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