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Suppression of Current-Induced Degradation in Laser-Crystallized Polycrystalline Silicon Films by Adding Oxygen

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We have investigated the behaviors of the grain-growth and the current-induced degradation in laser-annealed polycrystalline silicon films by adding oxygen (poly-SiO_x). The solidification velocity was decreased by the introduction of oxygen atoms into amorphous silicon (a-Si) films which promotes the grain-growth. The ratio of photo- to dark conductivity and the current-induced degradation were reduced in laser-annealed poly-SiO_x films probably due to the stable silicon networking. The electrical conductivity was reduced with the increase of the oxygen contents.

1. INTRODUCTION

The mechanism and thermodynamics involved in laser-induced grain-growth of amorphous silicon (a-Si) films have been investigated considerably[1-3]. The laser-induced grain-growth progresses through the solidification of molten silicon layer. It is reported that the decrease of solidification velocity promotes the grain-growth and amorphization takes places above 18 m/sec of solidification velocity which is indicating the competition between the kinetics growth rate and nucleation at a solidifying interface[4]. The defects like micro-twins, which may be easily degraded by the electrical stress, are also reduced by the decrease of solidification velocity through the promotion of stable silicon networking. The solidification velocity may be reduced by the blocking of heat flow such as the insertion of buffer oxide[5], dual-beam annealing[6] and substrate heating[7]. The increase of grain growth was observed by those methods. However, most of previous works have focused on the laser annealing effects on the amorphous silicon (a-Si) films while laser annealing effects on the oxygen-bonded amorphous silicon (a-SiO_x) films have been scarcely investigated. It is expected that the solidification velocity is reduced by employing low-thermal conductivity material such as a-SiO_x film.

In this paper, the grain-growth of laser-annealed poly-SiO_x films was investigated by controlling of the solidification velocity with introducing oxygen atoms. The electrical conductivity and the stress current were also measured to investigate the passivation of defects in the laser-annealed poly-Si(O_x) films.

2. EXPERIMENTAL

We have deposited initial films for laser-annealing by rf plasma enhanced chemical vapor deposition (PECVD) system with parallel electrodes. The SiH_4 and O_2 gas mixtures were used for the deposition gases. The rf power , deposition temperature and pressure were 30 W, 350 °C and 1 Torr, respectively. The O_2 flow rate was changed from 0 to 1 sccm at the constant 2 sccm of SiH_4 flow rate. The thickness of deposition films was 1900 ± 50 Å. Laser annealing was performed by XeCl excimer laser (λ = 308 nm) at the laser energy density of 300 mJ/cm^2. The samples was located on substrate in vacuum chamber of 10^{-4} Torr and the substrate was heated to 200 °C. The laser beam was irradiated uniformly over an area of 4×4 mm^2 by beam-homogenized optics. The initial films were dehydrogenated during 1 hour at the 400 °C before the laser-annealing.

Fourier transfer infra-red spectroscope (FTIR) data were used to investigate evolution of Si-O bonds in initial films. Time-resolved optical-reflectivity (TROR) measurements[8] were performed with a HeNe laser (λ=633 nm) to investigate the *in-situ* grain-growth mechanism in the laser-induced melting process. The HeNe laser beam was irradiated on the samples at an incidence angle of 30° and the reflected beam was detected by a fast-response photo-sensor. The grain growth was also observed by scanning electromicroscope (SEM) images. The aluminum electrodes were patterned into the coplanar structure on the laser-annealed films to measure the electrical conductivity and stress current.

3. RESULTS AND DISCUSSION

FTIR measurements was performed to investigate the evolution of oxygen in a-SiO_x films which may be a key factor to influence the grain-growth. Figure 1 shows FTIR data of dehydrogenated a-SiO_x films with various O_2 flow rates. The oxygen contents was increased with O_2 flow rate from the results of the decrease of transmittance at stretching Si-O band (1085 cm^{-1}).

The a-SiO_x films were irradiated by XeCl excimer laser and the TROR measurements were performed for the *in-situ* characterization of laser-induced melting and solidification phenomena. Figure 2 shows *in-situ* TROR data in laser-irradiation at 300 mJ/cm^2 with different O_2 flow rates. The peak reflectivity around A is due to the increase of surface reflectivity with metallic molten silicon layer caused by laser irradiation. The molten surface layer was maintained and solidified with the decrease of reflectivity around B and stopped around C. In O_2 introduced films (O_2 = 0.2, 0.5, 1 sccm), the melt duration and solidification times were increased more than those of pure amorphous silicon film ($O_2 = 0$ sccm).

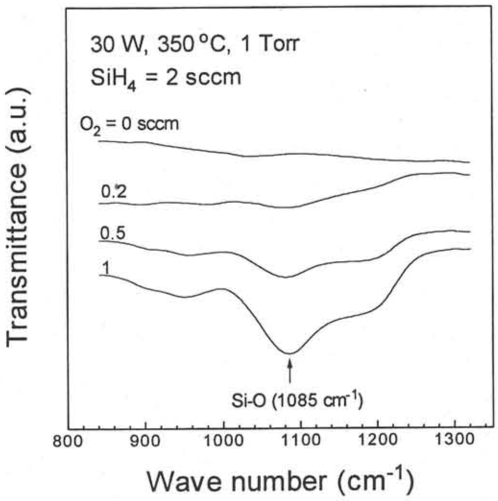

Fig. 1. FTIR data of deposited a-Si(O_x) films with different O_2 flow rates (0, 0.2, 0.5 and 1 sccm) at the constant 2 sccm of SiH_4 flow rate. The deposition power, temperature and pressure are 30 W, 350 °C and 1 Torr, respectively.

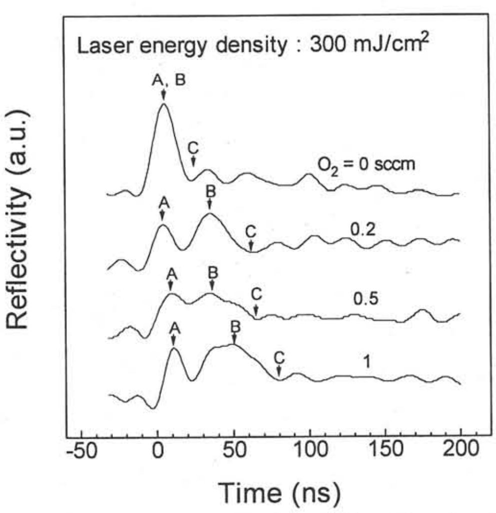

Fig. 2. Plot of *in-situ* TROR (Time-Resolved Optical-Reflectivity) characteristics with laser energy density of 300 mJ/cm^2. The laser irradiation was performed in vacuum chamber (10^{-4} Torr) at the substrate temperature of 200 °C.

We have evaluated the solidification velocity from the time interval B-C in Fig. 2 with laser-annealed films fully melted[9]. Figure 3 shows the solidification velocity as a function of O_2 flow rates. The abrupt decrease happened at the film of 0.2 sccm which confirms that the heat-flow is retarded by the Si-O bonds which show low-thermal conductivity and the solidification of melted layer progresses slowly. In excess of 0.2 sccm, the decrease of solidification velocity comes to be mitigated which may be resulted from that the possible increase of optical band gap with increase of Si-O bonds reduces the effective laser-absorption energy which affects the laser-induced melting and solidification phenomena[4].

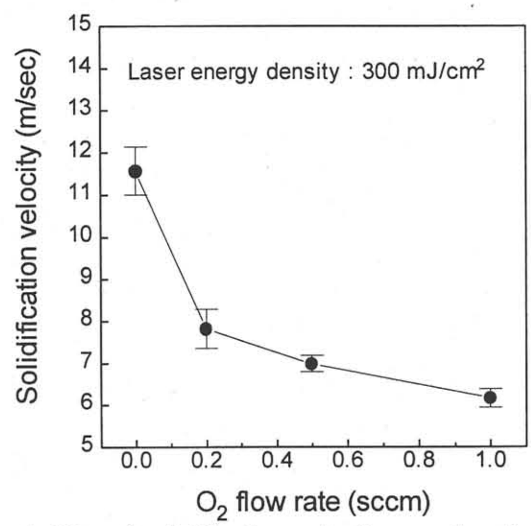

Fig. 3. Plot of solidification velocity as a function of O_2 flow rates. The solidification velocity was evaluated from the time interval B-C in Fig. 2 with laser-annealed films fully melted.

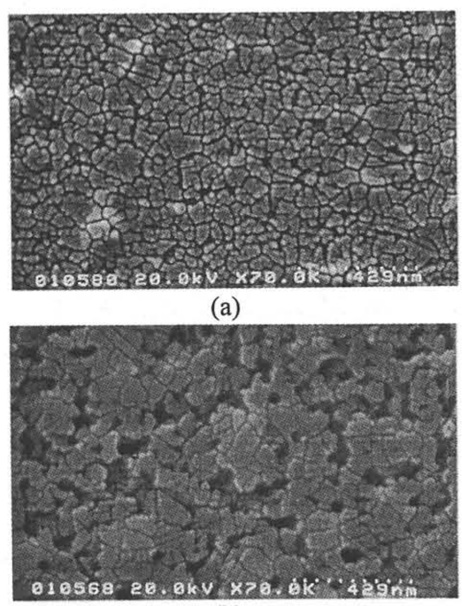

Fig. 4. SEM images of laser-annealed films of (a) 0 sccm and (b) 0.2 sccm of O_2 flow rates. The laser energy density, annealing pressure and substrate temperature were 300 mJ/cm^2, 10^{-4} Torr and 200 °C, respectively.

The SEM images of laser-annealed films of 0 and 0.2 sccm were shown in Fig. 4. In Fig. 4b, the grain growth was activated some extent by the decrease of solidification velocity, and the void may be originated from the effusion of oxygen in laser-annealing.

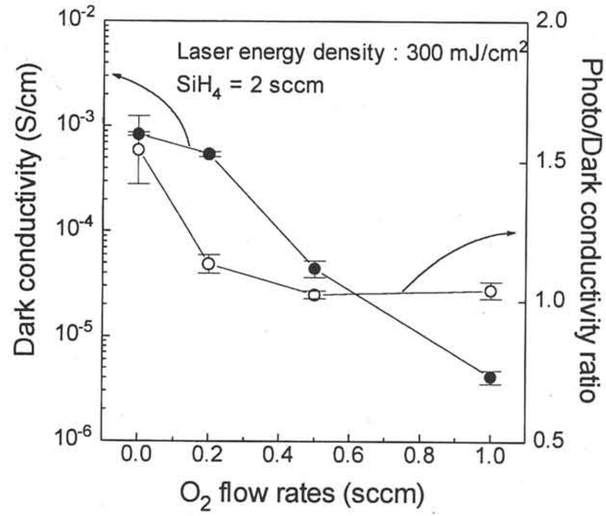

Fig. 5. Dark conductivity and the ratio of photo- to dark conductivity of laser-annealed films as a function of O_2 flow rates. The conductivity was measured at 20 °C and 200 mW/cm² of halogen lamp was used for photo-conductivity

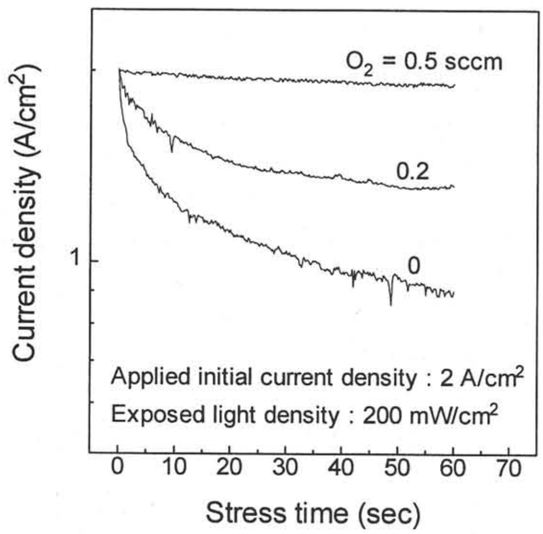

Fig. 6. Current density of laser-annealed films as a function of stress time with different deposition conditions of O_2 flow rates.

Figure 5 shows the dark conductivity and the ratio of photo- to dark conductivity of laser-annealed films as a function of O_2 flow rates. The conductivity was measured at 20 °C and the measurement of photo-conductivity was performed under the illumination of 200 mW/cm² of halogen lamp. The dark conductivity was decreased with increasing O_2 flow rates due to the enhancement of Si-O bonding. In case of 1 sccm, the dark conductivity is about two orders lower than that of the film with 0 sccm of O_2 flow rate. However, dark conductivity at the relative low O_2 flow rate of 0.2 sccm shows 5.45×10^{-4} S/cm, which is only 1.5 factor lower than that of 0 sccm. The ratio of photo- to dark conductivity shows low values of 1 ~ 1.6 which is resulted from that the band gap states like recombination centers were removed by the evolution of crystal networking. However, the oxygen-introduced films (O_2 = 0.2, 0.5, 1 sccm) still show the lower value than that of pure silicon film (O_2 = 0 sccm).

Figure 6 shows the characteristics of current density as a function of stress time. The current density of 2 A/cm² was applied initially and halogen lamp with 200 mW/cm² was exposed during a entire stress time. The change of current density and slope were decreased with increasing O_2 flow rates. It also confirms that the silicon bonds come to be stable with less defects by introducing oxygen due to the decrease of solidification velocity.

4. CONCLUSION

We have investigated the behaviors of the grain-growth and the current-induced degradation in laser-annealed poly-SiO_x films. The solidification velocity was decreased by the introduction of oxygen atoms which promoted the grain-growth and suppressed the current-induced degradation through the activation of stable silicon networking. We have found that the existence of small amount oxygen in initial films promotes the electrical stability in laser-annealing without much decrease of electrical conductivity.

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