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Crystallization of electron-beam evaporated a-Si films on textured glass substrates by flash lamp annealing

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Abstract

We investigate the crystallization of amorphous silicon (a-Si) films, by flash lamp annealing (FLA), formed by electron beam (EB) evaporation on textured glass substrates. We confirmed that EB-evaporated a-Si films formed on textured glass can be crystallized by FLA. Optical reflectance on EB-evaporated a-Si can be reduced by using the texture glass, leading to a reduction in the fluence of a FL pulse required for the crystallization. The usage of textured glass substrates leads the formation of polycrystalline Si (poly-Si) films with fine grains, unlike in the case of flat glass substrates. This may results from the prevention of lateral thermal growth and the suppression of explosive crystallization (EC). The fluence of a FL pulse for the crystallization of EB-evaporated a-Si films tends to increase with temperature during the EB evaporation of a-Si films. The pre-existing crystal grains in precursor Si films may affect the mechanism of their crystallization.

1. Introduction

Thin-film poly-Si solar cells formed on low-cost substrates, such as glass substrates, have been receiving attention as next-generation solar cells because of low material usage and high stability against light soaking [1]. The formation of poly-Si films through the short-duration annealing of precursor a-Si films can lead to more cost-effective fabrication of solar cells because of the usage of low-cost substrates and short process time. In this study, we utilize FLA for the crystallization of a-Si films to form poly-Si films. FLA is an annealing method using millisecond-order discharge light from Xe lamps, which results in a thermal diffusion length of several tens of µm in a-Si and glass. The proper thermal diffusion length enables the crystallization of µm-order-thick a-Si films with no serious thermal damage to entire glass substrates.

The crystallization of a-Si films by FLA takes place laterally based on a mechanism referred to as EC. This is caused by heat generation due to enthalpy difference between a-Si and crystalline Si (c-Si) and its diffusion to surrounding a-Si. In particular, when an EB-deposited a-Si film is used as a precursor, EC based on liquid-phase epitaxy occurs, and a poly-Si film composed of large grains can be formed [2].

Since the EB-evaporated a-Si films, formed under ultra-high vacuum, contains only small amount of impurities, their crystallization is more difficult to be triggared than the cases for other precursor a-Si films formed by different deposition methods such as catalytic chemical vapor deposition and sputtering, and a FL pulse light with higher fluence is required for their crystallization. In this study, we attempted to use textured glass for the substrates of EB-evaporated a-Si films, by which an antireflection effect and an increase in the optical path length are expected. This investigaton also clarify the impact of substrate roughness on the crystallization mechanism of EB-evaporated a-Si films.

2. Experimental

We first cleaned 19.8 mm × 19.8 mm-sized flat Eagle XG glass substrates ultrasonically in acetone, ethanol, and deionized water for 5 minutes, respectively. Reactive ion etching (RIE) was performed on the surface of the glass substrates to form textured structures. We systematically changed RIE duration to control the roughness of the glass surfaces. The surface roughness of the glass substrates was evaluated by atomic force microscopy (AFM). Fig. 1 shows the root mean square (RMS) roughness of textured structures formed on the glass substrates as a function of RIE duration. ~3 µm-thick a-Si films were then deposited by EB evaporation on the textured glass substrates at substrate temperatures of room temperature, 300 °C, and 500 ºC at a deposition rate of 4.6 nm/s.

FLA was performed on the precursor a-Si films using a pulse light at fluences of 7–19 J/cm^2 with a duration of 7 ms in Ar atmosphere without additional substrate heating. Only one pulse was irradiated for each sample. The crystalline fraction and grain size of the Si films after FLA were evaluated by Raman spectroscopy.

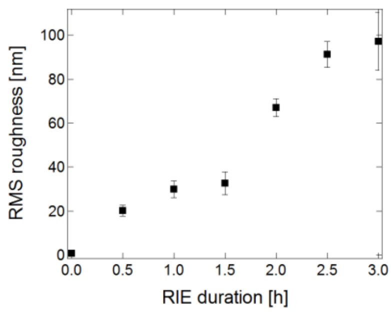

Fig. 1 RMS roughness of glass surfaces as a function of RIE duration.

3. Results and discussion

Fig. 2 shows the Raman spectra of Si films after FLA at a fluence of 17.04 J/cm^2 for a-Si films deposited at room temperature on glass substrates receiving RIE with durations of 0–3 h. A peak around 520.5 cm^{-1}, originating from c-Si phase, is seen only when RIE was performed for 2 hours or longer. This indicates that the crystallization of EB-evaporated a-Si films occurs at a lower fluence on a glass surface with more surface roughness. Fig. 3 shows the optical reflectance spectra of Si films before FLA formed on glass substrates with textures formed by RIE with various durations. The optical reflectance on the Si films greatly reduces by increasing RIE duration. The crystallization of a-Si films only for the films prepared on longer RIE-treated glass substrates is probably related to the lower optical reflectance and resulting more absorption of FL pulse light in the Si films.

When focusing on the full width at half maximum (FWHM) of c-Si peaks shown in Fig. 2, the values of 6–8 cm^{-1} are much larger than those reported previously (~4.5 cm^{-1}) [2]. The size of crystal grains in the poly-Si films simply estimated from the FWHM values are ≤10 nm [3]. This indicates that poly-Si films consisting of nm-order fine grains are formed on textured glass substrates, unlike in the case of the FLA of EB-evaporated a-Si film on flat glass substrates, under which several tens of μm-long grains are formed [2]. This fact indicates that the mechanism of crystallization varies depending on the roughness of glass substrates. The formation of textures on a glass surface may lead to the prevention of lateral thermal diffusion and resulting suppression of liquid-phase EC.

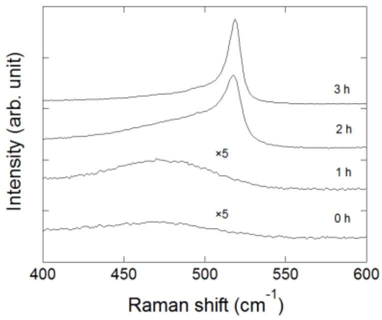

Fig. 2 Raman spectra of Si films after FLA at a fluence of 17.04 J/cm^2 prepared on glass substrates receiving RIE with durations of 0–3 h.

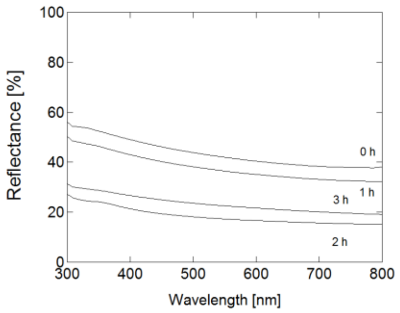

Fig. 3 Optical reflectance spectra of Si films before FLA on glass substrates with textures formed by RIE with various durations.

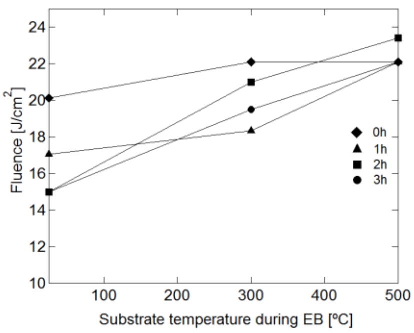

Fig. 4 Fluence of a FL pulse required for the crystallization of the EB-evaporated a-Si films on textured glass substrates as a function of substrate temperature during the EB evaporation of a-Si films.

Fig. 4 shows the fluence of a FL pulse required for the crystallization of the EB-evaporated a-Si films on the glass substrates with textures formed by RIE for 0–3 hours as a function of substrate temperature during the EB evaporation of a-Si films. As the substrate temperature during EB evaporation increases, the fluence required for crystallization tends to increase, independent of the presence or absence of textures on glass substrates. This may be due to the existence of c-Si grains formed during EB evaporation particularly at high substrate temperature, which we confirmed by Raman spectroscopy (not shown here). The pre-existing c-Si grains may influence the mechanism of crystallization and/or reduce the absorption of FL light due to less absorption coefficient of a-Si than c-Si. It is found that the usage of a-Si films deposited at lower temperature is more proper for the crystallization at lower fluence.

4. Conclusions

We confirmed the crystallization of EB-evaporated a-Si films on textured glass substrates by FLA. The usage of textured glass substrates can reduce the optical reflectance on a-Si surfaces, resulting in lower fluence required for their crystallization. We also observed changes in the mechanism of the crystallization of a-Si films by the usage of textured glass substrates or a-Si films prepared at high temperature during EB evaporation. The formation of poly-Si films on textured glass may contribute to more photocurrent in thin-film poly-Si solar cells because of less optical reflection and more effective light trapping.

Acknowledgements

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