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Description	



# THIN FILM P-I-N POLY-SI SOLAR CELLS DIRECTLY CONVERTED FROM P-I-N A-SI STRUCTURES BY A SINGLE SHOT OF FLASH LAMP

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## ABSTRACT

We propose a novel production method to fabricate high-efficiency thin-film poly-Si solar cells using flash lamp annealing (FLA) for crystallization of micrometer-order-thick p-i-n amorphous silicon (a-Si) structure, prepared by catalytic chemical vapor deposition (Cat-CVD, Hot-Wire CVD) on low-temperature glass substrates and following high-pressure water vapor annealing for defect passivation. The FLA enables us to crystallize a-Si films with only one pulse of less than 10 ms duration, and use of Cat-CVD provides a-Si cost-effectively because of high deposition rate of a-Si over 10 nm/s. Secondary ion mass spectroscopy (SIMS) profiles reveal that diffusion of dopants in p- or n-type layers is sufficiently suppressed after FLA, indicating possibility of simultaneous crystallization of p-i-n stacked a-Si films. High-pressure water vapor annealing (HPWVA) enhances the minority carrier lifetime of the poly-Si up to about 10  $\mu$ s and drastically improves diode properties of the p-i-n poly-Si structure. No light-induced degradation is observed in the solar cell property of the poly-Si solar cell after 24-hour 1-sun light soaking.

## INTRODUCTION

Cost reduction of solar cell fabrication is a severe issue to lower the power generation cost by solar cells down to that by thermal power generation. Both improvement of energy conversion efficiency and reduction of amount of used material are of great importance. Thin-film Si solar cells have been attractive from this point of view. a-Si and microcrystalline Si ( $\mu$ c-Si) films directly formed by deposition techniques for thin-film Si solar cells, however, have limitation in the deposition rate to preserve their film qualities and solar cell properties. Poly-Si films formed by post-annealing of a-Si can overcome this issue by controlling crystallization and defect passivation conditions. There have been many reports concerning solar cells using poly-Si films formed by solid-phase crystallization or by epitaxial growth on large-grained seed layers prepared by aluminum-induced crystallization [1-4]. Although highly efficient solar cells with conversion efficiency of up to 10 % can be achieved, these techniques require long annealing time of several hours or high epitaxial growth temperatures of over 1000  $^{\circ}$ C, resulting in low throughput and in utilization of high-cost substrates with high thermal resistivity. Rapid crystallization techniques should therefore be required for the further cost-effective process of fabricating solar cells using thin-film poly-Si films.

In this study, we propose a novel highly productive process concept to fabricate thin-film poly-Si solar cells. Figure 1 shows the process flow consisting of crystallization of a-Si by FLA and HPWVA for defect passivation. Unlike conventional rapid crystallization

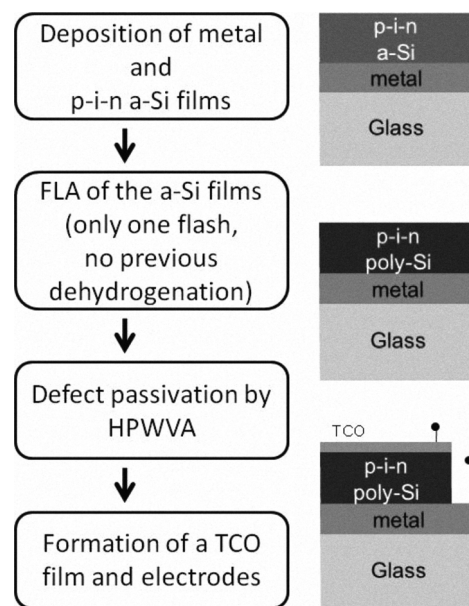


Fig. 1. The process flow for fabrication of thin-film poly-Si solar cells.

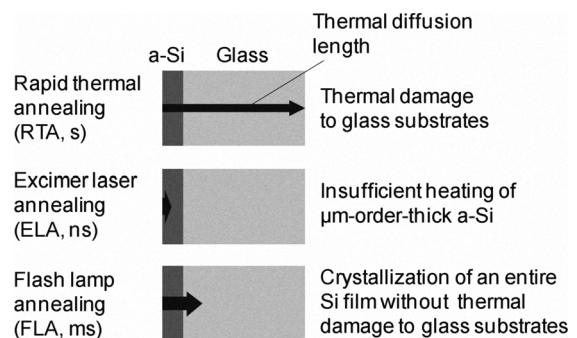


Fig. 2 Schematics of rapid crystallization of a-Si by RTA, ELA, and FLA.

such as rapid thermal annealing (RTA) or excimer laser annealing (ELA), FLA is a millisecond-order treatment within which the thermal diffusion lengths of a-Si and glass are both several tens of  $\mu\text{m}$ , resulting in crystallization of micrometer-order-thick a-Si without entire heating of glass substrates as illustrated in Fig. 2. We have already clarified that 4.5- $\mu\text{m}$ -thick a-Si films on quartz and soda lime glass substrates are successfully crystallized by FLA [5, 6]. We demonstrate the prototype solar cell formed using this poly-Si through the process proposed above.

### EXPERIMENTAL DETAILS

We first formed a Cr film on glass substrates for improvement of adhesion as well as for back electrodes and back reflectors in a solar cell structure. Precursor n-, i-, and p-type stacked a-Si films with thicknesses of 10 nm, 4.5  $\mu\text{m}$ , 10 nm, respectively, were deposited in this sequence by Cat-CVD, the method of which realizes a-Si with hydrogen content of as low as 3%, and enables us to skip a dehydrogenation process prior to FLA. Only one shot of FLA within 10 ms duration was treated to each stacked a-Si structure. HPWVA was treated to the formed poly-Si at a pressure of 0.9 MPa at 400  $^{\circ}\text{C}$  for 10 min. Diffusion of dopant and Cr atoms were characterized by SIMS.

### RESULTS AND DISCUSSION

Figures 3(a) and (b) show the surface and the Raman spectrum of the poly-Si after FLA of p-i-n stacked a-Si films, showing no peeling of Si and formation of poly-Si with high crystallinity close to unity. This crystallization is not due to the metal-induced crystallization since similar crystallization occurs even when a silicon nitride film is inserted between the Si and Cr films. We have also confirmed crystallization of a-Si even close to the Si/Cr interface [7]. The microwave photoconductivity decay ( $\mu\text{-PCD}$ ) measurement has revealed that the intrinsic poly-Si films formed by this technique have minority carrier lifetimes of about 10  $\mu\text{s}$  after HPWVA as has been previously reported [8]. Assuming the minority carrier mobility of 14  $\text{cm}^2/\text{Vs}$  estimated by Hall measurement of

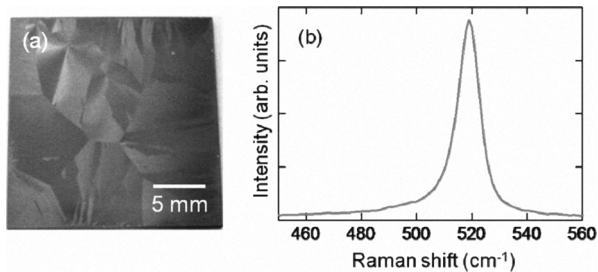


Fig. 3 (a) Surface and (b) Raman spectrum of the p-i-n stacked Si after FLA.

independently prepared n-type poly-Si formed directly on glass substrates, we obtained the minority carrier diffusion length of the poly-Si of about 19  $\mu\text{m}$ , which is four times larger than its film thickness.

Figure 4 shows SIMS profiles of Cr and P atoms in the bottom layers and of B in the surface doping layer before and after FLA. The abrupt profiles of the surface B atoms as well as of the bottom Cr and P atoms are maintained after FLA, which shows possibility of immediate formation of p-i-n poly-Si structure with only one irradiation of flash lamp for p-i-n stacked a-Si layers.

We have measured the dark and 1-sun-illuminated I-V curves of the p-i-n structures before and after HPWVA. In spite of no surface passivation and the unoptimized process, clear diode feature and photocurrent are seen in the device after HPWVA. The present solar cell properties are summarized in Table 1. The detailed I-V characteristics are summarized elsewhere [9]. The relatively poor solar cell properties are probably due to the unoptimized fabrication process and no surface passivation. Taking into account the excellent fundamental properties of the poly-Si such as the carrier lifetime and the mobility, further optimization of the solar

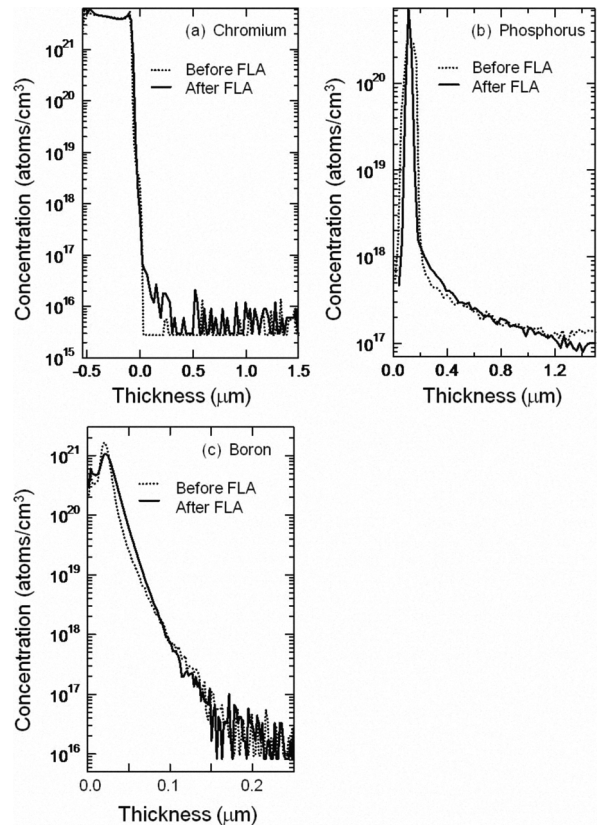


Fig. 4 SIMS profiles of (a) Cr, (b) P, and (c) B atoms before and after FLA.

Table 1. Present performance of the poly-Si solar cells.

$J_{sc}$ (mA)	$V_{oc}$ (V)	FF	Eff. (%)
7.15	0.21	0.404	0.606

cell process will lead to high-efficiency solar cells using this poly-Si.

Figure 5 shows the I-V characteristics of the poly-Si solar cells before and after light soaking under AM 1.5 1-sun irradiation for 24 hours. No significant light-induced degradation occurs in the poly-Si solar cells, showing high stability for light soaking.

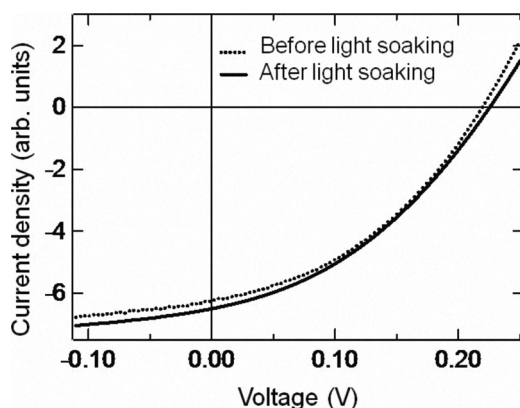


Fig. 5 I-V characteristics of the poly-Si solar cell before and after light soaking.

### SUMMARY

We have proposed the novel concept of fabricating thin-film solar cells on glass substrates using the  $\mu\text{m}$ -order-thick poly-Si films formed by FLA of precursor a-Si films. The Cr films inserted between Si and glass, acting as adhesion layers during FLA, can be utilized as back electrodes in the solar cell structure. No significant diffusion of dopant atoms as well as Cr atoms can be seen after FLA. The fabricated p-i-n poly-Si structures work as diodes and solar cells after defect termination by HPWVA. This solar cell also shows no light-induced degradation during light soaking under AM1.5 1-sun irradiation. These facts demonstrate high feasibility of this new process for solar cell fabrication.

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