

# Selection of Material for the Back Electrodes of Thin-Film Solar Cells Using Polycrystalline Silicon Films Formed by Flash Lamp Annealing

Keisuke Ohdaira, Tomoko Fujiwara, Kazuhiro Shiba, and Hideki Matsumura

Japan Advanced Institute of Science and Technology (JAIST)  
1-1 Asahidai, Nomi, Ishikawa 923-1292, Japan  
Phone: +81-761-51-1563 E-mail: ohdaira@jaist.ac.jp

## 1. Introduction

Thin-film polycrystalline silicon (poly-Si) solar cells have attracted considerable attention because of their effective usage of Si material and high stability against light soaking. High-performance solar cells have been realized using poly-Si films formed on borosilicate glass substrates by hour-order furnace annealing of precursor amorphous Si (a-Si) films [1]. Introduction of a rapid crystallization technique to the crystallization process will lead to the significant improvement of the throughput. Furthermore, if we choose a proper annealing duration, precursor a-Si films can be selectively heated without excess heating of whole glass substrate, which enable us to use low-cost, low heat-resistive substrates such as soda lime glass. We have demonstrated that flash lamp annealing (FLA), with millisecond-order duration, can form poly-Si films more than 4  $\mu\text{m}$  thick on glass substrates without serious deformation of glass substrates, and the poly-Si films show remarkable fundamental properties for solar cell material such as long minority carrier lifetime of approximately 100  $\mu\text{s}$  [2]. A Cr film inserted between a Si film and a glass substrate works as an adhesion film to prevent peeling of the Si film during FLA [3, 4]. The Cr films are also utilized as back electrodes when the poly-Si films are processed to solar cell [5], and we should know the possibility of other materials for the insertion layer with better reflectance and resistivity. In this study, we have investigated material dependence of the inserted layers on the effect to prevent the Si film peeling during FLA.

## 2. Experimental Details

Figure 1 shows the schematic diagram of the sample structure. Both quartz and soda lime glass were utilized as the substrates. We newly attempted Al, Ag, and Mo films as the insertion layer between Si films and glass substrates.

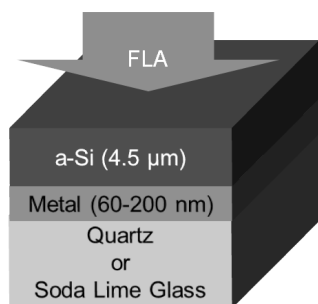


Fig. 1 Schematic of the sample structure containing precursor a-Si and metal layers.

All the metal films were formed by sputtering method. Precursor a-Si films 4.5  $\mu\text{m}$  thick were formed using catalytic chemical vapor deposition (Cat-CVD), which can provide a-Si films with low film stress and with low hydrogen content, resulting in formation of a-Si films resistant to peeling during deposition and FLA [6]. FLA was performed under fixed pulse duration of 5 ms, whereas its irradiance was systematically changed to find an optimum condition. Each sample received only one shot of flash irradiation. No dehydrogenation process was performed prior to FLA. The crystallization and crystalline fraction of the flash-lamp-annealed Si films were characterized by Raman spectroscopy.

## 3. Results and discussion

Figure 2 shows the surfaces of Si films after FLA on quartz substrates with various metal insertion layers. When Al or Ag is inserted, the Si films peel off along with the metal films during FLA. This is probably because of the low melting points ( $T_{\text{melt}}$ ) of Al and Ag. Since the temperature of the Si films during flash-lamp-induced crystallization increases up to 1400  $^{\circ}\text{C}$  [7], the metal films, which contact to the Si films, will have the almost same temperature, which is much higher than the  $T_{\text{melt}}$  of Al of 660  $^{\circ}\text{C}$  or of Ag of 962  $^{\circ}\text{C}$ . Thus, the Al-Al or Ag-Ag bonds are disconnected during FLA, resulting in peeling of the Si films with the metal layer. In contrast, when a Mo film is inserted, the a-Si film can be converted to poly-Si films without serious Si and metal film peeling. According to the previous discussion, this fact seems to be reasonable since the  $T_{\text{melt}}$  of Mo of 2623  $^{\circ}\text{C}$  is sufficiently high. According to these facts, we need to utilize metal layers with  $T_{\text{melt}}$  higher than the temperature required for the crystallization of a-Si films.

Metal	Al	Ag	Mo	Cr
Surface (20 × 20 mm <sup>2</sup> )				

Fig. 2 Surfaces of Si films after FLA on quartz substrates with various metal insertion layers. “a”, “c”, and “x” indicate a-Si, c-Si, and peeling, respectively.

Figure 3 shows Raman spectra of poly-Si films formed on Cr- and Mo-coated quartz glass substrates, indicating formation of poly-Si with high crystalline fraction close to unity. There are no significant differences in the peak

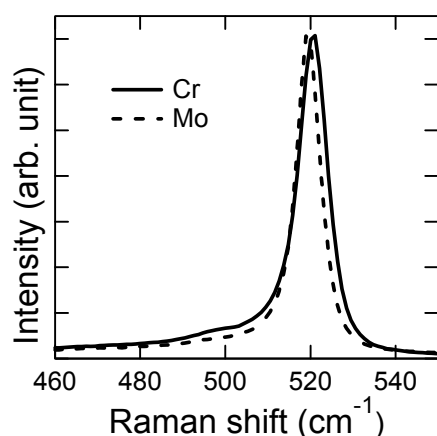


Fig. 3 Raman spectra of poly-Si films formed on Cr- and Mo-coated quartz glass substrates.

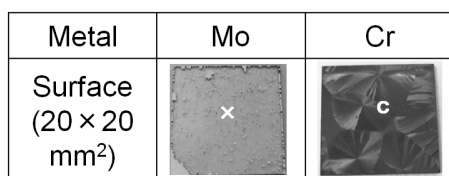


Fig. 4 Surfaces of Si films after FLA on soda lime glass substrates with Mo and Cr insertion layers.

Raman shifts and in the line widths between the two crystalline Si signals, which means that the metal layer does not affect the crystalline quality.

Figure 4 shows the surfaces of Si films after FLA on soda lime glass substrates with Mo and Cr insertion layers. When a Mo film is inserted between Si and glass, the Si and the Mo films seriously peel off, unlike in the case of quartz substrates. On the other hand, crystallization takes place on a Cr film without serious peeling, as has been reported previously [4]. These facts indicate that the adhesiveness of metal to glass and to Si is also an important factor other than sufficiently high  $T_{\text{melt}}$  for the inserted metal to suppress Si film peeling. Since soda lime glass has much larger thermal expansion coefficient of  $9.35 \times 10^{-6} / \text{K}$  [8] than that of quartz of  $0.54 \times 10^{-6} / \text{K}$  [9], better adhesiveness must be required for the metal layer on soda lime glass substrates. Cr is well-known to have excellent adhesiveness to glass [10], and one of the possible mechanisms of the high adhesiveness is the existence of an interfacial reaction zone at the glass/Cr interface [11]. These characteristics may be exerted also in our cases.

#### 4. Conclusions

Cr insertion films have superior ability to suppress peeling of Si films on glass substrates during FLA.  $T_{\text{melt}}$  higher than  $1400^\circ\text{C}$  is one of the essential factors for the insertion metals. Sufficient adhesiveness of metal films to glass substrates is also significantly required, especially when soda lime glass with large thermal expansion coefficient is utilized as substrates.

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