The investigation of ZnO:Al_2O_3/metal composite back reflectors in amorphous silicon germanium thin film solar cells*

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(Received 27 July 2012; revised manuscript received 4 December 2012)

Different aluminum-doped ZnO (AZO)/metal composite thin films, including AZO/Ag/Al, AZO/Ag/nickel–chromium alloy (NiCr), and AZO/Ag/NiCr/Al, are utilized as the back reflectors of p–i–n amorphous silicon germanium thin film solar cells. NiCr is used as diffusion barrier layer between Ag and Al to prevent mutual diffusion, which increases the short circuit current density of solar cell. NiCr and NiCr/Al layers are used as protective layers of Ag layer against oxidation and sulfurization, the higher efficiency of solar cell is achieved. The experimental results show that the performance of a-SiGe solar cell with AZO/Ag/NiCr/Al back reflector is best. The initial conversion efficiency is achieved to be 8.05%.

Keywords: a-SiGe solar cells, composite back reflector, NiCr diffusion barrier layer

PACS: 81.15.Gh, 88.40.jj, 42.82.Bq **DOI:** 10.1088/1674-1056/22/6/068102

1. Introduction

The silicon and relevant alloys are the most promising materials available for low-cost solar cells. Extensive research has been conducted by many laboratories to improve the stabilized conversion efficiency of solar cell.[1,2] The a-Si/a-SiGe tandem solar cell with thin intrinsic layers achieves high efficiency and stability.[3] For an efficient light trapping, the back electrode with a high reflectivity will reflect the light backward resulting in an absorption increase of absorber layer, thereby enhancing the short circuit current density (J_{sc}).[4–9] So the back electrode with a high reflectivity becomes a key technique for improving solar cell efficiency. Aluminum-doped ZnO (AZO)/Al structure is often preferred in the industrial amorphous silicon-based thin film solar cell due to its low cost and stable properties.[5] AZO/Ag composite films have been widely investigated due to their good reflective ability in the near infrared spectrum.[7,10,11] However, Ag is a kind of precious metal material. In addition, Ag film is susceptible to oxidation and sulfurization.[12] In the present study, metal or metal alloys are prepared in the outside of Ag layer as a protection layer. The emphasis is placed on the performance of solar cell to analyze the properties of different back reflectors. The objective of this work was to develop an effective and low cost back reflector for p–i–n silicon-based solar cell.

2. Experimental details

The solar cell was fabricated with a structure of glass/SnO_2:F/p–i–n a-SiGe/AZO/back reflector. The investigated back reflectors include Ag/Al, Ag/nickel–chromium alloy (NiCr), and Ag/NiCr/Al reflectors. The a-SiGe layers were fabricated in a capacitively coupled radio frequency plasma enhanced chemical vapor deposition (RF-PECVD) system. The AZO films were deposited by intermediate frequency magnetron sputtering from a sintered ceramic Al_2O_3-doped ZnO (3 wt%) in an argon atmosphere. The Al, Ag, and NiCr films were obtained by the direct current (DC) magnetron sputtering from pure Al, Ag, and NiCr (80% Cr) targets, respectively.

The thickness values of the thin films were determined by Bruker DEKTAK XT profiler. The scanning electron microscopy (SEM) (ZEISS SIGMA) was employed to characterize the cross-sectional images. The photo current-density versus voltage (J–V) characteristics of the solar cells were measured at 25 °C under 1-sun (AM1.5, 100 mW/cm^2) solar simulator radiation. The values of quantum efficiency (QE) were measured in a wavelength range of 350 nm–900 nm to evaluate the spectral response of the fabricated solar cells.

The silicon layer deposition conditions for a group of solar cells to be compared with each other were the same. There would be difference in silicon layer deposition condition between groups of solar cells.

3. Results and discussion

In order to check the AZO properties for our fabrication process directly, we prepare a-Si and a-Si/a-SiGe thin film solar cells with and without AZO back reflector on commercial Asahi glass substrates according to the deposition order used in the actual solar cell (shown in Fig. 1(a)). The thickness of the AZO film is about 90 nm. The transmittance from the film surface is measured under the solar spectral irradiance onto

*Project supported by the National Basic Research Program of China (Grant No. 2011CBA00705) and the High Technology Research Program of China (Grant No. 2011AA050502).

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the glass side. The obtained results are shown in Fig. 1(b). It can be seen that the insertion of a 90-nm-thick AZO layer improves the transmittance of a-Si or a-Si/a-SiGe thin film. The interface properties of the metal back reflector are improved by deposition on the AZO film, which can increase the reflectivity of AZO/metal back reflector.

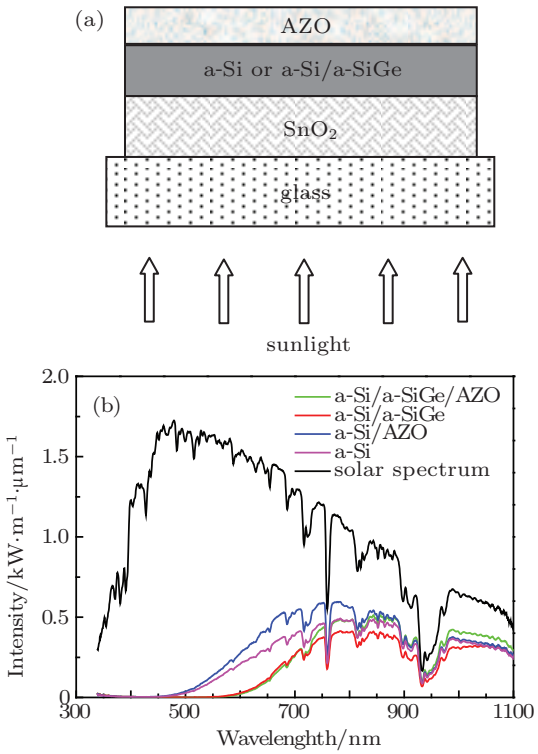


Fig. 1. (color online) (a) Structure of the superstrate p–i–n a-Si or a-Si/a-SiGe thin film solar cell with and without AZO back reflector; (b) optical transmittance spectra of diagram (a) under solar spectral irradiance onto the glass surface.

A single AZO/Ag back reflector has been investigated in Refs. [7], [10], and [11]. To reduce the cost and avoid oxidation, a thin Al layer is covered on the Ag. The cross-sectional image of the film is shown in Fig. 2(a). The films are deposited on polished silicon wafers. The section cannot be distinguished due to the inter-diffusion of Ag and Al films. In order to reduce the intermixing of Al and Ag, appropriate barrier layer should be used. The sufficient diffusion barriers have been achieved by ZnO,[13–18] SiO_2, SiO_x,[19] Al_2O_3[20] or Cr[21] layers to reduce the diffusion of metal atoms into the absorber layers of solar cells. The diffusion barrier between two kinds of metals is rarely investigated in the field of photovoltaics. We propose to deposit a NiCr film with good thermal and chemical stability between Ag and Al against the intermixing of them. The thickness of NiCr layer was kept at about 20 nm∼30 nm because of its high electric resistivity (10^{-6} Ω·m). Thus, the back reflector structure changes into AZO/Ag/NiCr/Al. The cross-sectional image of the film is shown in Fig. 2(b). The cross section between Ag and Al is sharper. No obvious interfacial diffusion is observed.

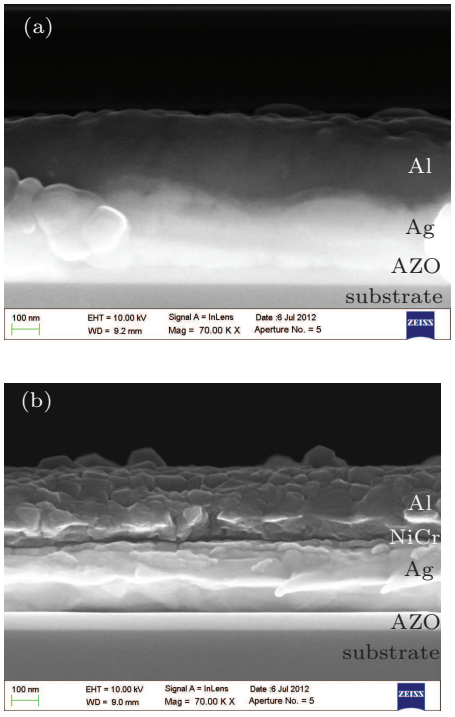


Fig. 2. Cross-sectional images of different thin films (a) with and (b) without NiCr diffusion barrier layer between Ag and Al.

In order to check the back reflector properties directly, we prepare the a-SiGe solar cells with and without NiCr diffusion barriers. QE curves of the solar cells are shown in Fig. 3. With the use of a NiCr diffusion barrier layer, there is a clear increase of the QE in the 600 nm–900 nm range. Compared with the solar cell with AZO/Ag/NiCr/Al back reflector, it is indeed the intermixing of Al and Ag that results in the J_{sc} reduction by 1.98 mA/cm^2 of the solar cell. This demonstrates NiCr layer has a great influence on Ag/Al bilayer and can prevent the inter-diffusion of Ag and Al.

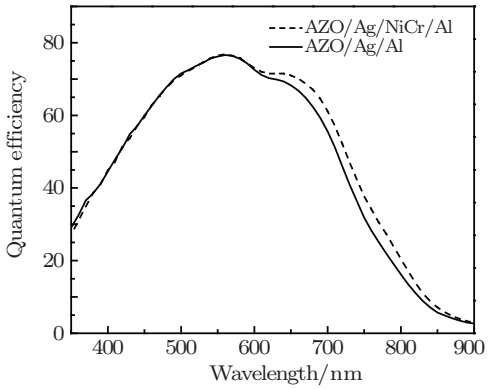


Fig. 3. QE curves of the a-SiGe solar cells with and without NiCr diffusion barrier in back reflector.

Aluminum is difficult to weld firmly. However, NiCr is often very easy to weld. So a 50-nm∼70-nm-thick NiCr film was deposited on Ag thin film as its protective layer. Table 1 shows the values of J_{sc}, open-circuit voltage (V_{oc}), fill factor (FF), efficiency (η), series resistance (R_s), and shunt resistance (R_{sh}) of the a-SiGe solar cells with and without Al back

reflector. Figure 4 shows the measured current–voltage characteristic of the solar cell with 8.05% initial conversion efficiency under illumination. It can be seen that the solar cells with and without Al back reflector both show the higher values of η. The solar cell without Al back reflector has a higher QE, reaching a 1.9% increase of J_{sc} and a 5% reduction of FF. We suggest that the deterioration of FF could be attributed to the high electric resistivity of NiCr film, which increases the value of R_s. The QE curves of the solar cells are shown in Fig. 5. The reduction of the quantum efficiency of solar cell with AZO/Ag/NiCr/Al back reflector in the 600 nm–900 nm range is probably due to NiCr layer being thinner, so that it could not prohibit completely the mutual diffusion of Ag and Al. An intensive optimization of the NiCr sputtering process will be done to improve the solar cell performance further in our coming work.

Table 1. Values of short-circuit current density (J_{sc}), open-circuit voltage (V_{oc}), fill factor (FF), efficiency (η), series resistance (R_s), and shunt resistance (R_{sh}) of a-SiGe solar cells with AZO/Ag/NiCr and AZO/Ag/NiCr/Al back reflector.

Back reflectors	J_{sc}/mA·cm^{-2}	V_{oc}/V	FF	η/%	R_s/Ω	R_{sh}/Ω
AZO/Ag/NiCr	18.53	0.75	0.56	7.78	4.98	264
AZO/Ag/NiCr/Al	18.19	0.75	0.59	8.05	4.13	348

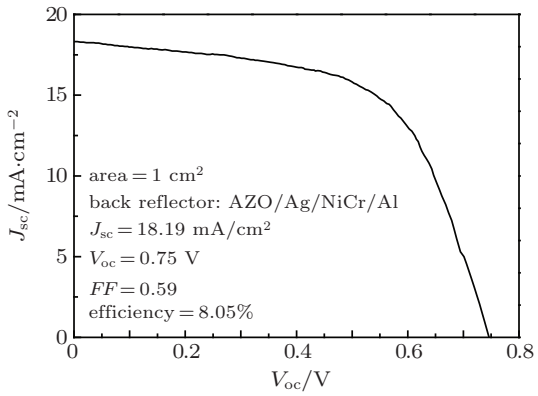


Fig. 4. Current–voltage characteristic of the p–i–n a-SiGe solar cell under illumination.

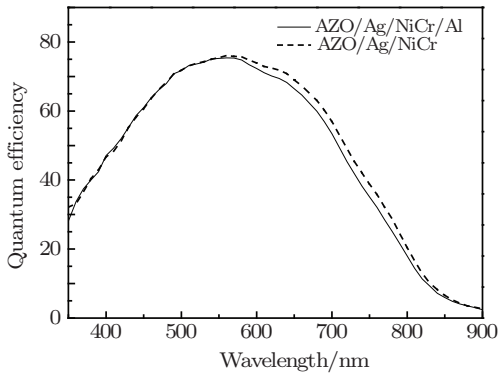


Fig. 5. QE curves of the a-SiGe solar cells with AZO/Ag/NiCr/Al and AZO/Ag/NiCr back reflector.

4. Conclusions

The deposition of AZO between n-layer and metal back reflector for a-Si or a-Si/a-SiGe solar cell enhances reflectivity of AZO/metal back reflector. The measured cross-sectional images of AZO/Ag/Al and AZO/Ag/NiCr/Al back reflector show that the NiCr film can effectively prevent the diffusion between Ag and Al, which results in the remarkable increase of the J_{sc} in a-SiGe solar cell. The NiCr/Al or NiCr acts as a protective layer of Ag layer, so high performance of solar cell is achieved, while the solar cell without Al back reflector achieves a 1.9% increase of J_{sc} and 5% reduction of FF. Through the optimization of the preparation process, we obtain a 8.05% (J_{sc} = 18.19 mA/cm^2, V_{oc} = 0.75 V, FF = 0.59) of initial conversion efficiency for a-SiGe solar cell with AZO/Ag/NiCr/Al back reflector.

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