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Fabrication of cadmium sulfide/p type silicon heterojunction solar cells under 300 °C with more than 10% efficiency

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ABSTRACT

Cadmium sulfide (CdS) film is combined to p-type silicon substrate in order to fabricate heterojunction solar cells. The optimized efficiency with inserting MoO_3 layer between cadmium sulfide and silicon reaches 10.64%, with open voltage, short current density and fill factor of 543 mV, 28.75 mA/cm^2 and 68.13% under traditional condition of 300 °C. Finally, the cell's degradation rate is 5.30% in two months, indicating that this is a stable cell design.

1. Introduction

Solar cells are in principle composed of a p-n junction close to the device's surface. Front strip finger ohmic contact and entire back ohmic contact are usually designed for one-side solar cells (Bullock et al., 2016; De Wolf et al., 2012; Hilali and Nakayashiki, 2006). In conventional silicon solar cells, p-n junction is fabricated by diffusion method at 800–900 °C (Polman et al., 2016; Jeffrey, 2014), resulting in a high energy consumption, which is also harmful to wafer quality. In contrast, heterojunction solar cells are appealing due to the low manufacture cost and low temperature coefficient. Silicon heterojunction solar cells (SHJ) stands for high open voltage, low temperature coefficient and small energy budget. This sort of device recently achieved the efficiency record of 26.67% for crystalline silicon solar cells (Kim and Kim, 2015; Yamaguchi et al., 2003; Kinoshita et al., 2011). These excellent performances mostly thank to surface passivation by intrinsic a-Si:H. However, the equipment of PECVD (Plasma Enhanced Chemical Vapor Deposition) which is used to fabricate the amorphous silicon film and low temperature silver past are expensive, which leads to the total cost of SHJ cells are still uncompetitive opposed to traditional thermal power generation (Mikio et al., 2014; Kim et al., 2015). Searching for novel heterojunction solar cell design is yet to be a hot issue.

Semiconductor compound film/silicon based heterojunction solar cells (other than amorphous silicon film) tend to solve the problems that both the low cost and high efficiency. CdS/p-Si heterojunction solar cells are one of this kind of solar cells. CdS/p-Si heterojunction solar cells were systematically investigated since 1980 (Arya et al., 1982; Coluzza et al., 1980; Swades Ranjan Bera and Satyajit Saha, 2016; Katiyar et al., 2015; Coluzza et al., 1980). Arya group reported an efficiency of 11.3% with a small area of 0.16 cm^2 (Arya et al., 1982). F. J. Garcia et. al published 8.1% efficiency, with larger area of 2×2 cm^2 (Garcia et al., 1988). Chuan He and co-workers applied ITO in CdS/p-Si solar cells, but the cells nearly have no efficiency (He et al., 2011). The efficiency of CdS/p-Si heterojunction solar cells with a larger area of 1×1 cm^2 in the present work reaches 10.64%.

2. Experimental

The fabrication procedure of CdS/p-Si heterojunction solar cells is described as below. Mirror-polished p type (1 0 0) CZ-Si wafer with 1–5 Ω cm resistivity was forward to standard RCA cleaning, followed by loading into a vacuum evaporation system. Cadmium sulfide powder (99.999% purity; Sigma company) was evaporated from the tungsten boat onto the silicon substrate, under temperature of 25 °C and pressure of 1e-3 Pa. The film growth rate is 0.5–3 Å/s and the thickness ranges from 60 nm to 300 nm. Next, aluminum doped zinc oxide (AZO) thin film was prepared by a DC magnetron sputtering, with power density around 4.1 W/cm^2 and substrate temperature of 250 °C. A piece of soda-lime glass employed as the substrate of CdS film was fixed on a parallel carrier to the target surface with the target-substrate distance of 90 mm. The moving speed of the carrier was 3 mm/s during deposition. After that, a stack with silver layer sandwiched by two AZO layers (AZO/Ag/AZO) film is prepared by co-sputtering silver and AZO targets; Hydrogen is adopted during sputtering in order to obtain AZO:H film.

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Finally, silver fingers with thickness of 400 nm were evaporated on the top of the cells and the silver paste covers the entire rear side.

3. Characterization

The surface morphology of the CdS and AZO:H thin films were measured by SEM (Bruker S-4800, with high voltage of 14.3 kV and pulse of 47.43 kcps). The absorption of CdS film was determined by Cary 5 spectrophotometer in the spectral range of 200–1100 nm. The sheet resistance of CdS films was measured using a linear array four-point probe. Hall measurements were carried out at room temperature by the van-der-pauw method. The measured error is within 2%. Films thickness was characterized by the surface measurement equipment of profilometer (Dektak 3). Cell I-V curves were recorded on a Keithley 2400 source meter under illumination of AM 1.5 G solar simulator (Oriel, model no. 91160, equipped with a 150 W xenon lamp), whose simulated light power was calibrated by an NREL standard Si solar cell.

4. Results and discussion

4.1. Parasitic absorption of CdS/p-Si heterojunction solar cells

Parasitic absorption is defined as that emitter material absorbed sunlight but didn't generate electric-hole pairs. In this research, cadmium sulfide is prepared by thermal evaporation method, so it is amorphous or multi-crystalline, in which there are lots of defects and dislocations in it. If sunlight is absorbed by cadmium sulfide, the generated electrons and holes in cadmium sulfide will be recombined, which leads to serious parasitic absorption (Coluzza et al., 1980). Because cadmium sulfide has large bandgap of 2.4 eV, it can not only act as emitter but also window layer, which can reduce parasitic absorption in silicon heterojunction (SHJ) solar cells. Fig. 1 shows the shading area of the parasitic absorption of CdS. Absorption ranges of c-Si and CdS are 300–1100 nm and 240–480 nm, respectively. Because most of the sunlight can be absorbed by silicon, and only the light from 300 to 480 nm is absorbed by cadmium sulfide, the parasitic absorption is little in CdS/p-Si heterojunction solar cells. Clearly, CdS is an ideal emitter in SHJ solar cells.

4.2. Structure of CdS/p-Si heterojunction solar cell

Fig. 2 is the structure of the CdS/p-Si heterojunction solar cell. P type silicon and n type cadmium sulfide form the heterojunction; AZO film act as electrode assistance; silver fingers act as front ohmic contact and the rear side is totally with Ag BSF.

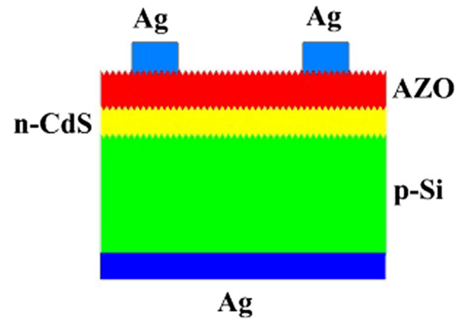


Fig. 2. Schematic structure of CdS/p-Si heterojunction solar cell.

4.3. Characterization of CdS films

SEM images and photos of CdS films are found in Fig. 3(a–d) and (e–h). The increase of the film thickness enhances the CdS particle size. Fig. 4 shows the transmittances of the CdS films with thickness of 60, 100, 200 and 300 nm are 82.5%, 78.6%, 66.7% and 59.4%, respectively. Apparently, the thicker the films are, the more sunlight is absorbed within these films. While high transmittance is preferred for cell performance. 60 nm thick film is adopted for CdS/p-Si heterojunction solar cell fabrication.

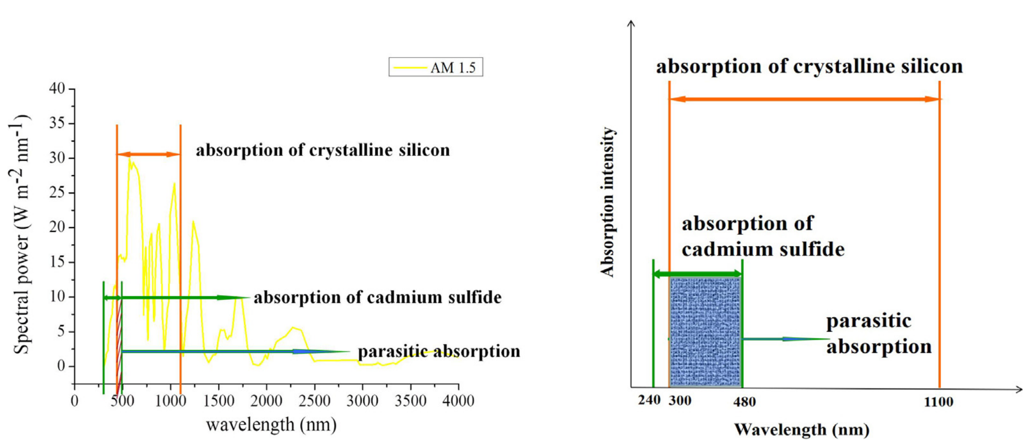
4.4. Optical and electrical properties of AZO films

In this work, the aluminum doped zinc oxide film (AZO), the stack with silver layer sandwiched by two AZO layers film (AZO/Ag/AZO) as well as aluminum and hydrogen co-doped zinc oxide film (AZO:H) are sputter coated respectively. Fig. 5 and Table 1 show the optical and electrical parameters of these films.

4.5. Performance of CdS/p-Si heterojunction solar cells

4.5.1. The electrical properties of CdS/p-Si heterojunction solar cells sputtered with AZO, AZO/Ag/AZO and AZO:H films, respectively

Three aforementioned AZO films are then utilized to prepare CdS/p-Si heterojunction solar cells. I-V curves are shown in Fig. 6. From Fig. 6 and Table 2, the cell with AZO:H film is the best. The average transmittance of AZO:H film from 300 nm to 1100 nm is 78.4%, promising abundant sunlight is absorbed by the silicon wafer. In contrast, the



(a) with actual absorption

(b) the enlarged drawing of parasitic absorption of cadmium sulfide and silicon

Fig. 1. Parasitic absorption of CdS/p-Si heterojunction solar cells, (a) with actual absorption, (b) the enlarged drawing of parasitic absorption of cadmium sulfide and silicon.