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Studies on fabrication and characterization of a ZnO/p-Si-based solar cell

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ABSTRACT

A kind of solar cell with the n-ZnO/p-Si hetero-junction interface structure has been fabricated by using DC magnetron sputtering, and its photovoltaic (PV) property is investigated by using the current–voltage (I–V) measurement under AM 1.5 illumination. The light I–V curves show a strong bias-dependent change and the photo-electric conversion efficiencies in the range of 0.7–1.14% have been achieved. The largest values of open circuit voltage (V_{oc}) and short circuit current (J_{sc}) were about 400 mV and 17.27 mA/cm^2, respectively. The crossover behavior of the dark and light I–V curves suggests that the recombination current arising from the interface states contributes to the bias dependence of the light I–V curve. The Si 2p spectra at the interface of ZnO/p-Si confirm the complexity of the interface quality and the existence of a large number of interface states. The bend behavior arising from the back contact barrier and the series resistance up to 50 Ω obtained from the dark I–V curve are also confirmed to be the crucial factors for achieving a good performance of the ZnO/p-Si-based solar cell.

1. Introduction

Recently, those hetero-junction solar cells with the configuration of a wide band gap transparent conductive oxide (TCO) on a single crystal silicon wafer have gained more attention due to potential advantages such as an excellent blue response, simple processing steps, and low processing temperatures [1]. In the previous, the conversion efficiencies in the range of 12–15% have been achieved by spray-deposited ITO films on Si substrates [2]. However, due to the limited source of

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indium on the earth, the utilization of abundant materials is required to improve this situation. As a replacement, zinc oxide (ZnO) film has good electrical and optical properties in combination with low cost, non-toxicity, and relatively low deposition temperature [3]. Furthermore, n-type conductivity is relatively easy to be realized by the excess of Zn or doping Al, Ga, or In [4]. All of these virtues can lower the cost of solar cells and make ZnO/Si hetero-junction solar cells to be competitive in the future photovoltaic (PV) market.

Although there presents a number of advantages for ZnO/Si-based solar cells, just a few people pay attention to this low-cost solar cell. Most of reports focus on the fabrication of Al-doped ZnO on n-Si to form MIS (Metal–insulator–semiconductor) junction [5,6]. In addition, the photoelectric properties of ZnO films, the current transport mechanism through the hetero-junction and the degradation of photovoltaic effect have been widely studied.

In comparison, fewer reports are about the investigation of n-ZnO/p-Si-based solar cells [1,7]. With this view in mind, in the present paper, a series of Al-doped ZnO (AZO) films were identically deposited on p-Si substrates by DC magnetron sputtering and reproducible efficiencies in the range of 0.7–1.14% have been obtained. We analyzed the dark and light *I–V* curves and proposed some key factors determining the efficiency of AZO/p-Si hetero-junction solar cells.

2. Experiment

Al-doped n-ZnO thin films were deposited for 12 min by a DC magnetron sputtering on the unpolished p-type (100) Czochralski silicon wafers (the resistivity of 3–6 Ω cm and the thickness of 220 μm) with a commercial ceramic target (98 wt% ZnO + 2 wt% Al_2O_3, 99.99% purity) under a power of 120 W. After the normal cleaning procedure, the silicon wafers were dipped in 10 wt% HF for 1 min and then directly delivered into the vacuum chamber without de-ionized water rinsing. The deposition temperature was 480 °C and the thicknesses of the deposited films were typically 300 nm, as measured by the surface profile measuring system (Ambios XP-2).The sheet resistances of AZO films were typically 30 Ω/□ measured by four-point probe. For realizing ohmic contacts with both the surface of AZO films and the back-side of p-Si, the 35-μm-thick Al electrodes were evaporated followed by a thermal annealing in N_2 ambient at 500 °C for 30 min.

The dark and light *I–V* curves of these AZO/p-Si hetero-junction devices with the size of 1×1 cm^2 were measured by using the Agilent 4155C (SS-PV-011) system and a solar simulator under AM1.5 illumination, respectively. The scanning mode is "source *V* measure *I*". The sensitivity of voltage is ±2 mV and the resolution of current is 1 μA. A cooling device is used to keep the device temperature at 24 ± 1 °C during the dark and illuminated *I–V* measurement. In addition, the cross section of the back contact between p-Si and Al was measured by a scanning electron microscope (SEM, JSM-6700F). The Si 2p spectra at the interface of AZO/p-Si were also measured by the X-ray photoelectron (XPS, Kratos Axis Ultra DLD).

3. Results and discussion

Fig. 1 shows the light *J–V* characteristics of the hetero-junctions as a function of the applied bias. Four samples show similar *J–V* shapes to each other. It is noteworthy that the current density of the light *J–V* curves varies with the applied bias. Taking sample 4 for example, the reverse current density saturates at a high value of 27.16 mA/cm^2 generated by light in the high reverse bias regime ($V < -0.4$). Nevertheless, the reverse current density is rapidly decreased in the low reverse bias regime ($-0.4 < V < 0$) and only kept at 11.12 mA/cm^2 when the bias voltage equals to zero. And the current density is continuously decreased in the low forward bias regime ($0 < V < 0.4$). In addition, apparent bend behaviors for the forward bias range $0.2 < V < 0.5$ are observed for all light *J–V* curves as indicated by the arrow.

The right lower inset of Fig. 1 gives the PV parameters of the four samples including open circuit voltage (V_{oc}), short circuit current density (J_{sc}), fill factor (FF) and efficiency (Eff.). The largest values of V_{oc} and J_{sc} arrive at 400 mV and 17.27 mA/cm^2, respectively. In contrast, the smallest values of V_{oc} and J_{sc} are 380 mV and 11.12 mA/cm^2. Furthermore, efficiencies in 0.7–1.14% range are gained and sample