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Aluminum doped zinc oxide wide band-gap n-type optical window for μc-Si superstrate solar cell

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ABSTRACT

ZnO:Al thin films were deposited onto glass substrates by RF-magnetron sputtering system. The crystallographic orientation of the films, determined using an X-ray diffractometer (XRD), had a high *c*-axis orientated crystalline structure along (002) plane. The grains are densely packed as shown in the surface micrograph. The electrical parameters were carried out using Hall Effect measurements. The optical band-gap of the films was estimated based on the thickness and the optical transmittance data and is about 3.78 eV for 50 W RF-power. All parameters obtained were used to simulate a new solar cell structure based on p-type microcrystalline silicon as an absorber and n-ZnO:Al as an optical window. The excellent optical properties of this layer result in a high light trapping yielding to efficiencies about 19%. In order to improve efficiency, we have used a p^+-μc-Si thin layer highly doped as a back surface field which minimizes significantly the impact of rear surface recombination velocity on voltage and current leading to a high efficiency of 22%. Optoelectronic parameters were determined using the current density-voltage (*J-V*) curve by means of an AMPS-1D device simulator.

1. Introduction

The increasing use of Al-doped (ZnO:Al) transparent-conductive oxide for large area electronic applications such as solar cells and displays has promoted this material development study. In this regard, thin films have attracted much attention because of their high optical transmittance and low electrical resistivity.

The most commonly used technique employed in the deposition of ZnO:Al films is radio frequency (RF) magnetron sputtering [1–5]. It is considered to be one of the most favourable deposition methods due to its high reproducibility and it permits deposition at low temperature with good surface uniformity.

Existing solar cells based on silicon are constantly increasing in efficiency [6,7]. To make a major impact, the cost has to decrease while the energy conversion efficiency increases. The basic factor that affects the efficiency of a solar cell is the reflection of light from its front surface, that is why it is impossible to produce efficient solar cells without any antireflective coating [8,9]. In addition, the trend towards thinner and more efficient silicon solar cells and in order to reduce the cost of PV modules, a new cell device structure is now considered using a heterojunction where the layer at the front surface of the homo-junction is replaced by a thin layer whose excellent optical properties result in a superior light trapping [10,11].

The aim of this work is to increase the energy conversion efficiency of the silicon solar cell by using a transparent conducting oxide as an optical window [12]. ZnO:Al is regarded as an ideal candidate because of its high transparency to visible light and high conductivity [12–14]. The cell performances are analysed numerically using the "one dimensional Analysis of Microelectronic and Photonic Structures" (AMPS-1D) device simulator [15]. We show how the device performance is affected by the silicon absorber parameters especially thickness. However, as the silicon wafer becomes thinner to save costs, back surface recombination will become more important limiting the improvement in cell efficiency [16]. It has been recognized that a thin layer heavily doped at the

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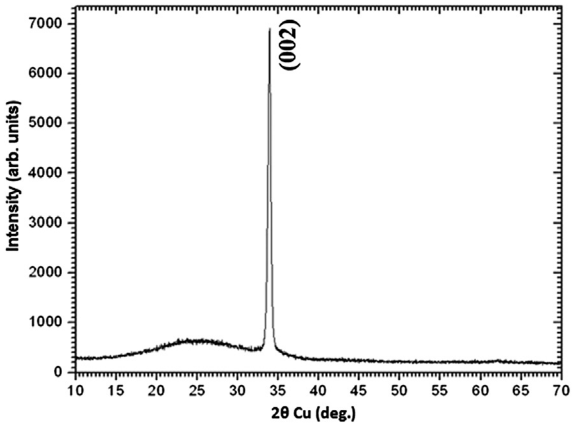

Fig. 1. XRD pattern of ZnO:Al thin films.

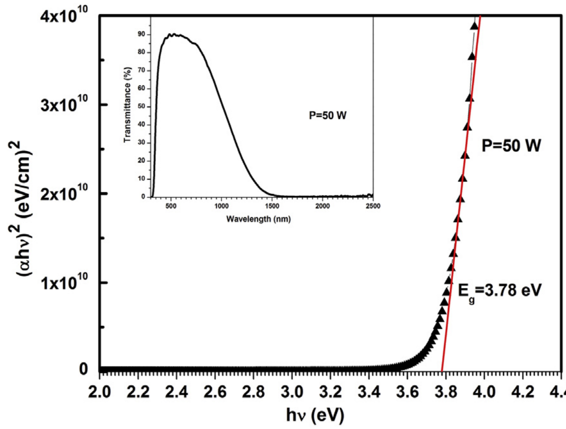

Fig. 3. The plots of $(\alpha h\nu)^2$ vs photon energy for the ZnO:Al thin films with transmission as inset.

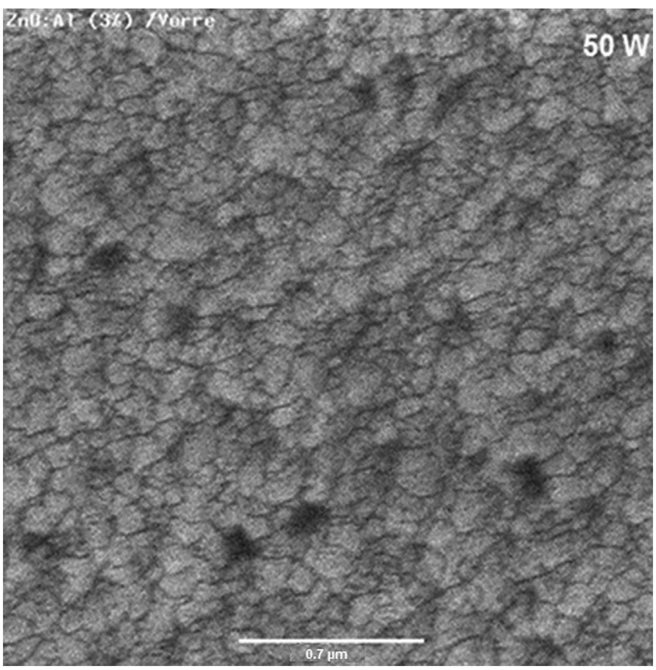

Fig. 2. Surface micrograph of the ZnO:Al thin films.

back side can generate an inner electron field to repel photo-induced minority carriers, thereby reducing the back surface recombination velocity [16–18].

2. Experimental details

ZnO:Al films are deposited by RF-magnetron sputtering from ZnO/Al_2O_3 (97/3 wt.%) target onto soda lime glass substrates. The glass substrates were ultrasonically cleaned in an acetone bath before loading into the sputtering system. The sputtering chamber was evacuated using a rotary pump and turbo-molecular pump. In this work, room temperature deposition is used and the thickness of the films is monitored by quartz microbalance placed near the substrate. The base pressure was 9×10^{-5} Pa. High purity (99.99% pure) argon and oxygen gases were introduced into the chamber and controlled by two digital-mass flow controllers. During sputtering, the total gas flow to the argon gas flow ratio was fixed at 2. The sputtering target was pre-sputtered for a few minutes before the deposition. Films were deposited at 50 W RF power for 15 min.

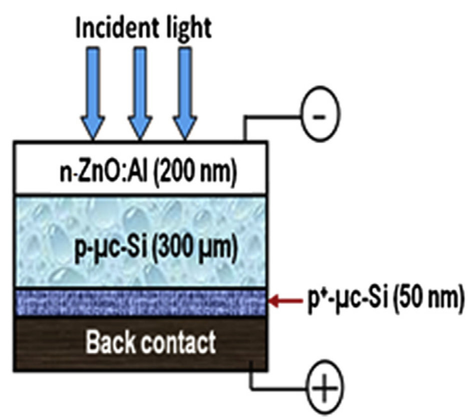

Fig. 4. Microcrystalline silicon superstrate structure.

We successfully prepared n-type ZnO:Al thin films using reactive rf-magnetron sputtering in the $Ar-O_2$ mixture atmosphere in this work. By controlling the Ar to O_2 ratio in ambient temperature, n-type ZnO:Al films with low resistivity and high transparency were obtained.

XRD spectra were determined using an X-ray diffractometer (Philips PW1729). The surface morphology and the roughness was measured using scanning electron microscopy (SEM, JEOL JSM-840) operating at 20 kV. The electrical resistivity was measured at room temperature with the Hall Effect HMS 5300 system and the optical properties were characterized by UV–Vis–NIR transmission spectroscopy using a Shimadzu–UV3101PC spectrophotometer in the wavelength range from 200 nm to 3000 nm.

Table 1
Simulation parameters set of the superstrate solar cell.

Parameters	Layers		
	n-ZnO:Al	p-µc Si	p^+-µc Si
ε_r (−)	9	11.9	11.9
χ (eV)	4.5	4	4
E_g (eV)	3.78	1.12	1.12
μ_n (cm^2/Vs)	43.6	856.6	171.3
μ_h (cm^2/Vs)	0.1	373.9	48.6
N_A (cm^{-3})	0	4×10^{16}	8×10^{19}
N_D (cm^{-3})	9.18×10^{20}	0	0