Journal of Alloys and Compounds 581 (2013) 28–34

Contents lists available at SciVerse ScienceDirect

Journal of Alloys and Compounds

journal homepage: www.elsevier.com/locate/jalcom

A novel ITO/AZO/SiO_2/p-Si frame SIS heterojunction fabricated by magnetron sputtering

Bo He [a,*], HongZhi Wang [a], YaoGang Li [a], ZhongQuan Ma [b], Jing Xu [c], QingHong Zhang [a], ChunRui Wang [a], HuaiZhong Xing [a], Lei Zhao [b], YiChuan Rui [a]

[a] Department of Applied Physics and State Key Laboratory for Modification of Chemical Fibers and Polymer Materials, Donghua University, 2999 Renmin Rd. North, Songjiang District, Shanghai 201620, People's Republic of China
[b] Department of Physics, Shanghai University, Shanghai 200444, People's Republic of China
[c] Instrumental Analysis and Research Center, Shanghai University, Shanghai 200444, People's Republic of China

ARTICLE INFO

Article history:
Received 18 April 2013
Received in revised form 21 June 2013
Accepted 24 June 2013
Available online 4 July 2013

Keywords:
Indium tin oxide (ITO)
Al-doped ZnO (AZO)
Magnetron sputtering
SIS heterojunction
Current–voltage (*I–V*) characteristics

ABSTRACT

The novel ITO/AZO/SiO_2/p-Si SIS heterojunction has been fabricated by low temperature thermal oxidation an ultrathin silicon dioxide and RF sputtering deposition ITO/AZO double films on p-Si (100) polished substrate. The microstructural, optical and electrical properties of the ITO/AZO antireflection films were characterized by XRD, SEM, UV–VIS spectrophotometer, four point probe and Hall effect measurement, respectively. The results show that ITO/AZO films are of good quality. And XPS was carried out on the ultrathin SiO_2 film. The heterojunction shows strong rectifying behavior under a dark condition, which reveals that formation of a diode between AZO and p-Si. The ideality factor and the saturation current of this diode is 2.7 and 8.68×10^{-5} A, respectively. High photocurrent is obtained under a reverse bias when the crystalline quality of ITO/AZO double films is good enough to transmit the light into p-Si. We can see that under reverse bias conditions the photocurrent of ITO/AZO/SiO_2/p-Si SIS heterojunction is much higher than the photocurrent of AZO/SiO_2/p-Si SIS heterojunction. Because the high quality crystallite and the good conductivity of ITO film which prepared by magnetron-sputtering on AZO film lead to a great decrease of the lateral resistance. The photon induced current can easily flow through ITO layer entering the Cu front contact. Thus, high photocurrent is obtained under a reverse bias.

1. Introduction

Semiconductor–insulator–semiconductor (SIS) diodes have certain features which make them more attractive for solar energy conversion than conventional Schottky diode, MIS, or heterojunction structures [1]. For example, efficient SIS solar cells such as indium tin oxide (ITO) on silicon have been reported, where the crystal structures and lattice parameters of Si (diamond, $a = 0.5431$ nm), SnO_2 (tetragonal, $a = 0.4737$ nm, $c = 0.3185$ nm), In_2O_3 (cubic, $a = 1.0118$ nm) show that they are not particularly compatible and thus not likely to form good devices. The SIS structure is potentially more stable and theoretically more efficient than either a Schottky or a MIS structure. The origins of this potential superity are the suppression of majority-carrier tunneling in the SIS structure, the absence of a thin metal which absorbs light and is subject to environmental degradation, an induced junction and thin interfacial layer which minimizes the amount and impact of interface states, and the wide choice of conductivities and band gaps allowed in the top layer. In addition, the top semiconductor thin film can serve as an antireflection coating, a low-resistance window, as well as the collector layer of the junction.

In a device such as the SIS diode, the two semiconductors are separated by an interfacial region. The insulator is sufficiently thin (10–30 Å) so that electrons transport through the interface by tunneling. While the tunneling process is sensitive, to a degree, to the sharp of the barrier, it is charge transport in the semiconductors that determines the *I–V* characteristics (in Fig. 1).

Zinc oxide (ZnO) is considered a promising wide-bandgap optoelectronic material in photoelectronics, such as solar cell, UV lasers and LEDs [2–11]. Some especially interesting properties of ZnO are low cost, availability, nontoxicity and high chemical stability in reducing environments. In a photodetector, designed to sense both UV and visible photons, a wide band gap (3.3 eV) semiconductor is very promising as window material due to its high transparency (>80%) in the visible region. At the same time, it can be used as a transparent conducting oxide electrode by doping with Al.

Al-doped ZnO (called AZO) layers are very frequently used as window layers in photovoltaic solar cell. In this application high electrical conductivity should be combined with a low value of the optical absorption constant in the visible range. Thus an appropriate measure of the performance is the ratio and the optimiza-

* Corresponding author. Tel.: +86 13917427283; fax: +86 02167792133.
E-mail address: laserhebo@163.com (B. He).

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http://dx.doi.org/10.1016/j.jallcom.2013.06.144

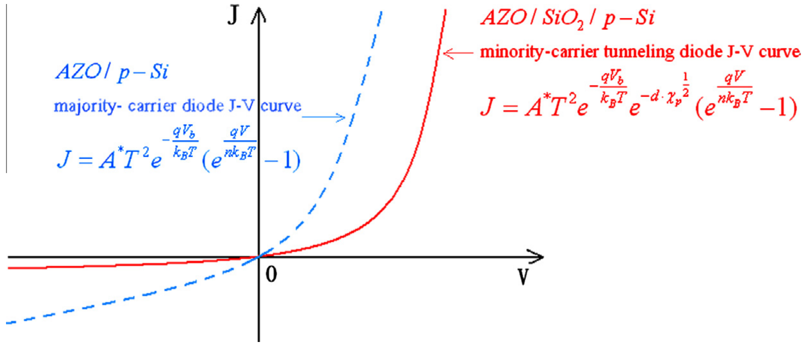

Fig. 1. Comparison of AZO/p-Si and AZO/SiO_2/p-Si *I–V* curves in dark.

tion consists in realizing high carrier concentration and mobility with a minimum optical loss due to free carrier absorption at long wavelength region. Such layers can be prepared by several techniques most frequently by magnetron sputtering either from compound targets or reactively from metallic targets.

In this work, ITO and AZO were deposited by magnetron sputtering on p type crystalline Si as a practical photo-window for Si photovoltaic device, and also as a semiconducting layer which causes a depletion region and a build-in barrier potential in the heterojunction. Because the work function of AZO is 4.2 eV lower than the work function of p-Si. The ultrathin SiO_2 layer grew on the surface of p-Si by heating oxidation at low temperature. It not only effectively passivated the surface of p-Si, but also reduced the mismatch of ZnO and Si. In addition, the top ITO/AZO double films can serve as an antireflection coating, a low-resistance window, as well as the collector layer of the junction [12]. The SIS structure with a wide gap semiconductor as the top layer eliminates the surface dead layer associated with homojunction devices. This absence of such absorption in a surface layer improves the ultraviolet response.

Thus, the present paper is based on study to use a polycrystalline AZO film deposited by direct-current (DC) magnetron sputtering on the ultrathin SiO_2/p-Si substrate as a photon window for photoelectric device as well as a semiconducting layer which creates a depletion region and build-in potential in produced heterojunction. The surface electrode was formed by radio-frequency (RF) sputtering a transparent ITO layer with a thickness of 70 nm on the AZO film as an antireflecting photo-window for SIS heterojunction.

2. Experiment

For the purpose of fabricating SIS structure, a p-type polished single crystal Si (100) wafer was used as the substrate of the heterojunction. The wafer was prepared by a stand cleaning procedure, then it was dipped in 10% HF solution for 1 min to remove native oxide layer. Finally, the wafer was dried in a flow of nitrogen.

By thermal evaporation, 1 μm-thick Al electrode was deposited on the back side. Then the sample was annealed at 500 °C for 30 min in N_2:O_2 = 4:1 condition to form good ohmic contact and an ultrathin oxide layer (about 15–20 Å) was grown on the p-Si surface.

The ITO and AZO films were deposited on the oxidized silicon substrate in a magnetron sputtering system. The targets were two sintered ceramic disks of In_2O_3 doped with 10wt% SnO_2 and ZnO doped with 2 wt% Al_2O_3 (purity 99.99%), respectively. The base pressure inside the chamber was pumped down to less than 5×10^{-4} Pa. Sputtering was carried out at a working gas (pure Ar) pressure of 1 Pa. The Ar flow ratio was 30 sccm. The temperature on substrates was kept at 480 °C. The DC power for sputtering AZO film was 100 W. While The RF power for sputtering ITO film was 100 W. Both sputtering was proceeded for 0.5 h. The thicknesses of ITO and AZO film are about 70 nm and 200 nm, respectively.

Finally, by sputtering, a 1 μm Cu metal film was deposited with a shadow mask on the ITO surface for the top electrode. The area of the Cu electrode is 1×1 mm^2.

The thicknesses of ITO and AZO films were measured by step profiler. The microstructure of the films was characterized by XRD and SEM. The optical transmission of the films was measured by UV–VIS spectrophotometer. The electrical properties of ITO and AZO films were characterized by four point probe and Hall effect measurement (Accent HL5500pc) at room temperature. And XPS was carried out on the ultrathin SiO_2 film. The current–voltage (*I–V*) characteristic of the device was measured by Agilent 4155C semiconductor parameter analyzer. Figs. 2 and 3 show the schematic and bandgap structure of the novel ITO/AZO/SiO_2/p-Si SIS heterojunction.

3. Results and discussion

3.1. Microstructure, optical and electric properties of ITO and AZO films

Fig. 4 shows the XRD spectra of ITO/AZO films on glass, which were deposited by magnetron sputtering. The dominant peaks located at 30.5° and 34.4° are attributed to the ITO (222) and AZO (002) diffraction, respectively. The results indicate that the ITO film has a cubic bixbyite structure with its dominant orientation along the (222) perpendicular, while the AZO film has a hexagonal wurtzite structure with its dominant orientation along the *c*-axis perpendicular to the substrate surface. XRD spectrum of the 200 nm AZO film deposited by DC magnetron sputtering on glass is shown in inset Fig. 4.

Fig. 5 shows the SEM image of the Al doped ZnO film deposited by DC magnetron sputtering on glass. The AZO film has the globular shaped grains. It can be easily seen that the grains are tightly packed and the size varies from 80 to 200 nm. The SEM image of ITO film deposited by RF magnetron sputtering on ZnO:Al/glass substrate is shown in Fig. 6. The ITO film has the snowflake shaped grains.

In order to detect the chemical compositions and chemical bonds structure of the ultrathin SiO_2 film prepared at 500 °C for 30 min, X-ray photoelectron spectroscopy (XPS) was carried out on the SiO_2 film. Fig. 7 shows the wide range XPS spectra of the ultrathin SiO_2 film surface. It can be clearly seen that on the SiO_2 film surface, Si 2p, O 1s and C 1s peaks appear at 99.3 eV, 533.0 eV and 285.1 eV, respectively. The presence of a C 1s peak in the spectra can be attributed to contamination which resulted from the sample being exposed to air before the XPS measurements. Narrow scan XPS spectra of Si 2p state of the ultrathin SiO_2 film is shown in inset Fig. 7. Sharp double peaks were due

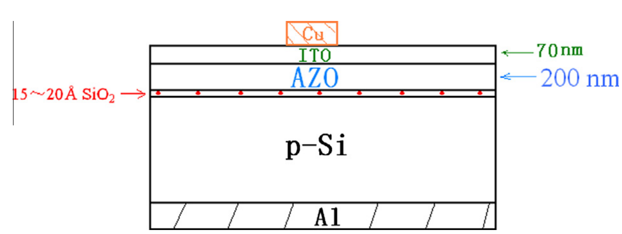

Fig. 2. Schematic of the novel ITO/AZO/SiO_2/p-Si SIS heterojunction.