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A comparative study of characteristics of AZO based MISIM photodetectors with Al_2O_3 and SiO_2 passivation layers

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This paper reports aluminum (Al) doped zinc oxide (AZO) based metal-insulator-semiconductor-insulator-metal (MISIM) ultraviolet (U) photodetectors. Spray-coated Al_2O_3 and sputtered SiO_2 have been used as passivation-layer for two different sets of MISIM devices, respectively. The spray-coated Al_2O_3 passivation-layer has been used first-time for AZO based MISIM U-photodetectors. A comparative study of current versus voltage characteristics of MISIM and MSM (without passivation-layer) devices have been done systematically. The MISIM devices with Al_2O_3 passivation-layer showed better performance than MSM and MISIM (with SiO_2) U-photodetectors. These AZO based MISIM (with spray-coated Al_2O_3) U-photodetectors can be used for low-cost optoelectronic applications.

Keywords: AZO, Aluminum oxide (Al_2O_3), Silicon dioxide (SiO_2), Passivation-layer, Spray- deposition, U-photo detectors

1 Introduction

Zinc oxide (ZnO) based ultraviolet (U) photodetectors have attracted much attention of the researchers in the recent times[1-3]. These photodetectors have various applications in the areas of space communications, U-astronomy, fire detection, missile warning systems and optical switching etc[2]. There are different kinds of configurations of photodetectors, which were used by research-groups now a days[2-4]. Metal-semiconductor-metal (MSM) structure of photodetectors is among one of the popular-configuration, because of its high-efficiency[5-7]. But this configuration faces some limitations, as the surface-states in pure and doped ZnO thin-films cause serious effects on the output of the photodetectors[3]. This problem is solved by researchers by adding a very thin passivation layer above ZnO thin-films[8-10]. In that case the structure of MSM photodetectors look like, metal-insulator-semiconductor-insulator-metal (MISIM) configuration. In the recent past, various research groups have reported the effect of passivation-layer addition for pure ZnO and for Al, Mg doped ZnO based photodetectors[11,12]. Recently Zhou *et al.*[8] demonstrated ZnO nanorod based U-photodetectors, where they have shown the effect of addition of metal-oxide layer above ZnO nanorods. They have investigated performance of the photodetectors with addition of MgZnO, MgO and AZO passivation-layers above ZnO layer. They have reported that due to insulating layer, the sensitivities of the photodetectors were improved[8]. Young *et al.*[9] reported the effect of SiO_2 passivation-layer for pure ZnO-based MIS U-photodetectors. Liao *et al.*[10] reported MISIM photodetectors with Au-MgO-ZnO configuration. Yu *et al.*[11] investigated the properties of ZnO based MSM U-photodetectors. They have used an insulating layer of MgO for fabricating MISIM U-photodetectors. Zhu *et al.*[12] fabricated two kinds of MgZnO based U-photodetectors, first is with MgO-layer and second without MgO-layer. They have investigated the effect of addition of MgO-layer on the characteristics of their U-photodetectors.

In this work we have reported Al doped ZnO (AZO) based U-photodetectors and we have investigated the performance of photodetectors for Al_2O_3 and SiO_2 passivation layers respectively. The thin film of AZO can be obtainedby various methods such as microwave assisted wet-chemical (MAWC) method[13], sol-gel[14,15], hydrothermal-method[16], radio frequency (RF) sputtering[5,17] and thermal evaporation[18] etc. Among all these methods, RF sputtering method is the commonly used method for AZO thin film deposition, which we have used here. In this paper, we have compared the performance of AZO MISIM photodetectors (having Al_2O_3 and SiO_2 passivation-layers) with AZO MSM (without passivation-layer) photodetectors systematically.

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2 Experimental Details

2.1 Deposition of AZO thin film by RF-sputtering

Silicon wafers of *p*-type doping <100> orientation and resistivity ~ 0.001-0.005 Ω.cm were used in the work. Thin film of AZO was grown on these silicon wafers by Nordiko metal sputter system. Before deposition of AZO thin-films silicon wafers were dipped and cleaned by RCA-1 and RCA-2 solutions and then rinsed by DI water at last. The AZO target was made up of 2 wt % Al doped ZnO material[5]. The detail of RF-sputtering-deposition is listed in Table 1.

2.2 Details of deposition of SiO_2passivation-layer by DC-sputtering and Al_2O_3 by spray-coating method

A thin passivation layer of SiO_2 was deposited above AZO/Si samples by DC magnetron sputtering. The detail of DC magnetron sputtering is listed in Table 1.

The thin layer of Al_2O_3 was deposited by spray-deposition method above AZO film. Before spray-deposition, aluminum nitrate nonahydrate and 2-methoxyethanol precursors were mixed and solution was prepared. Nitrogen-gas (N_2) was used as carrier gas. Annealing of the samples was done at 400 °C for 5 min after the spray-process. The detail of Al_2O_3 deposition method can be obtained from the elsewhere[19].

2.3 Detail of fabrication steps for MISIM devices

Inter digited electrode designs were pattered over Al_2O_3/AZO/Si and SiO_2/AZO/Si samples with double sided mask aligner (DSA). The cross-sectional view of MISIM devices are shown in the Fig. 1. The size of inter digited electrode structures was similar for all the devices (MISIM & MSM). The electrode finger-spacing (*p*) and the electrode-width (*q*) were keptsame 10 µm and the length was 500 µm. After electrode patterning with DSA, a layer of ~90 nm thick Pd metal was deposited by sputtering and finally the metal-contacts were designed using lift-off mechanism.

3 Results and Discussion

The X-ray diffractometer (XRD) spectra of AZO thin-film are shown in Fig. 2. Diffraction angle (2θ) was ploted with respect to the intensity of X-Ray. Figure 2 shows that AZO thin-film exhibits mainly (0 0 2) peak, while the other (100) and (001) peaks were also observed with very low intensity. It was also seen that these is no any peak corresponding to Al_2O_3, Al and Zn etc[20].

The structural characteristics of the AZO thin film were examined by scanning electron microscopy (SEM) and atomic force microscopy (AFM). The inset of Fig. 2 displays the SEM images of AZO thin film. It shows that the surface of AZO thin-film was uniform with homogeneously grown-grains[21]. The

Table 1 – Details of SiO_2 deposition by DC-sputtering and AZO deposition by RF magnetron sputtering

AZO by RF-sputtering		SiO_2 by DC-sputtering	
Target size	4”	Target size	2”
Ambient gas	Ar	Ambient gas	Ar
Power	100 W	Power	150 W
Sputtering pressure	2.6×10^{-3} mbar	DC pressure	2.2×10^{-2} mbar
Base pressure	2.0×10^{-5} mbar	Base pressure	2.0×10^{-5} mbar
Gas flow	2 mbar	Gas flow	2 mbar

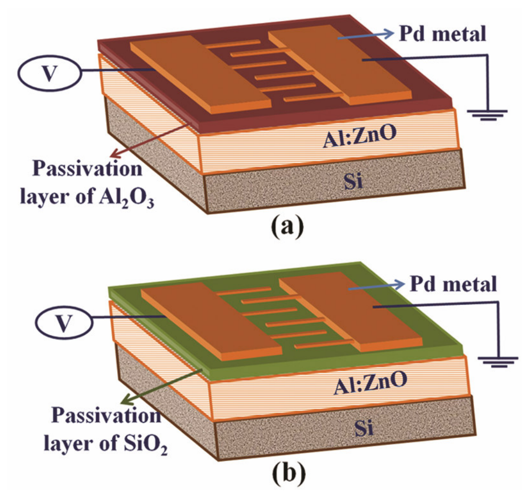

Fig. 1 – Schematic diagram of MISIM deviceswith $Al_2O_3$and SiO_2 passivation layers

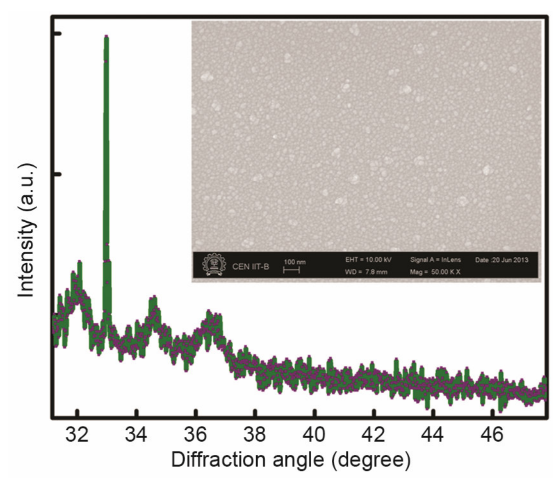

Fig. 2 – XRD spectra of AZO thin film. Iinset shows SEM image of AZO thin film

AFM image of AZO film was shown in Fig. 3 (b), it shows that the growth of AZO grains was smooth with average roughness ~7.09 nm. The optical properties of AZO thin-film were investigated by UV-vis spectroscopy. The obtained, absorbance vs wavelength spectra was shown in the Fig. 3(a), which confirmed that the main absorbance occurred in UV-range of wavelength (i.e., from 320–365 nm).

The current-voltage characteristics of AZO based MISIM devices were investigated by *I-V*/*C-V* tool Phoenix (from Keithley instruments). Figure 4 displays the change of dark current for AZO based MISIM devices with Al_2O_3 and SiO_2 passivation-layers. The dark current for AZO based MSM (without passivation-layer) were also plotted and compared with similar-structured MISIM devices in the same graph of Fig. 4. The top-view of metal-electrodes with 10 µm finger-spacing and 10 µm width is shown in the inset of Fig. 3. The dark

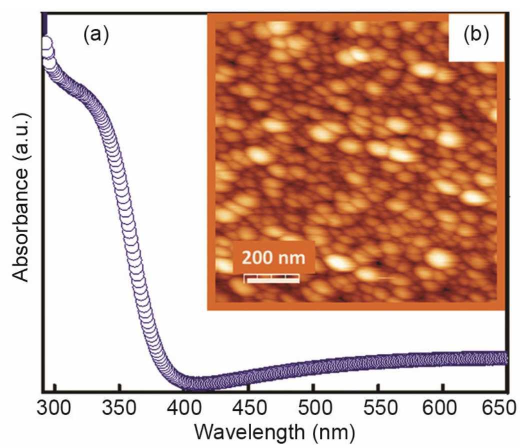

Fig. 3 – (a) Absorbance vs wavelength spectra of AZO thin film and (b) AFM image of AZO thin film

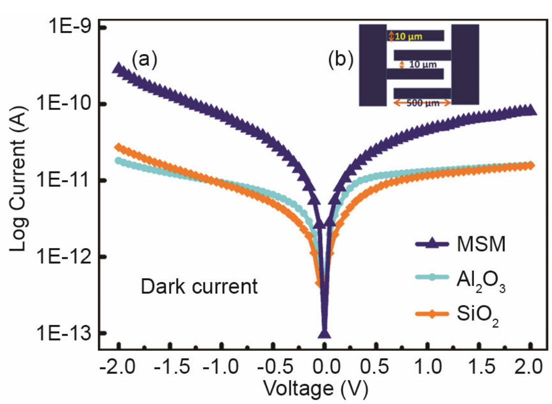

Fig. 4 – (a) *I-V* characteristics of AZO based MISIM and MSM devices under dark condition and (b) Schematic top-view of interdigited electrodes

current and voltage characteristics of all devices were plotted in log scale (as shown in the Fig. 4). The dark-current's value is lesser for MISIM photo detectors as compared to MSM photo detector. The reason behind this can be understood by the fact that the dangling bonds on the surface-boundary of AZO thin film get reduced due to insertion of the thin passivation-layers of Al_2O_3 and SiO_2 films[3]. The thin passivation-layer in the MISIM devices allows the flow of tunnelling-current[8-12].

Similarly, the change of photo-current for AZO based MISIM devices with Al_2O_3 and SiO_2 passivation-layers were shown in Fig. 5. As shown in Fig. 5 that the photo-current for MISIM detectors with Al_2O_3 passivation-layer was higher in comparison to MSM and MISIM device with SiO_2 passivation-layer. The mathematical equation and other details for *I-V* characteristics for MISIM devices have been discussed by others elsewhere[6,22-24]. For explaining the influence of Al_2O_3 and SiO_2 passivation-layers on the *I-V* characteristics for MISIM photodetectors, band-diagrams is plotted as shown in the Fig. 6. Figure 6(a) shows band diagram of the junction for MSM photodetectors under forward bias, i.e., when a positive voltage is applied on Pd-electrodes under dark condition. Similarly, Fig. 6(b) and (c) show band diagram of the junction for MISIM photodetectors. It could be observed from the Fig. 6(b) and (c) that the movement of electrons (e) were blocked by thin Al_2O_3 and SiO_2 passivation-layers, which causes reduction of dark-current in comparison to MSM photodetectors. Again Fig. 7(a-c) shows the band diagram of junction for MSM and MISIM photo detectors under reverse bias, under dark condition. It can be seen from the band-diagrams that the dark-current is very less for MISIM devices under reverse-bias condition[9,24].

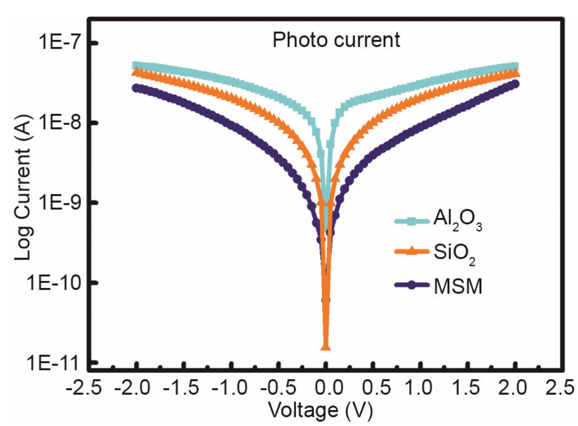

Fig. 5 – *I-V* characteristics of AZO based MISIM and MSM devices under U-light.

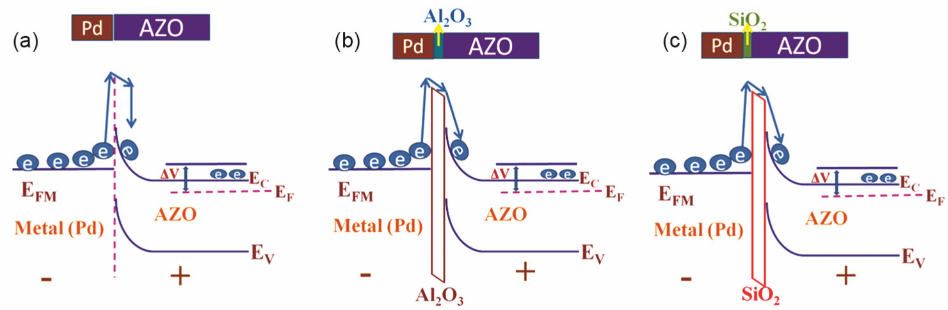

Fig. 6 – Energy band diagram of junction under dark, with a forward bias (a) MSM structure, (b) MISIM with Al_2O_3 passivation-layer and (c) MISIM with SiO_2 passivation-layer

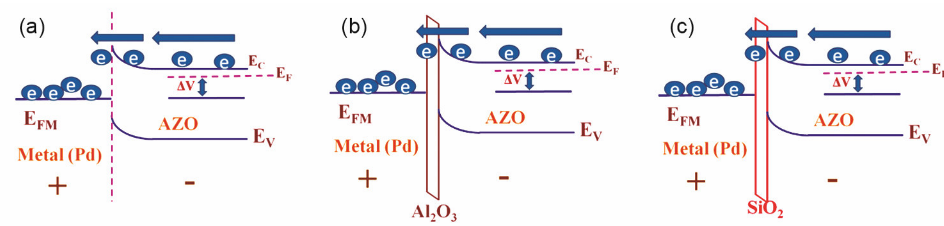

Fig. 7 – Energy band diagram of junction under dark, with a reverse bias (a) MSM structure (b) MISIM with Al_2O_3 passivation-layer and (c) MISIM with SiO_2 passivation-layer

Table 2 – Detail parameters of all U-photodetectors

S No	Parameters of photodetector	MSM U-photodetectors	MISIM U-photodetectors (with Al_2O_3)	MISIM U-photodetectors (with SiO_2)
1	Dark current (A) (at V= -2.0 V)	2.84×10^{-10} A	1.81×10^{-11} A	2.72×10^{-11} A
2	Photocurrent (A) (at V= -2.0 V)	4.26×10^{-8} A	5.21×10^{-8} A	2.73×10^{-8} A
3	Contrast ratio	1.5×10^{2}	2.87×10^{3}	1.00×10^{3}

Power of UV-Light=2.8 micro watt and wavelength=372 nm

Under the U-illumination condition the photo-generated e's were moved by an accelerating process under the forward bias or the reverse bias. Hence, all of the photo-generated e's got enough-energy to flow to the corresponding electrodes[10]. The values of dark currents were 2.84×10^{-10} A, 1.81×10^{-11} A and 2.72×10^{-11}A, for MSM and MISIM photo detectors with Al_2O_3 and SiO_2 passivation-layers respectively at –2.0 V. And the photo current values for these MSM and MISIM photodetectors were 4.26×10^{-8}, 5.21×10^{-8} and 2.73×10^{-8} A, respectively, at –2.0 V applied bias. The detail U-photodetectors parameters are listed in Table 2.

4 Conclusions

AZO based MISIM U-photodetectors were fabricated for two different passivation-layers SiO_2 and Al_2O_3, respectively. SiO_2 layer were deposited by DC-sputtering system whereas Al_2O_3 layer was deposited first-time by spray-coating method, in this work. The performance of AZO based MISIM devices has been studiedand compared with similarly fabricated MSM device, under dark and under U-light. *I-V* characteristics of MISIM devices with spray-coated Al_2O_3 passivation-layer were better in comparison to MISIM devices with SiO_2 passivation-layer.

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