

Photoelectric characteristics of the photodiode structure Al/ZnO:MgO/p-Si/Al

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Abstract. This paper presents the results of investigations of the photoelectric characteristics of the Al/ZnO:MgO/p-Si/Al photodiode structure. ZnO:MgO films were obtained by the sol-gel method with a ratio of 1:5. Silicon wafers KDB-4.5 were used as substrates, and the thickness of the obtained ZnO:MgO films was about 100 nm. The current-voltage characteristics have been measured and analyzed under the influence of optical radiation of different wavelengths (278 nm, 405 – 1064 nm), the absolute spectral sensitivity at low and high bias voltage was calculated. It is shown that the photosensitivity of the Al/ZnO:MgO/p-Si/Al photodiode structure increases with the rise of the bias voltage from 2.5 V to 20 V in the UV region of the spectrum, reaching 12.2 A/W at a wavelength of 278 nm, and in the visible and IR wavelength ranges it is from 2.5 to 5 A/W.

I. Introduction

Zinc oxide (ZnO) is a wide-bandgap semiconductor with unique electrophysical and optical properties, high thermal stability, radiation and chemical resistance. Due to the relatively high optical transmittance, good electrical conductivity and photosensitivity, this material is widely used in solar cells as contact, passivating or transport layers; in light-emitting devices, gas and biological sensors, detectors of ultraviolet, X-ray and gamma radiation [1]. To vary the optical and electrical properties, ZnO is doped with metals from the periodic table of group III, such as B, Al, Mg, Ca, Cd and Ga [2]. It is important that the radius of the doping element is approximately equal to the radius of the replaced element, which ensures the formation of a compound with small distortions of the crystal lattice. In this aspect, the radius of Mg²⁺ ion (0.57 Å) is comparable to that of Zn²⁺ ion (0.60 Å), which makes Mg suitable for substitution in the Zn lattice and facilitating the increase in the band gap [3].

II. Methodology of synthesis and measurements

Layers based on ZnO:MgO films were obtained by the sol-gel method using separate hydrolysis. The following materials were used as starting ones: zinc acetate dihydrate; magnesium acetate; isopropyl alcohol; distilled water; diethanolamine. To prepare the film-forming solution, zinc acetate and magnesium acetate were separately dissolved in isopropyl alcohol and stirred at 60 °C for 10 minutes. Then the sols were mixed in a concentration of 1:5. The film was deposited by centrifugation at a rotation speed of 2000 rpm for 40 s, after which each layer was dried at 60 °C for 10 minutes. After applying each layer, the films were pre-dried in an oven (SNOL) for 5 minutes at a temperature of 250 °C. After applying the second layer, annealing has been carried out at a temperature of 550 °C for an hour. The thickness of the obtained ZnO:MgO films was about 100 nm. Silicon wafers KDB-4.5 were used as substrates.

After applying ZnO:MgO films to the obtained structure by thermal evaporation using a UVN-71P-3 vacuum evaporation unit, metal wiring based on a thin aluminum layer was applied through a metal mask, as shown in Fig. 1a. A continuous aluminum layer was applied to the back side of the silicon. To separate the photodiode structures into individual elements, an EM-2048A wafer mounting unit and an EM-2085V ultra-thin wafer separation unit were used. The dimensions of the manufactured photodiode structures were 10×5 mm², their top view and transverse structure are shown in Fig. 1.

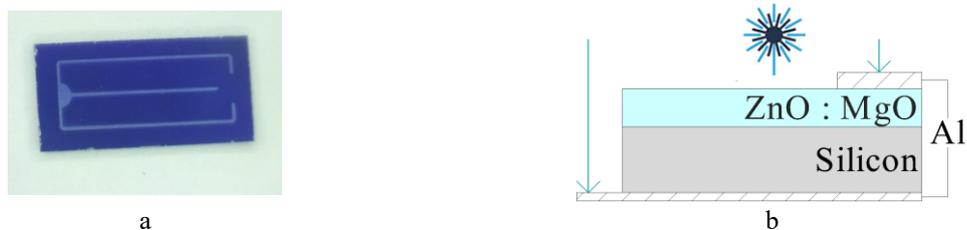


Fig.1. Appearance (a) and cross-sectional structure (b) of the Al/ZnO:MgO/p-Si/Al photodiode system

The current-voltage characteristics were measured in the dark and under the influence of optical radiation using tungsten probes, and the probes were connected according to the circuit shown in Fig. 1b. The voltage on the current-voltage characteristics corresponds to the voltage supplied to the upper electrode to the ZnO:MgO film.

The optical module of the measuring complex included a positioning module for placing the test sample and a multispectral laser radiation source consisting of a set of 9 laser diodes with wavelengths of 405, 450, 520, 660, 780, 808, 905, 980 and 1064 nm with a common fiber optic output and with control boards with a radiation power of about 2 mW [4]. A TO-3535BC-UVC265-30-6V-E LED placed in a specialized fixture was used as a source of deep ultraviolet (UV) radiation with a wavelength of 278 nm. All measurements have been performed with a voltage sweep from -20 to $+20$ V at room temperature.

III. Results and Discussion

Fig. 2a shows the dependence of the current-voltage characteristic of the photodiode structure on the wavelength. It follows from the graphs that the current-voltage characteristic has a practically symmetrical form with clearly expressed photosensitivity. The calculation of the absolute spectral sensitivity was carried out using the formula:

$$S = \frac{I_P - I_D}{P} \quad (1)$$

where I_P is the photocurrent, I_D is the dark current, P is the power of the radiation source. The results of calculating the absolute spectral sensitivity at low (2.5 V) and high (20 V) voltage are shown in Fig. 2b.

From the analysis of the dependences presented in Fig. 2b, it follows that at a voltage of about 2.5 V, the Al/ZnO:MgO/p-Si/Al structure has photosensitivity in the visible and IR spectral regions, and if in visible radiation the photosensitivity is in the range from 0.01 A/W to 0.02 A/W, then upon reaching the IR spectral region with an increase in wavelength, a sharp increase in photoconductivity occurs from 0.02 A/W at 808 nm to 0.14 A/W at 1064 nm. A negative photoelectric effect is observed in the UV region.

The lack of sensitivity to UV radiation at low voltage and a sharp increase in photoconductivity with increasing wavelength in the IR region of the spectrum corresponds to p-Si, which indicates that in this photodiode structure, selectivity to UV radiation is not observed due to the small thickness of the ZnO:MgO film.

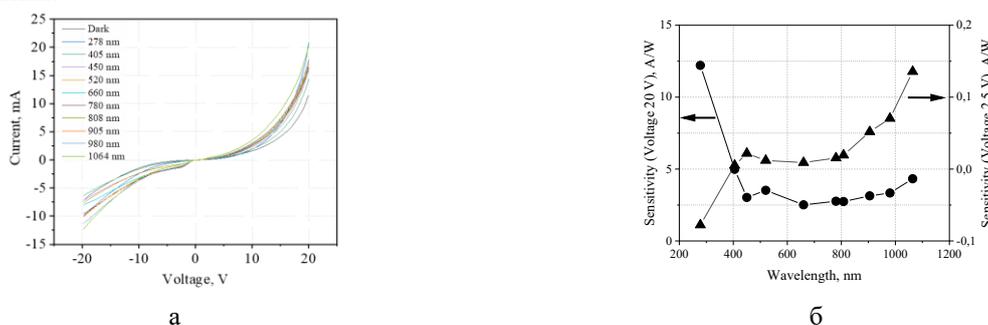


Fig.2. Dependences of the current-voltage characteristics (a) and absolute spectral sensitivity (b) of the photodiode structure Al/ZnO:MgO/p-Si/Al on the wavelength

When the voltage increases to 20 V, the photosensitivity is most pronounced in the UV region of the spectrum, reaching 12.2 A/W at a wavelength of 278 nm and decreasing as it approaches the visible range to 5 A/W at a wavelength of 405 nm. In the visible region of the spectrum, the photosensitivity is in the range from 2.5 to 3.5 A/W. Upon reaching the near IR region, photosensitivity begins to increase with increasing wavelength from 2.7 A/W for 808 nm to 4.3 A/W for 1064 nm.

The appearance of photosensitivity in the UV region of the spectrum at high voltage applied to the electrode on the ZnO:MgO film is caused by the photogeneration of minority charge carriers during the bending of the p-n junction zones.

III. Conclusion

Experimental samples of the Al/ZnO:MgO/p-Si/Al photodiode structure were synthesized and their photoelectric characteristics have been measured. It was shown that at a voltage of about 2.5 V, photosensitivity of the visible and IR spectral regions is observed, and in the IR region, as the wavelength increases, a sharp increase in photoconductivity occurs. A negative photoeffect is observed in the UV region. This indicates the absence of selectivity to UV radiation due to the small thickness of the ZnO:MgO film.

When the voltage is increased to 20 V, due to the photogeneration of minority charge carriers during the bending of the p-n junction zones, high photosensitivity of the Al/ZnO:MgO/p-Si/Al photodiode structure to deep UV radiation appears.

References

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