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Transparent ultraviolet photodiodes based conductive gallium-indium-oxide films/p-type silicon for solar panel tracking systems

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ABSTRACT

The conductive gallium-indium-oxide films/p-type silicon heterojunction photodiodes were prepared by sol gel method. The effects of In content (x) on rectification and photoresponse properties of the conductive gallium- indium-oxide films/p-type silicon diodes. The fabricated diodes show a rectifying non- ideal behavior. The ideality factor values obtained from dV/d(lnI) vs. I plots are higher than the ideality factor values obtained from ln$I$ vs. V plots. This confirms that the larger n values could be due to the presence of series resistance, interface states, and the voltage drop across the interfacial layer. The capacitance values of the Al/(Ga1−xInx)2O3/p-Si/Al diode is controlled by bias voltage, frequency, illumination intensity and In content (x) value.The obtained results confirmed that conductive gallium-indium-oxide films/p-type silicon heterojunction diodes can be used as a photodiode in optoelectronic applications.

1. Introduction

Over the last years, transparent electronics and opto- electronics are a rising technology involving the realization of invisible electronic and optoelectronic applications. Transparent conducting oxides (TCOs) have been received notable attention in a wide electronic and opto-electronic technology such as gas sensors, flat screens, display devices, solar/photovoltaic cells, dye-sensitized solar cells, electro-chromic devices, thin-film transistors (TFTs) and light-emitting diodes (LEDs) [1,2] due to their thermal stability, large free carrier mobility, high optical transmittance, low temperature processing, low cost, good chemical stability, good transparency and low electrical resistivity [1,3–7].

Gallium oxide (Ga2O3) is significant material and its thin films have been received considerable interest in fields of the electronic, optoelectronic and photoelectronic applications due to their good optical transparency and electrical conductivity [8,9]. Indium oxide (In2O3) is also an important semiconductor, its optical band gap is about 2.9 eV. In2O3 is widely used in many fields such as transparent contacts, light emission diodes, liquid crystal displays and photovoltaic devices [10].

The (Ga1−xInx)2O3 films have been synthesized by various methods such as molecular beam epitaxy (MBE) and metalorganic chemical vapor deposition (MOCVD) [11]. The MBE and MOCVD systema are very expensive systems. Thus, we prefer sol gel method which is the low cost and easy preparation method to find low cost photodiodes for optoelectronic applications.

To our knowledge, there are not yet any experimental results on the Al/(Ga1−xInx)2O3/p-Si/Al. This is the first time; we have fabricated Al/(Ga1−xInx)2O3/p-Si/Al diodes.

In here, we investigated in detail the current–voltage and capacitance–voltage properties of the Al/ (Ga1−xInx)2O3/p-Si/Al diodes for various In content (x) values, illumination intensities and frequencies.

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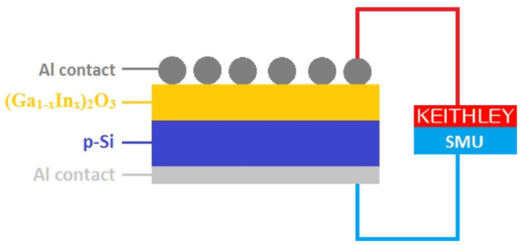

Fig. 1. The cross- section of the Al/$(Ga_{1-x}In_x)_2O_3$/p-Si/Al diodes.

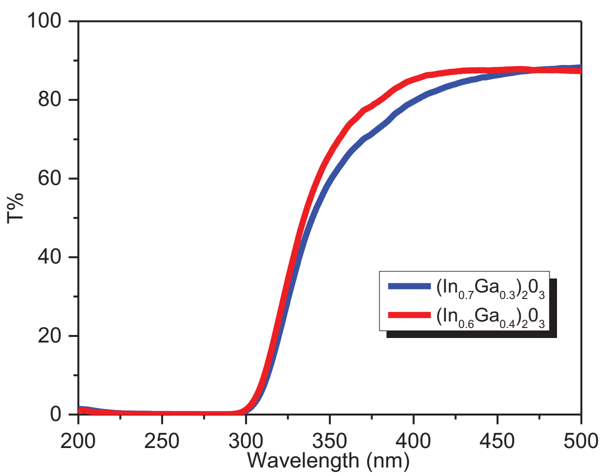

Fig. 2. Transmittance plots of $(Ga_{1-x}In_x)_2O_3$ films.

2. Experimental

We used the following precursors, gallium isopropoxide, indium isopropoxide, 2-methoxyethanol and ethanolamine. The solutions of gallium isopropoxide and indium isopropoxide were prepared in 2-methoxyethanol and monoethanolamine at 60 °C for 1 h. The molar ratio of monoethanolamine to metal isopropoxide was taken as 1.0. The concentration of solution was 0.4 M. The soluitons were prepared for the various molar ratios of indium isopropoxide to gallium isopropoxide. The films were coated on p-Si substrate having Al ohmic contact by spin coating method at 3000 rpm. After coating procedure, the solid films were obtained at 150 °C in air for 10 min. The obtained solid films were calcinated at 500 °C for 1 h. The top contacts were preapred as dots on (Ga1−*x*In*x*)2O3 films using thermal evaporation system at 10^{-5} Torr. The diode contact area was found to be 3.14×10^{-2} cm^2. Al/ (Ga1−*x*In*x*)2O3/p-Si/Al diodes were obtained and the cross-section of the Al/(Ga1−*x*In*x*)2O3/p-Si/Al diodes is shown in Fig. 1. The prepared diodes were characterized electrically using a SCS-4200 Keithley semiconductor characterization system. The optical spectra of the films were performed using a Shimadzu 3600 UV-VIS-NIR spectrophotometer. The surface morpholoy of the films was investigated using a Park XE 70 atomic force microccopy.

3. Results and discussion

3.1. Structural and optical properties of (Ga1−xInx)2O3 films

The transmittance spectra of the (Ga1−*x*In*x*)2O3 films are shown in Fig. 2. As seen in Fig. 2, the transmittance of the films was about 85% at 450–500 nm. A sudden drop in transmittance of the films was observed after 450 nm. This drop is due to optical transitions between valence band and conduction band of (Ga1−*x*In*x*)2O3 films. A shifting in this drop is observed due to the change in optical band gap of the films with In content. In semiconductors, the electronic transitions occurs between valence and conduction bands. The optical band gap of the (Ga1−*x*In*x*)2O3 films can be analyzed by the following relation [12],

$$(\alpha h\nu)^2 = B(h\nu - E_g) \quad (1)$$

where *B* is a constant, α is the absorption coefficient and hν is the photon energy. In order to calculate the optical band gap of the films, we plotted curves of $(\alpha h\nu)^2$ vs. hν, as shown in Fig. 3. The *Eg* values of the films were determined by extrapolating the linear portion of a plot of $(\alpha h\nu)^2$ versus hν to $(\alpha h\nu)^2 = 0$. The E_g values of (Ga0.7In0.3)2O3 and (Ga0.6In0.4)2O3 films were found to be 4.08 and 4.04 eV, respectively. The obtained E_g values of the (Ga0.7In0.3)2O3 and (Ga0.6In0.4)2O3 films are smaller than that of (Ga0.7In0.3)2O3 and (Ga0.6In0.4)2O3 films [13]. The decrease in the optical band gap can be due to band tailing effects resulted from the defects in (InGa)2O3 films. The current-voltage (I–V) characteristics of (Ga0.7In0.3)2O3 and (Ga0.6In0.4)2O3 films are shown in Fig. 4. The electrical conductivities, σ, of (Ga0.7In0.3)2O3 and (Ga0.6In0.4)2O3 films were calculated from I–V characteristics and were found to be 9.59×10^{-2} S/m and 2.19×10^{-2} S/m, respectively. The σ value of the (InGa)2O3 films is changed with *x* content of In. The obtained electrical conductivity values suggest that the (InGa)2O3 films exhibited the semiconductor behaviour. AFM images of the (Ga1−*x*In*x*)2O3 films are shown in Fig. 5. As

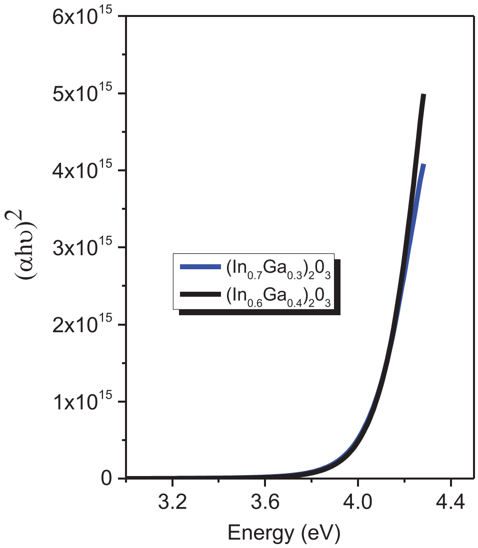

Fig. 3. Plots of $(\alpha h\nu)^2$ vs. hν of $(Ga_{1-x}In_x)_2O_3$ films

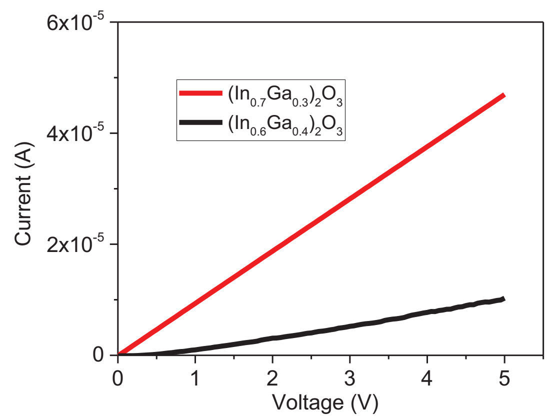

Fig. 4. *I–V* characteristics of $(Ga_{1-x}In_x)_2O_3$ films.