Int. J. Exp. Res. Rev., Vol. 22: 1-7 (2020)

International Journal of Experimental Research and Review (IJERR)

ISSN: 2455-4855 (Online) ***Original Article***

Received: 8th May, 2020; **Accepted:** 14th June, 2020; **Published:** 30th August, 2020

DOI: https://doi.org/10.52756/ijerr.2020.v22.001

Wavelength dependent photosensitivity modulation of Aluminium/Lead sulphide/Indium tin oxide back-to-back diode

Abhijit Banerjee

Department of Electronic Science, Acharya Prafulla Chandra College, New Barrackpore, Kolkata-700111, India

Author's E-mail: abhijit@apccollege.ac.in, abhijit_bnrj@yahoo.com

Abstract

The photosensitivity of aluminium (Al)/lead sulphide (PbS)/indium tin oxide (ITO) thin layered structure is investigated considering the photon wavelength dependent current-voltage and capacitance-voltage characteristics of the device. The current-voltage characteristics of the test structure are analyzed adopting the back-to-back Schottky barrier diode model. The diode possesses low dark current in contrast to the high value of photocurrents measured under different illumination wavelengths. The change in photocurrents with different illumination wavelengths clearly indicates the change in photo-sensitivity of the device. The capacitance-voltage characteristics of Al/PbS/ITO structure demonstrate a definite improvement of the device capacitance with the higher wavelength exposures. The matter is explained in terms of the additional capacitance owing to the excess carrier generation within the device under illumination. The photosensitivity modulation of the device can be exploited in photo-sensor or photo-detector applications in various electronic devices.

Keywords: Aluminium/lead sulphide/indium tin oxide, Back-to-back diode, Current-voltage, Capacitance-voltage, Photo-sensitivity.

Introduction

The electrical and optoelectronic properties of a variety of metal-semiconductor-metal (M-S-M) back-to-back diode structures are studied in numerous occasions earlier (Chu et al., 2005; Pandit and Cho, 2018; Khalli and Debbar, 2019; Ruzgar and Caglar, 2020; Averin et al., 2020). Majority of these studies have mainly investigated the photosensitivity of the device in terms of the improvement of diode current and responsivity. However, to assess the quality of the photodiode, the role of photon wavelength dependent photo-carrier generation and subsequent transportation through the device requires added attention and need to be studied in a more accurate manner. In fact, the reflection from the semiconductor surface and surface metal, the finite photo-generated carrier lifetime, the rate of recombination in the surface and deep traps within the semiconductor are largely dependent on the photon wavelength, which eventually controls the quality of the photodiode in terms of the device photosensitivity.

In the present work, the photon wavelength dependent photosensitivity modulation of a metal-semiconductor-metal configuration is investigated considering the aluminium/lead sulphide/ indium tin oxide structure and the role of exposure wavelength on the current-voltage and capacitance-voltage characteristics of the device are analyzed. Lead sulphide (PbS) is a direct narrow band gap IV-VI semiconductor ($E_g \approx 0.41$ at 300 K for bulk crystal) (Banerjee, 2019). The electrical and optoelectronic properties of PbS nano-structures and thin films are studied extensively time to time and subsequently employed in different semiconductor devices, namely the infrared detector (Ghamsari et al., 2006), solar cell (Gunes et al., 2007), Pb^{2+} ion selective sensors (Hirata and Higashiyama, 1971), photo-resistor (Miroshnikova, 2010), humidity and temperature sensors (Pop et al., 1997; Seghaier et al., 2006). In the present work, the photon wavelength dependent photosensitivity of the Al/PbS/ITO M-S-M structure is investigated considering back-to-back Schottky barrier diode model. The results of such investigations are reasonably interesting and discussed in the following sections.

Materials and Methods

A 20mm×15mm×2mm ITO coated glass slide is cleaned ultrasonically in distilled water, trichloroethylene, acetone and methanol, respectively. To grow the PbS film over the ITO coated surface, the uncontaminated slide is dipped vertically into a reactive mixture of 0.2 M aqueous solution of lead nitrate [$Pb(NO_3)_2$] with 0.1 M aqueous solution of thiourea [$SC(NH_2)_2$]. The alkalinity of the solution is set by 0.6M aqueous solution of sodium hydroxide [NaOH]. The solution is stirred continuously within 100-120 rpm keeping the solution temperature within 35-40°C. The slide is removed from the solution after 30 min, dried at room temperature and subsequently placed into a stack furnace and annealed at 400 K for 20 min. The homogeneity of the deposited PbS film is primarily monitored by a metallurgical microscope (Banbros: BMU 101). The average film thickness of the deposited PbS layer is measured 20μm using a digital electronic micrometer (Toolsden DM0251). The FESEM surface morphology of the PbS film is shown in fig.1.

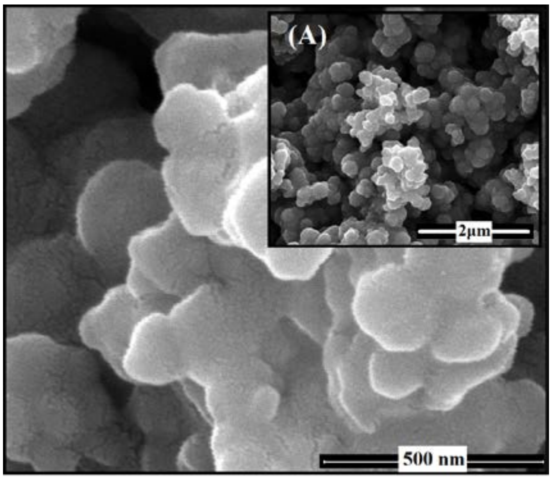

Figure 1. FESEM surface micrographs of chemical bath deposited PbS film in two different scales.

Two identical aluminium contact leads are bonded 2 mm apart using silver epoxy [Alfa Aesar (42469); sheet resistance < 0.025 Ω/sq (0.001 in. thick)], one over the exposed ITO layer (back electrode) and other on the PbS deposit (top electrode). The scheme is illustrated in Fig 2. All the current (*I*)-voltage (*V*) measurements in dark and illuminated conditions are performed using Keithley 2401 source measurement unit. The optoelectronic *I-V* measurements are carried out under 510-550 nm, 585-605 nm and 620-640 nm of continuous illumination. Additionally, the capacitance (*C*)-voltage (*V*) measurements of the device are carried out under both dark and steady illuminations (same set of wavelengths used for dc optoelectronic measurements) using SM6020 LCR meter. All the measurements are carried out at room temperature (~300 K).

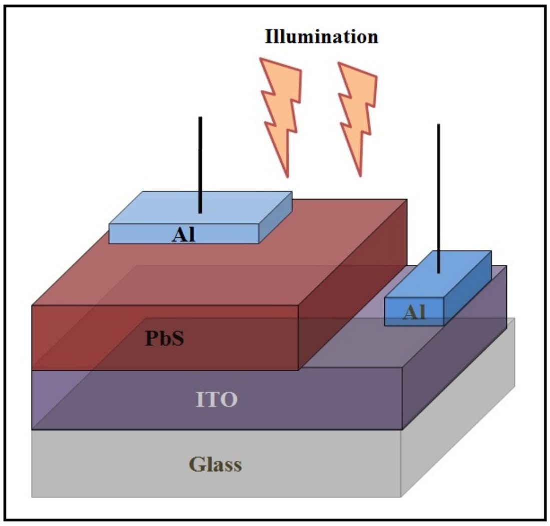

Figure 2. Schematic of aluminium/ lead sulphide/ indium tin oxide organic diode with metal contacts as electrodes.

Results and discussions

The absorbance plot of the PbS film clearly indicates that the PbS structure well absorbs the photon nearly 530 nm. Fig.3 shows the absorbance as well as the transmittance (%) plot of the deposited PbS film. The minor scattering and some other inconsequential peaks observed in the absorbance plot are attributed to the lattice resonance and sub-band transitions related to the deposited material. The measured forward and reverse current-voltage characteristics of the Al/PbS/ITO diode are shown in fig. 4. The plot shows a definite improvement in the forward current, when ITO contact (back contact) is

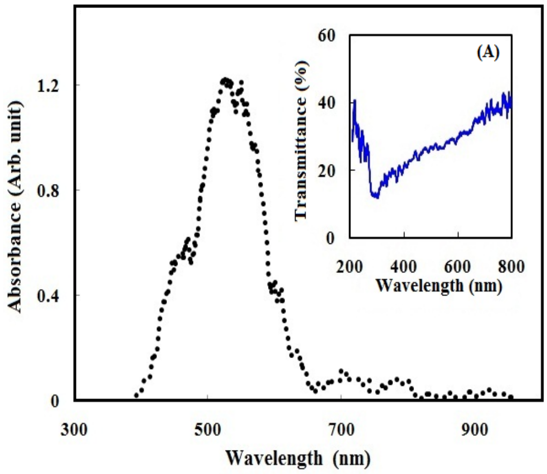

Figure 3. Normalized absorbance vs. wavelength plot of PbS thin film. Inset (A) demonstrates the transmittance (%) vs. wavelength plot of the same deposited film.

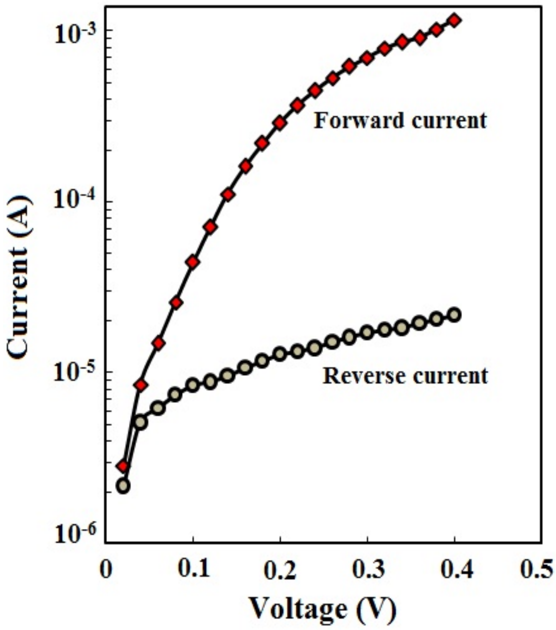

Figure 4. Forward and reverse current-voltage characteristics of the Al/PbS/ITO diode.

kept at lower bias condition with respect to Al contact over PbS layer (top contact) and when the applied bias is more than ±0.2V, the forward to reverse current ratio is found to be nearly 10^2. The fact is encouraging to apply the device in case of precision rectification in different semiconductor devices. Moreover, the device is found to be largely photosensitive. The fact is elucidated during the time of current-voltage measurements, when the diode is exposed under a set of different photon wavelengths.

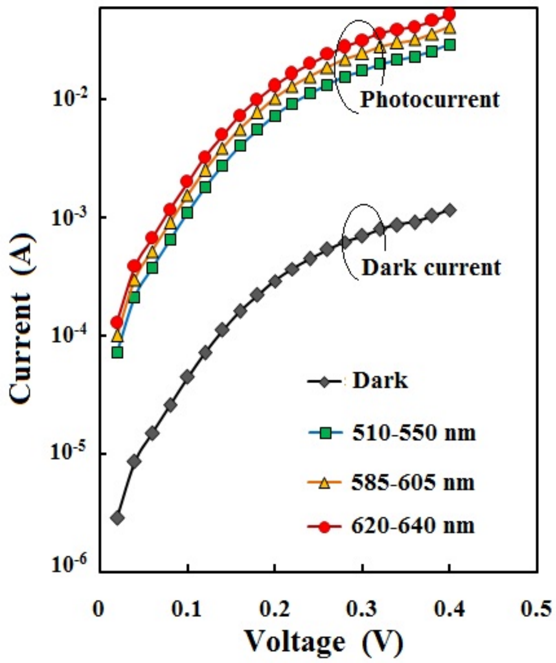

Figure 5. Forward dark current and photocurrent under three different ranges of exposure wavelengths (510-550 nm, 585-605 nm and 620-640 nm).

During steady illumination, the diode possesses at least 80-100 times higher forward current, in contrast to the dark current. As the wavelength increases, the diode forward current increases significantly. The matter is shown in fig. 5, where the measured forward current under three different wavelength regions (510-550 nm, 585-605 nm and 620-640 nm) are plotted along with the measured dark current. The photon wavelength dependent deviation of the device current can be explained considering the excess photocurrent generation due to absorption of photon energy $(h\nu)$, higher than the transition energy of the material. In such situation, the photocurrent density in the semiconductor layer of device can be expressed as (Banerjee, 2019)-

$$J_{photo} = \left(\frac{P_{opt}}{h\nu}\right)\frac{\eta\tau q}{A}\left(\frac{1}{t_e}+\frac{1}{t_h}\right) \quad (1)$$

where P_{opt} is the incident optical power, τ is the excess carrier recombination time, η is the quantum efficiency and A is the area. The parameters t_e and t_h are the transit time of electrons and holes within the semiconductor.

The voltage dependent device current of the test structure is analyzed considering the back-to-back diode model of Schottky barrier diode and in such case the generalized form of the current-voltage relation is given by (Nouchi, 2014; Osvald, 2015)-

$$I = \frac{2\frac{I_{01}}{A_1}\frac{I_{02}}{A_2}Sinh\left(\frac{qV}{2nkT}\right)}{\frac{I_{01}}{A_1}\exp\left(-\frac{qV}{2nkT}\right)+\frac{I_{02}}{A_2}\exp\left(\frac{qV}{2nkT}\right)} \quad (2)$$

where I_{01} and I_{02} are the reverse saturation currents of the two asymmetric diodes and can be expressed as

$$I_{01} = A_1A^*T^2\exp\left(-\frac{q\phi_{B1}}{kT}\right) \quad (3)$$

and

$$I_{02} = A_2A^*T^2\exp\left(-\frac{q\phi_{B2}}{kT}\right) \quad (4)$$

where ϕ_{B1} and ϕ_{B2} are the two asymmetric barrier heights. A^* is the Richardson constant, A_1 and A_2 are the effective junction area of the two diodes. However, this type of metal-semiconductor-metal devices can suffer from a large amount of series resistance. In presence of series resistance, the voltage across the two terminals of the device is expressed in terms of device current (I) as (Osvald, 2015)-

$$V = V_1 + V_2 + IR_s \tag{5}$$

$$V = \frac{n_1 kT}{q}\ln\left(\frac{I}{I_{01}}+1\right) - \frac{n_2 kT}{q}\ln\left(-\frac{I}{I_{02}}+1\right) + IR_s \tag{6}$$

To assess the nature of two major device parameters, namely, the dynamic resistance and the conductance of this device, the voltage variation of the dark current is used to estimate the parameters numerically. Fig. 6 shows the voltage dependence of the dynamic resistance and conductance of the device. The voltage variation of the dynamic resistance has shown a decreasing trend with the development of applied bias. The fact is well endorsed by the conductance plot of the device, where the parameter has shown an increasing trend with the applied bias.

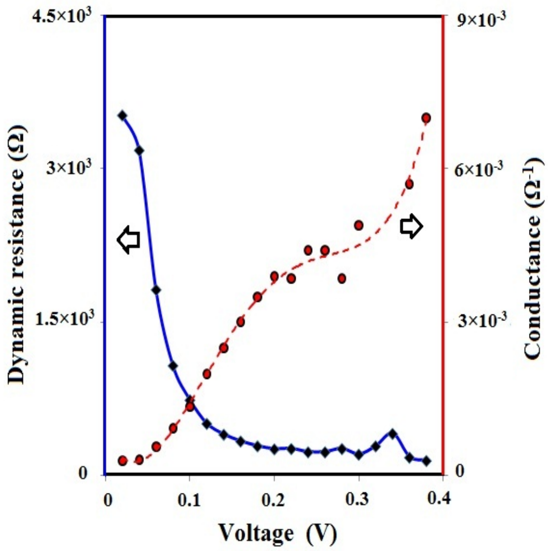

Figure 6. Voltage variation of dynamic resistance and conductance of Al/PbS/ITO diode. The parameters are extracted numerically from the measured dark current of the device.

In the ac analyses, the capacitance-voltage characteristics of the Al/PbS/ITO structure are investigated considering both dark and illuminated conditions. Fig.7 shows the variation of capacitance within the voltage range of ±0.4V. Interestingly, a distinct divergence in the device capacitance is observed under a variety of illumination wavelengths. The nature of such capacitance-voltage characteristics clearly substantiates the role of photon wavelength on the origin of excess capacitance in addition to the dark capacitance. During illumination the photo-generated carriers contribute to the total capacitance of the device, ensuing the improvement of the capacitance. The wavelength dependent capacitance-voltage characteristics can be utilized in a variety of semiconductor optoelectronic devices.

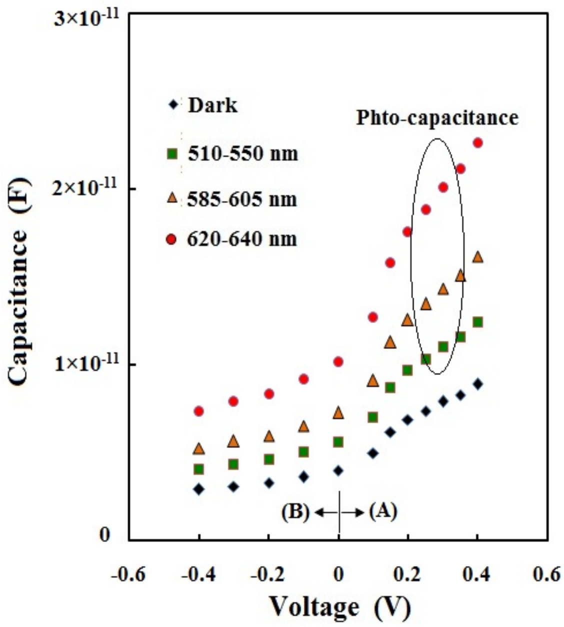

Figure 7. The capacitance-voltage characteristics of Al/PbS/ITO diode for (A) Al +ve and ITO –ve and (B) Al –ve and ITO +ve bias conditions.

Conclusion

In conclusion, an Al/PbS/ITO diode is fabricated in the present work, by chemical bath deposition technique. Different electrical and optoelectronic properties of the diode are investigated experimentally. The device is found to be a good photo-sensor, as both the current-voltage and capacitance-voltage characteristics are largely influenced by the illumination wavelength. The diode can be used as a photo-sensor or photo-capacitor device in different optoelectronic applications.

Acknowledgement

This work is partly supported by the infrastructure provided at the Department of Electronic Science, Acharya Prafulla Chandra College under DST-FIST scheme, Govt. of India. (Sanction order: SR/FST/College-008 dated 15/02/2012). The author is grateful to Mr. S. Chatterjee, Institute of Electronics Engineering, National Tsing Hua University (Taiwan), for FESEM micrograph of PbS thin film and Dr. Saktibrata Bhowmik (Principal, A.P.C. College) for his support to carry out this work.

References

Averin, S. V., Kuznetzov, P. I., Zhitov, V. A., Zakharov, L. Yu. and Kotov, V. M. (2020). MSM-photodetector with ZnSe/ZnS/GaAs Bragg reflector. *Opt Quantum Electron*. 52: 93:1-7.

Banerjee, A., (2019). Electrical and optoelectronic properties of chemically prepared PbS/MnS Heterojunction. *J. Electron. Mater*. 48: 438-444.

Chu, C. S., Zhou, Y., Chen, K. J. and Lau, K. M. (2005). Q-Factor Characterization of RF Gan-Based Metal-Semiconductor-Metal Planar Interdigitated Varactor. *IEEE Electron Device Lett*. 26: 432-434.

Ghamsari, M. S., Araghi,M.K. and Farahani, S.J. (2006). The influence of hydrazine hydrate on the photoconductivity of PbS thin film. *Mater. Sci. Eng. B*. 133: 113-116.

Gunes, S., Fritz, K. P., Neugebauer, H., Sariciftci, N.S., Kumar, S. G. and Scholes, D. (2007). Hybrid solar cells using PbS nanoparticles. *Sol. Energy Mater. Sol. Cells*. 91: 420-423.

Hirata, H. and Higashiyama, K. (1971) Analytical study of the lead ion-selective ceramic membrane electrode. *Bull. Chem. Soc. Jpn.* 44: 2420-2423.

Khalli, N. A., and Debbar, N. (2019). Performance enhancement of ZnO-based MSM photodiodes by optimizing structure parameters. *Int J Numer Model*. 32: e2519: 1-10.

Miroshnikova, I. N., Komissarov A. L., and Miroshnikov,B. N. (2010). Noise of Pbs-based semiconductor photoresistors. *Meas. Tech.* 53: 621-625.

Nouchi, R. (2014). Extraction of the Schottky parameters in metal-semiconductor-metal diodes from a single current-voltage measurement. *J. Appl. Phys*. 116(184505): 1-6.

Osvald, J., (2015) Back-to-back connected asymmetric Schottky diodes with series resistance as a single diode. *Phys. Status Solidi A*. 212: 2754–2758.

Pandit, B., Cho, J. (2018). Metal-semiconductor-metal ultraviolet photodiodes based on reduced graphene oxide/GaN Schottky contacts. *Thin Solid Films*. 660: 824-827.

Pop, I., Nascu, C., Ionescu, V., Indrea, E. and Bratu, I. (1997). Structural and optical properties of PbS thin films obtained by chemical deposition. *Thin Solid Films*. 307: 240-244.

Ruzgar, S. and Caglar, M. (2020). Fabrication and characterization of solution processed Al/Sn:ZnO/p-Si photodiodes. *Mat. Sci. Semicon. Proc*. 115(105076): 1-11.

Seghaier, S., Kamoun, N., Brini, R. and Amara, A. B. (2006). Structural and optical properties of PbS thin films deposited by pulsed laser deposited (PLD) technique at different annealing temperature. *Mater. Chem. Phys.* 97: 71-80.