Recent Development on ZnO Based Nano Structured Photodetectors-A Short Review

Bholanath Ghosh
Basic science and Humanities
Dr.B.C.Roy Polytechnic
Durgapur, India
bholanath.ghosh@bcrec.ac,in

Arnab Chatterjee
Basic science and Humanities
Dr.B.C.Roy Polytechnic
Durgapur, India
arnab.chatterjee @bcrec.ac,in

Samya Neogi
Basic science and Humanities
Dr.B.C.Roy Polytechnic
Durgapur, India
samya.neogi@bcrec.ac,in

Ujjal Kar
Basic science and Humanities
Dr.B.C.Roy Polytechnic
Durgapur, India
ujjal.kar @bcrec.ac,in

Souvik De
Basic science and Humanities
Dr.B.C.Roy Polytechnic
Durgapur, India
souvik.de@bcrec.ac,in

Abstract—

Metal-Oxide Semiconductor (MOS)nanostructures have a potential future prospect large number of novel phenomena at the nanoscale and investigating size and dimensionality dependence of nanostructure properties for potential applications. The fabrication and design of photodetectors or optical switches based on nanostructures with different morphology, suitable choice of substrate with different growth techniques have shown rapid advancement in past few years. Nanostructure photodetector can be designed in different ways either based on the device structure or based on mechanism of photoconduction. Possibly the most simple type of device structure is metal semiconductor metal (MSM) type which can be operated based on resistive nature of the materials whose conductions are modulated by generation of electron-hole pairs in presence of excitation by suitable frequency of photon and its transportation in external circuit. Photodiodes, avalanche photodiodes (APD), phototransistors and Photo multiplier tube(PMT) type complex device architecture with high end fabrication techniques are being used for high speed applications in communication systems. Apart from high end fabrication techniques like chemical vapour deposition (CVD), atomic layer deposition (ALD), physical vapor deposition (PVD) and use of different substrates, techniques like design of hetero structure devices, doping the active material with suitable elements, surface modification of the active materials and integration of closely spaced interdigtated electrodes have been employed for the enhancement of the performance of the device. This article presents a brief review on the state-of-the-art research in the photodetector with mainly focused on the metal oxide nanostructures such as ZnO, SnO2, TiO2, and their photoresponses. The review starts with a survey on one dimensional metal-oxide semiconductor nanostructures and the photodetector principle, then explores the recent development on metal-oxide nanostructures and their photoresponses with advanced design, fabrication and use doping methods for performance enhancement.

Keywords—Photo-detector, metal-oxide,responsivity,nano-materials

I. INTRODUCTION

Semiconductor based photo-detectors (PDs) convert optical signals i.e stream of photons into electrical signals via internal photoelectric effect, that includes the generation, separation, and transportation of the photo induced charge carriers (electrons and holes), as well as the transportation of these carriers to external circuits. Metal oxide semiconductors being a class of material with specific electronic and optoelectronic properties, are widely used as building blocks in photoelectric devices [1]. But when we compromise between enhancement of photo-response and the speed of response then it limits the practical applications of PDs. As the behaviors of the charge carriers play important roles in the photoelectric conversion process of these PDs, researchers have proposed several strategies, including modification of light absorption, design of novel PD hetero structures, construction of different geometries, and adoption of specific electrode configurations to modulate the charge-carrier behaviors and improve the photoelectric performance of PDs [2].

Improved physical and chemical properties of nanostructures have enabled it use as an attractive and efficient material in the field of optoelectronics, nanoelectronics, photocatalysis, sensors, biomedicine, lasers, and wearable flexible technology[3]. Considering the modern development it is quite evident that many of the electronic devices have direct or indirection association with the light-matter interaction for different type's applications. For an instance, there are some diseases which can be treated with suitable lasers exposure and for optical communication purpose high speed detectors are widely used. From this perspective the application of photodetectors (PDs) is inevitable. Specifically based on the spectral region of application photodetector application can be classified as (i) ultra-violet (UV) region of application used for ozone layer damage detection, detection of environmental contamination, detection of flame or detection of hazardous gases (ii) visible region of application as nonconventional source energy, high speed optical communications, video imaging (iii) infrared (IR) region mainly for defense, bio-medical application and space applications[4].Wide range of materials has already been explored for the PDs application that includes metal oxides, transition metal halides and perovskites and different composites[5]. It has been found that if the composite materials are coupled with different nanostructures, the sensitivity of the device can be enhanced. Therefore, it is required to study and explore different growth techniques, efficient types of device architectures with suitable materials for improved photodetector performance. In recent time Hanna et al proposed Visible-blind UV photo detectors using a polymer/ZnOnano composite thin film with on-off ratio, 1.4 $\times 10^4$; responsivity, 14.43 A/W; linear dynamic range, 83.09 dB and detectivity, 2.27×10^{13} with 365 nm light illumination[6].

High-performance self-powered ultraviolet photo-detector in SnO2 microwire/p-GaNheterojunction using graphene as charge collection medium and Self-powered high-performance ultraviolet C photo-detector is reported very recently by Xu et al. This includes a high responsivity 223.7 mAW^{-1}, with detectivity nearly 6.9×10^{12} Jones having response speed (rising/decaying times ~ 18/580 µs), and excellent external quantum efficiency ~ 77% with an incident wavelength of 360 nm light illumination in absence of an external power supply[7].

In general, nanostructured engineered materials are widely in use for the development of photodetectors due to their fascinating electronic & optoelectronic properties, high photo sensitivity, high carrier mobility, high thermal stability and some with flexible in nature[8]. As a result, several PDs with improved photodetection have been created based on vibrant nanostructures (nanowires, nanorods, and quantum dots).[9-11]. This brief review aims to introduce and summarize the latest researches to enhance the photoelectric performance of PDs based on oxide based semiconductors.

II. PHOTODETECTION MECHANISM

In theory, photo detection transforms an incoming optical input into a different kind of signal, usually an electric signal. The majority of photo-detectors transform optical impulses into electrical ones so that they can be stored or processed further. Because the majority of photo-detectors are square-law detectors, which react to the power or intensity of the input signal rather than the field amplitude of an optical signal, power or intensity of the input signal is an important aspect of the input signal. A photocurrent or a photovoltaic signal, proportional to the optical signal's power, is the electrical signal produced by it. A photon detector reacts to the amount of photons absorbed by the detector; photo-detectors operate on the basis of the internal photoelectric effect, which transforms a photon into an emitted electron or an electron–hole pair.

Based on the method of detection of incident photon after the generation of electron-hole pair the photo detectors can be classified as follows.

A. *Photoconductive*

The basis of the operating concept is how exposure to light alters electrical conductivity. A appropriate frequency of incident photon flux causes the material to produce electron-hole pairs [12], which changes the conductivity of the material. Semiconductors make up the majority of photoconductive detectors [13].

B. *Photo emissive or photoelectric*

An incident photon releases a material's outermost orbital electron, liberating the electrons in a gas or vacuum.

C. *Thermal*

In wavelength areas that are challenging to access using the photon detection concept, thermal detectors are typically utilized [14], especially for long-wavelength infrared light. These detectors measure temperature changes brought on by light. Heat signals are produced when photons induce electrons to transition to mid-gap states and subsequently decay back to lower bands. This non-radiative transition is mediated by phonon production.

D. *Polarization*

Certain materials' polarization states can vary as a result of photon energy [15]. This could result in further polarizationeffects or a change in refractive property.

E. *Photochemical*

A material changes chemically as a result of incidence of photons.

F. *Weak interaction effects*

In photon drag detectors and Golay cells, for example, photons can cause changes in gas pressure or secondary effects.

III. BASIC CHARACTERISTICS PARAMETERS OR FIGURE OF MERIT OF A PHOTO-DETECTOR

The effectiveness of a detector can be evaluated quantitatively and qualitatively using a few different measures. The following factors can be used to calculate a photo-detector's figure of merit.

A. *External quantum efficiency*

The number of carrier fluxes created that add to the photocurrent of the total photon flux on the detector is the measure of a photo detector's quantum efficiency.

$$(\boldsymbol{\eta}) = \frac{\textit{carrier flux generated that contribute to the photocurrent}}{\textit{photon flux}(\boldsymbol{\phi})}$$

$$= \frac{\frac{I_P}{e}}{\frac{P}{h\nu}}$$

B. *Spectral response*

It describes a detector's sensitivity over a range of incident light wavelengths. Only a tiny portion of electromagnetic radiation (between 400 and 700 nm) is visible to the average person, but a detector can be sensitive to a large spectrum of incident radiation. It is therefore a crucial component of the photo-cell. This illustrates how a photo cell's light response varies over a variety of incident wavelengths [16]. The sensitivity of the various semiconducting materials varies with the incident wavelength, as seen in Figure 1 below.

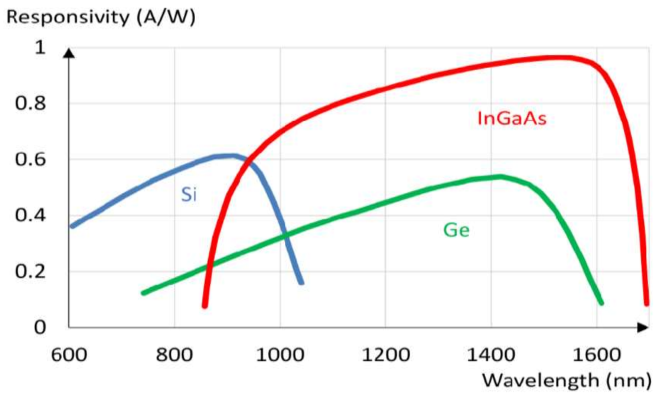

Fig. 1 shows that the variation of photo-sensitivity of different materials

[C.Casado, A.Calvo, M. Calvo, Free-space optical links for space communication networksRamon, (2020)]

C. *Responsivity*

The ratio of optical current to incident optical power is used to determine a detector's responsivity[17].Measured in amperes or volts per watt of incident radiant power, responsiveness(R)=I_{opt}/P_{opt}. This can also be stated in terms of the detector's quantum efficiency. Since λ is in um, R = η eλ/hc=ηλ/(1.24).Responsivity is therefore directly proportional to the detector's quantum efficiency for a given incident light wavelength. The recombination time τ and the transit time of electrons and holes are not taken into account in the foregoing estimate of η. When both are taken into account during computation, the responsivity equation is changed to R= ηλ/(1.24)(τ/t). The gain in the detectors' responsivity is introduced by the factor (τ/t). The reason for this is that the e-h pair's recombination time is substantially longer than the electron and hole transition times.

D. *Gain (on/off ratio) or Sensitivity*

For a fixed applied bias voltage, the ratio of photo current (I_P) to dark current (I_D) represents the gain, or on/off ratio, of a photo-detector. Hence, (on/off ratio)= I_P/I_D, where, I_P is photocurrent, or the current across the detector when light radiation is present, and I_D is the current across the detector when there is no light.

E. *Noise equivalent power(NEP)*

The input power of a detector that yields an output signal power which is equal to the device's internal noise. The rms noise current in a 1 hertz bandwidth is equivalent to the least input optical power required to generate photocurrent, which is known as Noise-Equivalent Power (NEP) [18]. Because it directly compares noise to optical power, this evaluates the minimal observable signal. The modulated signal's frequency, the noise measurement bandwidth, the detector's area, and the operating temperature all affect NEP.

F. *Detectivity*

A photo-detecting device's detectivity is a parameter that can be expressed as the reciprocal of the (NEP). A detector with a higher detectivity value is appropriate for detecting faint light signals [19]. The detectivity normalized to a unit detector area (1 m2) and detection bandwidth (1 Hz) is known as the specific detectivity. It can be computed by multiplying the detectivity by the square root of the product of the detector's bandwidth (in Hz) and active area (in square centimeters).D* = √(A×Δf)/NEP yields specific detectivity, where A is the detector area in cm2, Δf is the signal bandwidth in Hz, and NEP stands for "Noise Equivalent Power," the optical input power required by the detector to achieve a unity signal-to-noise ratio (S/N=1). D* is a crucial "figure of merit" in comparison analyses.

G. *Speed (rise and decay time) and frequency response*

A photo detector's frequency response is directly proportional to its response speed. It determines a detector's capacity to track an optical signal that varies quickly. In order for a photo-detector to effectively record an optical signal, it must be able to react far faster than the signal's quickest temporal fluctuations, or, in other words, it must have a frequency response that spans the full incoming signal's bandwidth. Figure 2.(a) and 2.(b) below show the frequency response and increase and decay of photo-current in the light and dark, respectively.

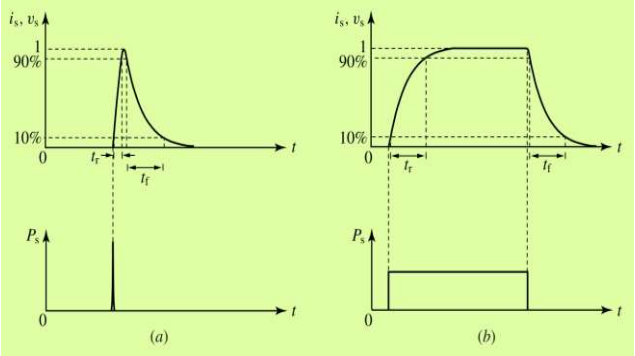

Fig. 2(a) shows frequency response, (b) increase and decay of photo-current

The response's rise time is defined as the amount of time it takes to climb from 10% to 90% of its peak value, while the response's fall time is defined as the amount of time it takes to decrease from 90% to 10% of its peak value or, in the absence of photon flux, to return to 90% of its original value. Generally speaking, a photo-detector's intrinsic bandwidth and RC circuit-limited bandwidth both affect its speed. The inherent bandwidth of a photo-detector determines the rising time of the impulse response, whereas its RC circuit-limited bandwidth determines the square-pulse response [20]. The relationship between the rising time and related bandwidth is as follows: $t_r = 0.35 / f_{3B}$, f_{3B} is the 3-dB cutoff frequency is defined as f_{3B} =0.886B=0.448/T

IV. METAL OXIDE BASED PHOTO-DETECTORS

When a proper light signal is present, photoconductivity governs the ability to generate extra carriers, their conveyance, and the energy-harvesting efficiency of optoelectronic devices. The most effective materials to utilize in photo-detectors are metal oxide films (NWS/NRS) due to a special oxygen-sensitized photoconduction (PC) process [21]. Metal oxide (NWS/NRS) photo-detectors, including SnO_2, TiO_2, WO_2, Fe_2O_3, V_2O_5, and $In_2Ge_2O_7$, with PC gains that can readily reach 10^3.ZnO NWs-based detectors have also been reported to have a maximal gain of up to 10^8, this was achieved by the use of a costly and difficult device fabrication approach [22].The advancement of quasi-one-dimensional (1D) nano materials has led to a constant improvement in the performance of sensing devices, optoelectronics, and nanoscale electronics over the last several years. These materials provide a continuous carrier transport channel and shape constrained by size. Metal oxide semiconductors, such as ZnO, SnO_2, TiO_2, WO_3, Cu_2O, Ga_2O_3, and In_2O_3, in addition to group IV, group III-V, and group II-VI compounds, have sparked interest in investigating novel phenomena in nano scale science and in creating next-generation nano devices [21]. In contrast to most semiconductor systems, metal oxides have remarkably active surfaces when exposed to light. Metal oxide 1D nano materials with surface-enabled photo activity and molecular sensitivity make for an excellent photo-detector system [23]. Here, we will restrict our discussion mainly with in the domain of ZnO based detectors.

ZNO-BASED PHOTODETECTORS

Among the metal-oxide family of MOS, zinc oxide is one of the most commonly used. It is widely employed in UV detection, which also involves enhanced charge carrier production, or electron-hole pair and their segregation, and has a broad band-gap of 3.37 eV and a large exciton binding energy of 60 mev[24]. This guarantees effective room-temperature excitonic UV emission. Moreover, ZnO is biocompatible and harmless [25]. Regarding 1D ZnO nanostructures, numerous published studies have demonstrated their critical significance in the advancement of nano-science and nanotechnology. It is reasonable to say that one of the most significant Metal-Oxide-Semiconductor 1D nanostructures in current research is likely ZnO 1Dnanostructures. Promising applications in nanoscale technologies and devices are driving interest in the fabrication and physical or chemical modification of ZnO nanostructures.

A. M-S-M TYPE (PRISTINE & DOPED)

We talked about a few recent advancements in ZnO-based photo conductive devices (PDs) based on the device architecture and the growing process of oxide materials. The Solgel process has been shown to be one of the most adaptable and widely used methods for the creation of metal oxide based micro metals, as confirmed by experiments[26,27]. ZnO based M-S-M UV photo detectors can be fabricated with the help of the sol-gel process[28].

Using the M-S-M structure, Shaikh et al. have shown how to build stable ZnO films chemically and how this results in UV photoconductive properties. They also discovered that the period of deposition permitted in the CBD process may be used to adjust the UV detection performance. Ag was used as a material to construct two electrodes in the Ag/ZnO/Ag (M-S-M) device configuration. With a bias voltage of 5 volts and an incident wavelength of 365 nm, the device generated increased photocurrent production of 113.83 μA and responsivity of 28.14 A/W under UV light intensity of 1.8 mW/cm2. It has been noted that the crystalline quality of ZnO film improves with variable deposition time, contributing to the increased photo response. The rise time of as low as 9 s and fall duration of 21 s reported. The aforementioned results demonstrate that improving carrier transport through the metal-semiconductor interface can be achieved by applying time modulation deposition after the chemical bath process. Consequently, the detector's total performance is enhanced[28].

In order to reduce the operational limiting condition and improve the performance of MOS-based photo-detection, an alternate method that has received a lot of attention recently is the manufacture of nano-composites devices. Graphene oxide (GO) or reduced graphene oxides (RGO) are used as a composite material despite having photo-responsivity (~0.5mA/W) at bias voltages of up to 80V. This is because they have exceptional electron mobility at room temperature (250000 cm^2/Vs) and unparalleled thermal conductivity (5000W/mK) with band gap tunability through functionalization[29]. Because of their extremely high electron mobility, GO and RGO are frequently used as quick electron transport media.

Using graphene quantum dots as photosensitizers and excellent electron transport across grain boundaries, the decorated graphene quantum dots on vertically aligned ZnOnano reported a high detectivity of 1.78×10^{15} Jones and responsivity of around 6.62×10^4 A/W at a low applied bias of 2 V [30]. Fig.3 below shows the total photo-conducting performance, which includes detectivity, I-V response, responsivity, transient response, and stability performance.

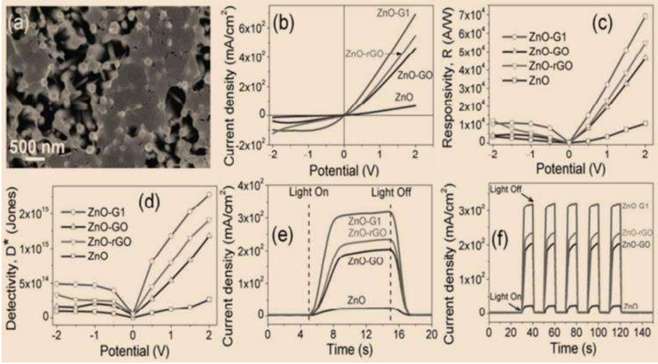

Fig.-3

Fig.3 (a) FESEM image of rGO deposited on ZnOnano rod array, (b) Current density vs. voltage characteristic under 365 nm UV light ,(c) Responsivity , (d) Detectivity , (e) time response curve under periodic chopped UV light and (f) the stability test for five successive on/off states for ZnO, ZnO-G1, ZnO-GO and ZnO-rGO

[D.Ghosh,S. Kapri, S. Bhattacharyya, ACSAppl. Mater. Interfaces, 8, 51, 35496–35504,(2016)]

Apart from incorporation of material like graphene with high charge transportion characteristic doping of ZnO with different transition elements has been found to an effective way to improve the performance characteristic of pristine ZnO based detectors[31].

In this instance, the M-S-M structural arrangement was created by Shewale et al. on both ZnO and Ti-doped ZnO samples through a rigorous investigation of the photo detector performance of pure and Ti-doped ZnO films under Sn as a metal electrode contact[32]. As a result, the ohmic connections between the semiconductor (Ti doped ZnO) and metal (Sn) layers were validated by the linear (I-V) response of M-S-M structure under forward and reverse bias. Under UV irradiation (365 nm), Ti-doped ZnO exhibited superior photocurrent of 112.68 μA at a selective bias voltage of 5 V, surpassing that of the dark state with dark current of 6.10 nA. Simultaneously, the responsivity under 2 mW/cm2 of light was approximately 0.051 A/W. To sum up, the charge carrier density in ZnO was found to be greatly enhanced by Ti metal doping, resulting in higher UV photo detector performance.

In essence, the effective LSPR effects of nano materials (NPs) based on noble metals, including Au[33], Ag [34], Pt[35], etc., have attracted special attention. These nano materials are frequently combined with ZnOnano materials to increase photoconduction. Ag NPs-decorated ZnO NWs for UV PD were reported by Liu et al. and are depicted in (Fig.4(a,d)) (device design)[36]. The I-V characteristics (Fig.4(b)) demonstrate that when exposed to UV light, the Ag NPs-decorated ZnO NWs exhibit a greater photo response than their bare counterpart. This is attributed to the Ag NPs' LSPR effect, which enhances light absorption. The Ag and ZnO hetero junction's energy band (top schematic) is depicted in (Fig.4(c)). When exposed to UV light, the electrons and holes are produced and move the hot electrons from the Ag NPs to the CB of ZnO to improve photoconduction.

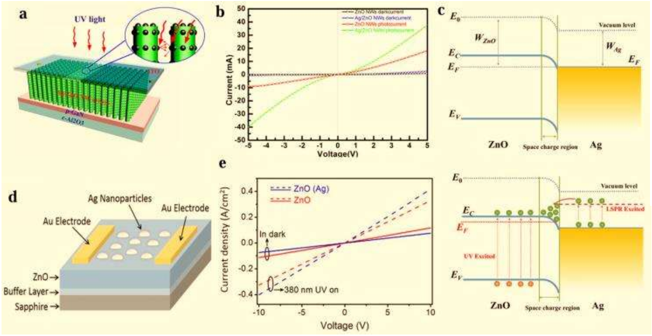

Fig. 4. (a,b) shows Schematic representation of Ag NPs/ZnO NWs based plasmonic PD and the respective I-V response in presence and absence of UV excitation (365nm, 0.24 mW/cm2). (c) The Ag/ZnOheterojunction energy band diagrams are shown in the top schematic, and the bottom schematic shows how UV radiation causes LPSR excited electrons to move from Ag to ZnO. (d) Diagram of the ZnO-based PD decorated with Ag NPs. (e) J-V characteristics of pure ZnO and Ag NPs incorporated ZnO based PDs in both presence and absence of UV exposure.

[X. Wang, K. Liu, X. Chen, B. Li, M. Jiang, Z. Zhang, H. Zhao, D. Shen, ACS Appl. Mater. Interfaces, 2017, 9, 5574.]

ultraviolet high-density GZO nanorod UV photodetector on a flexible PEN substrate. On the PEN substrate, the nanorods were grown vertically[37]. The outcomes showed that, in comparison to the ZnO sample, the GZO nanorod UV photodetector worked better. Through Ga-doping at 1 V bias voltage, the photocurrent-to-dark current ratio increased from 8.5 to 570.2. In order to comprehend the impact of mechanical strain and tension on the proposed photo-detector, the transient response under stretch and compression conditions was examined. The developed photo-detectors were found to be stable and reproducible, with no discernible changes in the I-V characteristics, following several bending cycles. The below figure 5 represents the Schematic of the device design and figure 6 represents current-voltage response and periodic growth and decay of current under dark and with illumination.

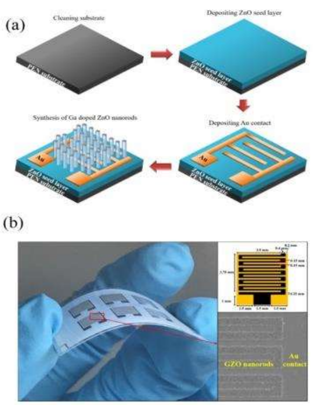

Fig.5 (a) Schematic illustration of thefabrication process for ZnO and gallium-doped ZnO (GZO) nanorod metal–semiconductor–metal photodetectors. (b) Image of the fabricated photo detectors. PEN, polyethylene 2,6-naphthalate.

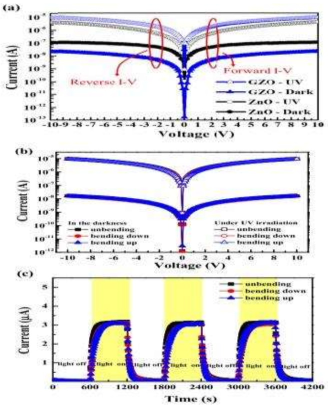

Fig. 6(a) Current–voltage curve of UV photo detectors constructed from pure ZnO and gallium-doped ZnO (GZO) nano rods. (b)Current–voltage curve properties of GZO nano rods PD under different bending conditions. (c) Transient switching photo response curves.

Young et al.ACS Appl. Electron. Mater. 2, 3522–3529 (2020)

In recent development it has been observed that instead of using sophisticated and expensive deposition techniques like CVD, double doping of pristine ZnO could also be an effective method to modulate the response characteristic of a detector[38].Very recently, co-dopped zinc oxide (ZnO) thin films containing tin (Sn) and titanium (Ti) have been shown to have increased photosensitivity of MSM type ZnO based photo-detection[39]. The film was doped using the sol-gel method. Under 365 nm light illumination, the thin films doped with 0.5% Sn and 1% Ti have demonstrated the best sensitivity. The regulated addition of Sn and Ti increased the photosensitivity from 42 to 1552. Furthermore, by regulating the doping concentration to 1% Sn and 1% Ti, the pristine photo-detector's decay time is shortened from 31.2 s to 5.4 s. It has been demonstrated that co-doping ZnO thin films with carefully chosen additions of Ti and Sn can significantly improve the photodetector's decay time and on/off current ratio. Figure 7 below shows the decrease in the recovery time with the subsequent doping of Sn and Ti

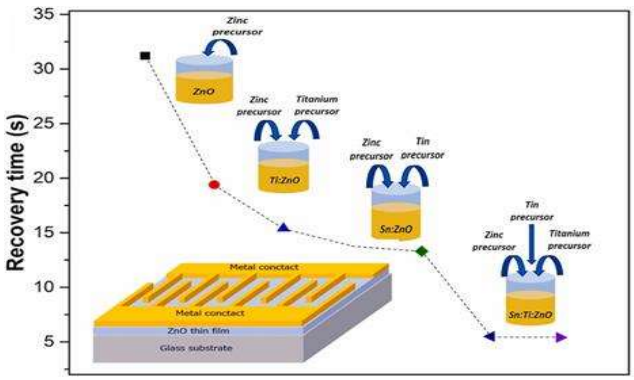

Fig.-7 , The improvement in recovery time with Sn and Ti doping

[E. Aslan, M. Zarbali, *Optical Materi*als, 125, 112030,(2022)]

B. *ZnO AND POLYMER-BASED COMPOSITES*

In spite of doping being an attractive and relatively more feasible approach for the enhancement of ZnO based photo detectors' performance characteristic, the possibilities with ZnO and polymer composites were explored and that revealed promising outcomes[40]. The use of polymer matrix has been found to be very effective to suppress the surface imperfection, resulting enhancement in photoconductive behavior.

According to reports, ZnO and polymer-based composites, such as Zno-PVP, exhibit visible blind photoconductivity (PD) with a sensitivity of roughly 69% and a rise time of about 167 ms[41].

In a report the synthesis of PMMA/ZnO, PS/ZnO, and P(VDF-TrFE)/ZnOnanocomposites and their photo-response characteristics were examined. It has been found that the ZnO surface imperfections were efficiently suppressed by the polymer matrix. The P(VDF-TrFE)/ZnOnano composite device's increased absorption in the UV region led to an improved photo-response. P(VDF-TrFE) with a 5 wt%ZnOnano composite and Ag as the top electrode had the greatest performance with a 365 nm light illumination, on-off ratio of 1.4 ×10^4, responsivity of 14.43 A/W, linear dynamic range of 83.09 dB, and detectivity of 2.27 × 10^{13}[42]. The device structure schematic **(Fig.8 (a))**and current-time response (Fig.8 (b))with light and dark conditionsfor PMMA/ZnO, PS/ZnO, and P(VDF-TrFE)/ZnOnano composites architectures are displayed below.

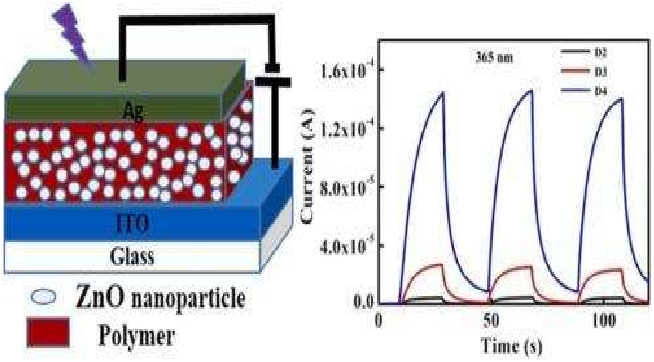

Fig.-8

(a) Scematic of the device structure, (b) current-time response for PMMA/ZnO, PS/ZnO, and P(VDF-TrFE)/ ZnO nano composites

[B. Hanna, L.R. Pillai,K. Rajeev, K.P. Surendran, K.N.N. Unni, Sensors and Actuators A: Physical, 338, 113495 (2022)]

C. *CONCLUSION AND OUTLOOK*

The brief review concludes with highlighting the noteworthy advancements in the field of ZnO nanostructured photo detectors. It has been reported that sensitivity, response speed, and overall performance have significantly improved as a result of ZnO's special optical and electrical characteristics and creative synthesis and device fabricaton methods. The article highlights both the recent successes and the obstacles that still need to be overcome, such as problems with the devices' scalability, reliability, and reproducibility.

Future studies should concentrate on improving ZnO-based photo detectors' stability and longevity, investigating cutting-edge doping techniques, and creating hybrid materials to further improve performance. Furthermore, incorporating ZnO nanostructures into wearable and flexible technologies offers a fascinating chance to increase the spectrum of applications for these materials. Overcoming current obstacles and realizing the full potential of ZnO-based photo detectors in a variety of domains, such as advanced imaging systems, medical diagnostics, and environmental monitoring, would require sustained interdisciplinary cooperation and nanotechnology advancements.

ACKNOWLEDGMENT

With deep appreciation, we would like to thank everyone who helped us finish this article. We would like to express our gratitude to our mentors and colleagues for their crucial assistance and guidance during this period of time. We would especially want to thank Dr. B.C. Roy Polytechnic, our institution, for providing the facilities and resources that allowed this study to be conducted.

REFERENCES

[1] W. Ouyang, F.Teng, Jr-Hau He and X. Fang, “Enhancing the photoelectric performance of photodetectors based on metal oxide semiconductors by charge-carrier engineering” Advanced Functional Materials, vol. 19, pp 1807672, 2019

[2] Z.Li, Z.Li and C. Zuo, “Application of nanostructured TiO_2 in UV photodetectors: a review” Advanced Materials, vol. 34(28), pp 2109083, 2022

[3] P.V.K. Yadav, B. Ajitha, Y.A.K. Reddy and A. Sreedhar, “Recent advances in development of nanostructured photo detectors from ultraviolet to infrared region: a review”, Chemosphere, vol. 279, pp 130473, 2021

[4] Y.Fu, T. Liu, H. Wang, Z. Wang, L. Hou, J. Jiang and T. Xu, “Applications of nanomaterial technology in biosensing” Journal of Science: Advanced Materials and Devices, vol. 9(2), pp 100694, 2024

[5] A.C.-Casado and R.M. -Calvo, “Free-space optical links for space communication networks”, 2020

[6] B. Hanna, L. R. Pillai, K. Rajeev, K.P. Surendran and K.N.N. Unni, “Visible-blind UV photodetectors using a polymer/ZnO nano composite thin film” Sensors and Actuators A: Physical, vol. 338, pp 113495, 2022

[7] T. Xu, M. Jiang, P. Wan, Y. Liu, C. Kan and D.Shi. “High-performance self-powered ultraviolet photodetector in SnO_2 microwire/p-GaN heterojunction using graphene as charge collection medium”. J. Mater. Sci. Technol., vol. 138, pp 183-192, 2023.

[8] A. Mondal, P.V. K. Yadav and Y. A. K. Reddy “A review on device architecture engineering on various 2-D materials toward high-performance photo detectors”, Materials Today Communications, vol. 34, pp 105094, 2023

[9] E. P. de Araújo, A. N. Arantes, I. M. Costa and A. J. Chiquito “Reliable Tin dioxide based nanowire networks as ultraviolet solar radiation sensors” Sensors and Actuators A: Physical, vol. 302, pp 111825, 2020.

[10] Q.-M. Fu, J.-L. Peng, Z.-C. Yao, H.-Y. Zhao, Z.-B. Ma, H. Tao, Y-F. Tu, Y. Tian, D. Zhou and Y.-B. Han, “Highly sensitive ultraviolet photodetectors based on ZnO/SnO_2 core-shell nanorod arrays” Applied Surface Science, vol. 527, pp 146923, 2020.

[11] P.V.K. Yadav, B. Ajitha, Y.A.K. Reddy and A. Sreedhar, “Recent advances in development of nanostructured photo detectors from ultraviolet to infrared region: a review”, Chemosphere, vol. 279, pp 130473, 2021

[12] A. Hagfeldt and E. A. Gibson, McEvoy's Handbook of Photovoltaics Third Edition, 2018.

[13] R. H. Kingston, Encyclopedia of Physical Science and Technology Third Edition, 2003.

[14] R.Paschoota R.P. Photonics encyclopedia. Thermal detectors, https://www.rp- photonics.com/thermal_detectors.html

[15] K. W. Böer and U. W. Pohl, “Semiconductor Physics, Photon–Phonon Interaction”, Springer, Cham., 2020.

[16] A Owens, “Synchrotron radiation, semiconductor materials and radiation detection”,vol.13(2), pp 143-150, 2006.

[17] S. Al-Janabi and N. Al-Janabi, “Data Science for Genomics”, Academic Press , Chapter 10, pp. 165-178, 2023.

[18] V.Mackowiak (GMBH), J. Peupelmann (GMBH), Y.Ma (USA), and A. Gorges (USA), NEP - noise equivalent power, https://www.thorlabs.com/images/tabimages/noise_equivalent_power_white_paper.pdf

[19] A. A. Khan, Z. Yu, U. Khan and L. Dong, “Solution processed trilayer structure for high-performance perovskite photodetector” Nanoscale Res Lett vol.13, pp 399, 2018.

[20] R. Hui ,“Photodetectors, Introduction to Fiber-Optic Communications”, 1^{st}edition,Academic Press, 2019.

[21] R. S. Chen, W. C. Wang, C. H. Chan, M. L. Lu, Y. F. Chen, H. C. Lin, K. H. Chen, and L. C. Chen, “Photoconduction efficiencies of metal oxide semiconductor nanowires: the material's inherent properties” Applied Physics Letters. vol. 103 (22), pp 223107, 2013.

[22] J.H. He, P.H Chang, C.Y Chen and K.T Tsai, “Electrical and optoelectronic characterization of a ZnO nanowire contacted by focused-ion-beam-deposited Pt” Nanotechnology vol. 20, pp 135701, 2009.

[23] T. A. Dontsova,S.V. Nahirniak and I. M. Astrelin, “Metaloxide Nanomaterials and Nanocomposites of Ecological Purpose” Journal of Nanomaterials, pp 5942194, 2019.

[24] K.Davis, R.Yarbrough, M. Froeschle, J. White and H.Rathnayake, “Band gap engineered zinc oxide nanostructures *via* a sol–gel synthesis of solvent driven shape-controlled crystal growth”, RSC Adv. Vol. 9, pp 14638-14648, 2019.

[25] H. Mirzaei and M. Darroudi, “Zinc oxide nanoparticles: Biological synthesis and biomedical applications”, Ceramics International, vol. 43, pp 907-914, 2017.

[26] Imoisili, Patrick Ehi, Jen, Tien-Chien and Safaei, Babak. "Microwave-assisted sol–gel synthesis of TiO2-mixed metal oxide nanocatalyst for degradation of organic pollutant" Nanotechnology Reviews, vol. 10, no. 1, pp 126-136, 2021.

[27] M. Parashar, V. K. Shukla and R. Singh, “Metal oxides nanoparticles via sol–gel method: a review on synthesis, characterization and applications”, J Mater Sci: Mater Electron vol. 31, pp 3729–3749 2020.

[28] S. K. Shaikh, S. I. Inamdar, V. V. Ganbavle and K. Y. Rajpure, “Chemical bath deposited ZnO thin film based UV photoconductive detector”, Journal of Alloys and Compounds, vol. 664, pp 242-249, 2016.

[29] F. Xia, T. Mueller, Y. –m. Lin, A. V. -Garcia and P. Avouris , “Ultrafast graphenephotodetector” , IBM Thomas J. Watson Research Centre, Yorktown Heights, NY 10598

[30] D.Ghosh,S. Kapri and S.Bhattacharyya, “Phenomenal Ultraviolet Photoresponsivity and Detectivity of Graphene Dots Immobilized on Zinc Oxide Nanorods” ACS Appl. Mater. Interfaces, vol 8 (51), pp 35496–3550, 2016.

[31] P. Kumari, K. P Misra, S. Chattopadhyay and S. Samanta. “A brief review on transition metal ion doped ZnO nanoparticles and its optoelectronic applications”, Materials Today: Proceedings. Vol. 43(5) pp 3297-3303, 2021.

[32] P. S. Shewale, N. K. Lee, S. H. Lee, K. Y. Kang, Y. S. Yu, “Ti doped ZnO thin film based UV photodetector: Fabrication and characterization”, Journal of Alloys and Compounds, vol. 624, pp 215-257, 2015.

[33] X. Ding, D. Li, J. Jiang, “Gold-based Inorganic Nanohybrids for Nanomedicine Applications”, Theranostics. vol. 10(18), pp 8061-8079, 2020.

[34] S. Kim, J. -M. Kim, J.-E. Park and J. -M. Nam, “Nonnoble-Metal-Based Plasmonic Nanomaterials: Recent Advances and Future Perspectives” Advanced Materials. Vol. 30 (42), pp 1704528.

[35] A. Z. -Jurek, “Progress, Challenge, and Perspective of Bimetallic TiO_2-Based Photocatalysts.” Journal of Nanomaterials. Vol. 2014(1) pp 208920, 2014.

[36] X. Wang, K. Liu, X. Chen, B. Li, M. Jiang, Z. Zhang, H. Zhao and D. Shen, “Highly Wavelength-Selective Enhancement of Responsivity in Ag Nanoparticle-Modified ZnO UV Photodetector” ACS Appl. Mater. Interfaces, vol. 9(6), pp 5574-5579, 2017.

[37] S. –J. Young, Y. –H. Liu, M. D. N. I. Shiblee, K. Ahmed, L. –T. Lai, L. Nagahara, T. Thundat, T. Yoshida, S. Arya, H. Furukawa and A. Khosla, "Flexible Ultraviolet Photodetectors Based on One-Dimensional Gallium-Doped Zinc Oxide Nanostructures" vol. 2(11) pp 3522-3529, 2020.

[38] I. B. Elkamel, N. Hamdaoui, A. Mezni, R. Ajjel and L. Beji, "Photodetectors for Weak Signal Conditions from Au/Cu co-doped ZnO" vol. 53 (386), 2021.

[39] E. Aslan and M. Zarbali, "Tuning of photosensitivity and optical parameters of ZnO based photodetectors by co-Sn and Ti doping" Optical Materials, vol. 125, pp 112030, 2022.

[40] S. Patra, A. Ray, A. Roy, P. Sadhukhan, S. Pujaru, U. K. Ghorai, R. Bhar, S. Das, "ZnO polymer composite based visible blind UV photo detector", Materials Research Bulletin. Vol. 10, pp 240-245, 2018 .

[41] S. Patra, A. Ray, A. Roy, P. Sadhukhan, S. Pujaru, U. K. Ghorai, R. Bhar, S. Das, "ZnO polymer composite based visible blind UV photo detector", Materials Research Bulletin. Vol. 10, pp 240-245, 2018.

[42] B. Hanna, L. R. Pillai, K. Rajeev, K. P. Surendran, K. N. N. Unni, "Visible-blind UV photodetectors using a polymer/ZnO nanocomposite thin film", Sens. Actuators A. Phys. vol. 338, pp 113495, 2022.