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RESEARCH ARTICLE

Intensity Dependent Photoconductivity in ZnO Nanostructured Film

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ABSTRACT

Many studies on the Photoconductivity of ZnO have been performed with an indication of reliable optical application due to fast photo response. This paper reports study of intensity dependent photoconductivity in ZnO nanostructured thin film with a thickness of 800 nm. ZnO nanostructured thin film on ultra clean glass substrate has been deposited using sol-gel spin coating technique. Conductivity at various illumination intensity has been measured using two probe method and found that photoconductivity increases by increasing illumination intensity. Photoconductivity can be utilized in the devices fabrication which are based on the decrease in the resistance of certain materials when they are exposed visible radiation. Photosensitivity and persistent photo conductivity also found to be increasing with illumination intensity. Photo sensitivity enhancement in Nanostructured ZnO is expected due to its large surface to volume ratio which is fundamentally more suitable for optical devices application. Persistent photoconductivity in the ZnO nanostructure thin film can be utilize in memory device applications.

1 Introduction

Photoconductivity is considered as an optical and electrical phenomenon where a material becomes electrically more conductive by absorbing electromagnetic radiation [1], [2]. It is the consequences of carrier excitation due to light absorption and its novelty depends on the light absorption efficiency [3], [4]. The increase in conductivity is due to an increase in the number of mobile charge carriers in the material. Photoconductive materials form the origin of light controlled electrical devices due to current ceases when the illumination is removed. These materials are also used to manufacture detection devices for infrared radiation in military applications such as missiles guidance to heat producing targets. Photoconductivity has broad commercial application in the process of Xeroxography which uses selenium but now relies on photoconductive polymers. Zinc oxide (ZnO) is an important photonic material because of its wide band gap of about to 3.37eV and large exciton binding energy of 60 meV of excitons at room temperature [5]. Recently, ZnO attracted a great deal of attention due to its light detection properties with several studies related to photoconductivity [6]–[9]. Our previous study shows that laser light irradiation can produce significant effect on materials which is attributed to the optical absorption [3], [4], [10]–[12] however we didn't made study on Zn based material. There has been a significant rise in the number of scholarly publications addressing Zn based materials in the last decade indicating significant new interest [13]–[15]. Post-illumination persistence photoconductivity has been reported in ZnO based UV photodevices by Moore *et al* [16]. The exploration of photoconductivity in ZnO nanostructures gained attention due to existence of visible-ultraviolet photo response in ZnO nanowire. Photoconductivity in various ZnO nanostructures such as nano needles, nano rods, nano films and nano wires have been considerably investigated by many researchers [6]–[8], [17]–[21] for the UV devices applications and fundamental studies. Hong-Liang Lu *et al* [22] reported a new type of memory device by utilizing photoconductivity effect. They found that the insulating LAO/STO interface can be converted to its metallic state by UV or visible light illumination. The metallic state kept maintained even after light is off due to Persistent photoconductivity effect. Suhail *et al* [23] reported fabrication of Fast Response ZnO/porous Silicon UV Photoconductive Detector thin films onto nanospikes silicon layer with various etching time through spray pyrolysis using 0.1 M aqueous solution of Zinc acetate. Jiming Bao *et al* [8] studied photoconductivity in individual ZnO nanowires under ultraviolet illumination and they observed that the induced photocurrents persist both in air and in vacuum. Pavel Reyes *et al* [24] reported a ZnO-based thin film transistor UV photodetector with a back gate configuration. Srivastava *et al* [25] reported anomalous behaviour of photocurrent in ZnS:Mn nanoparticles, where the photocurrent decreases even during steady illumination. Many materials have been studies for designing UV devices based on thin films and nanostructures but could not hold significant interest either due to complexity in design or limit of responsivity in such devices. Within the various studied materials, Zinc oxide drawn broad attention due to its notable features of good UV photoconductivity and established material growth techniques in thin film form or nanostructures.

Literature review shows that intensity dependent photo response study in ZnO nanoparticles has not been explored yet. Intensity dependent photo response can be utilized in Intensity tuned Intensity sensor device application as well as in memory devices. However, the true measurement of photoconductivity towards the ZnO nanostructure with change in incident intensity remains unknown for efficient detection. Study of the intensity dependent photoconductivity in ZnO nanostructured thin films and its result might be promising for optical devices fabrication in future.

2 Materials and methods

ZnO thin film of thickness 800 nm has been deposited on ultra clean glass substrate using sol-gel spin coating technique. ZnO solution has been prepared by dissolving diethanolamine, monoethanolamine, sodium dodecyl sulfate and zinc acetate dihydrate in absolute ethanol solution. Film deposition process by sin coating technique has been conducted by spraying Argon gas in two steps. Speed of 500 rpm has been kept for 6 seconds in first step and then speed of 1500 rpm has been used for 20 seconds in second step for final film deposition. Finally, the deposited film has been annealed at 300 ^{0}C for 1 hour for further use. As prepared thin film has been characterized by Scanning Electron Microscope which confirms nanostructure of ZnO film as shown in Figure 1.

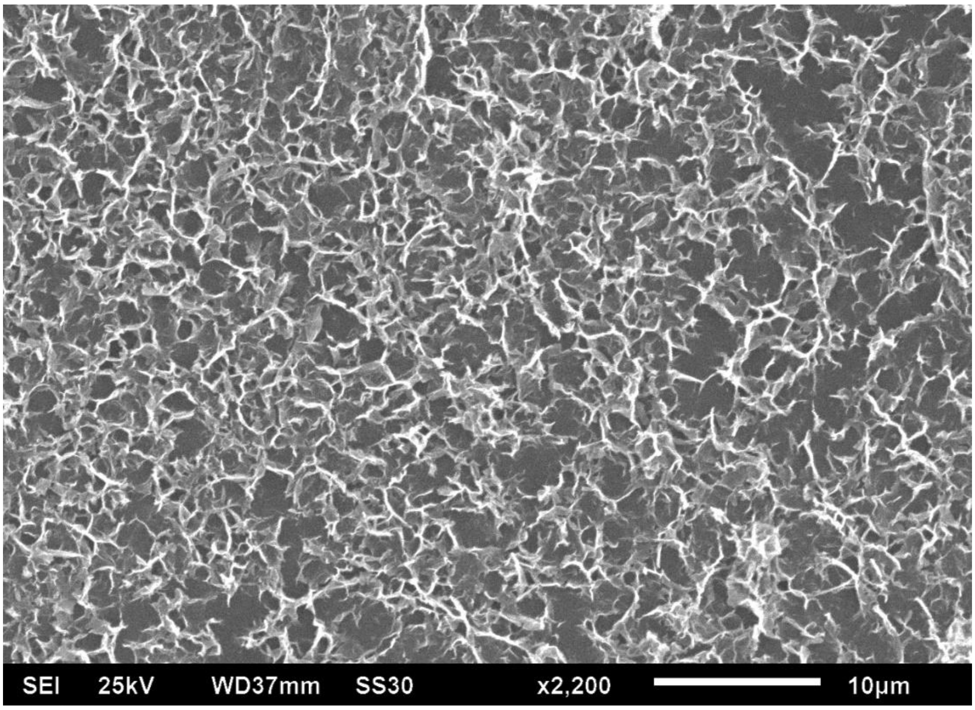

Figure 1: *Scanning Electron Microscope image of as deposited ZnO film.*

Bahishti *et al.*, *Adv. Nan. Res.;* Vol. 1, Issue 1, pp: 23-30, 2018

For photoconductivity study, electrical contact in prepared thin films has been developed using Silver paste and sample were mounted in a sample holder. Conductivity measurement has been done by standard and most common two-probe method by applying fix biasing potential of 5V at room temperature. 200W tungsten lamp has been used as illumination source. Light of different intensity has been shined on sample and corresponding illumination current was recorded using I-V measurement unit which basically contains electrometer and stable voltage source. Intensity of used light has been measure using a digital Lux-meter. For the transient photoconductivity measurement, light has been shone on sample and photocurrent of corresponding time has been recorded. When saturation was reached, the light was turned off and the decay in the current with time has been recorded.

3 Results and Discussion

Dark current (I_{dc}) and photocurrent under iIlumination (I_{ill}) has been measured and the photocurrent (I_{ph}) is calculated using relation [26]-

$$I_{ph} = I_{ill} - I_{dc} \quad 1$$

The conductivity of the film has been calculated using equation

$$\sigma = \frac{IL}{VA} \quad 2$$

where, I is the current measured in ampere, the voltage in volts, A is the cross-sectional area in cm^2 and L is the length of the sample in cm.

Dark current of the prepared ZnO thin film sample has been measured at room temperature 298 K by applying a constant biasing potential of 5 V and found 293 pA. The photocurrent of the same sample has been measured against different illumination intensity of 150 Lux, 250 Lux, 350 Lux, 450 Lux, 550 Lux and 650 Lux by keeping experimental parameters same. Measured photocurrent has been used to calculate photoconductivity at different illumination intensity using equation 2 and given in Table 1. The variation in photoconductivity with the illumination intensity has been shown in Figure 2.

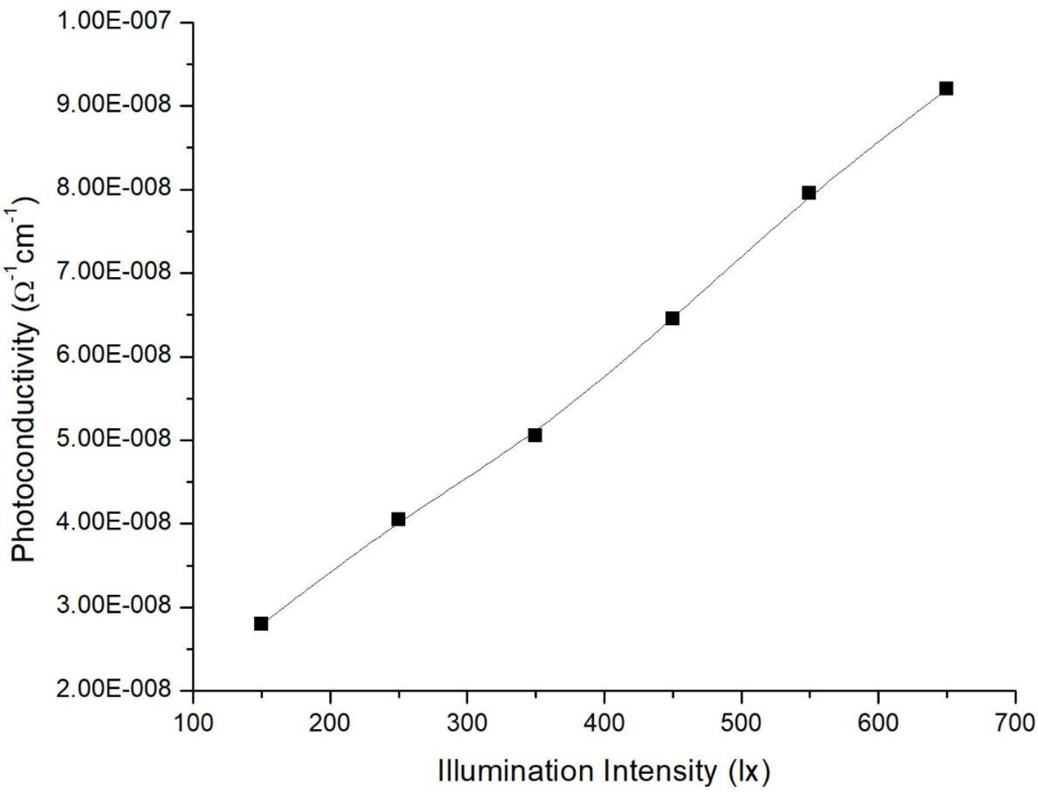

Figure 2: *Variation of photoconductivity in ZnO with illumination intensity.*

Above Figure 2 shows that photoconductivity increases linearly with increasing illumination intensity. Linear dependency of photoconductivity on light intensity indicates that photoconductivity follows a power law with light intensity [2]

$$\sigma_{ph} \propto F^{\gamma} \quad (3)$$

Where γ represents dependency factor of photoconductivity on illumination intensity. To calculate the power γ a curve of $ln\sigma_{ph}$ versus lnF has been plotted as shown in Figure 3 whose slope gives the value of γ as 0.81.

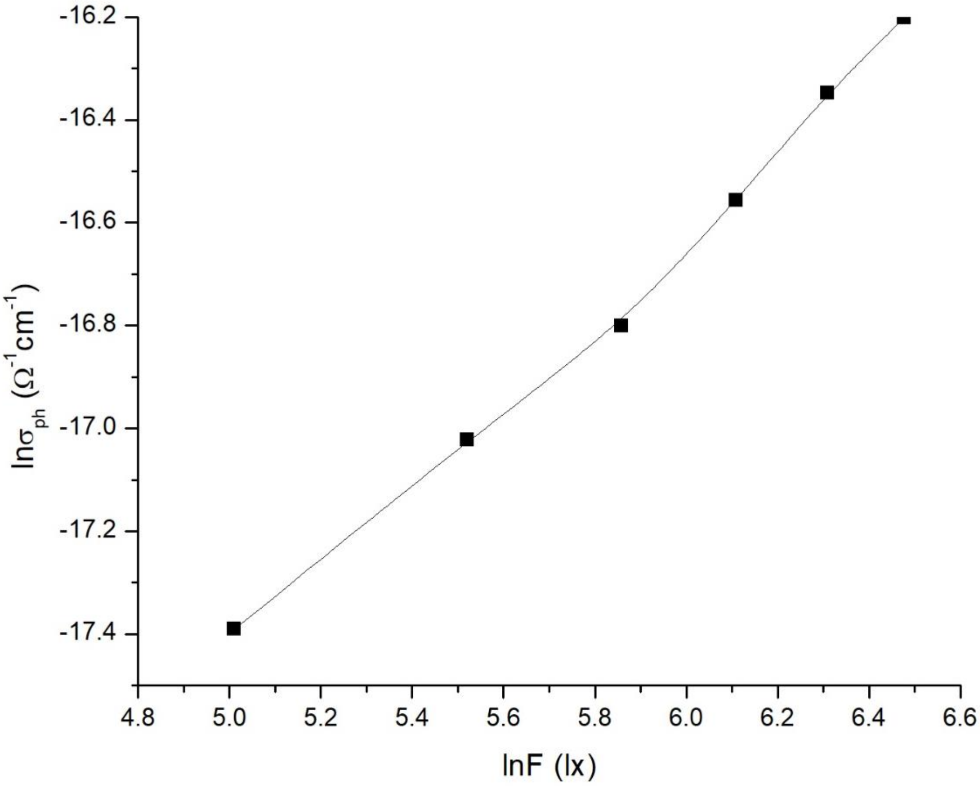

Figure 3: *Variation of* $ln\sigma_{ph}$ with lnF *in ZnO film at room temperature*

Table 1: *Various conductivity parameters at room temperature*

Illumination Intensity / Parameter	150 lx	250 lx	350 lx	450 lx	550 lx	650 lx
σ_{ph} ($\Omega^{-1}cm^{-1}$)	2.8 X 10^{-8}	4.05 X 10^{-8}	5.05 X 10^{-8}	6.45 X 10^{-8}	7.95 X 10^{-8}	9.2 X 10^{-8}
σ_{ph}/σ_{dc}	0.1	0.14	0.17	0.22	0.27	0.32
PPC	0.038	0.044	0.051	0.055	0.101	0.140

Bahishti *et al.*, *Adv. Nan. Res.;* Vol. 1, Issue 1, pp: 23-30, 2018

Photosensitivity of the material is another important parameter to decide its use in photoconductive applications. Photosensitivity is defined as ratio of photoconductivity to the dark conductivity (σ_{ph} /σ_{dc}). σ_{ph} /σ_{dc} values for different illumination intensity have been calculated at room temperature and given in Table 1. Variation of photosensitivity with illumination intensity is shown in Figure 4. It is observed that photosensitivity increases from 0.1 to 0.32 with increasing illumination intensity from 150 to 700 lx.

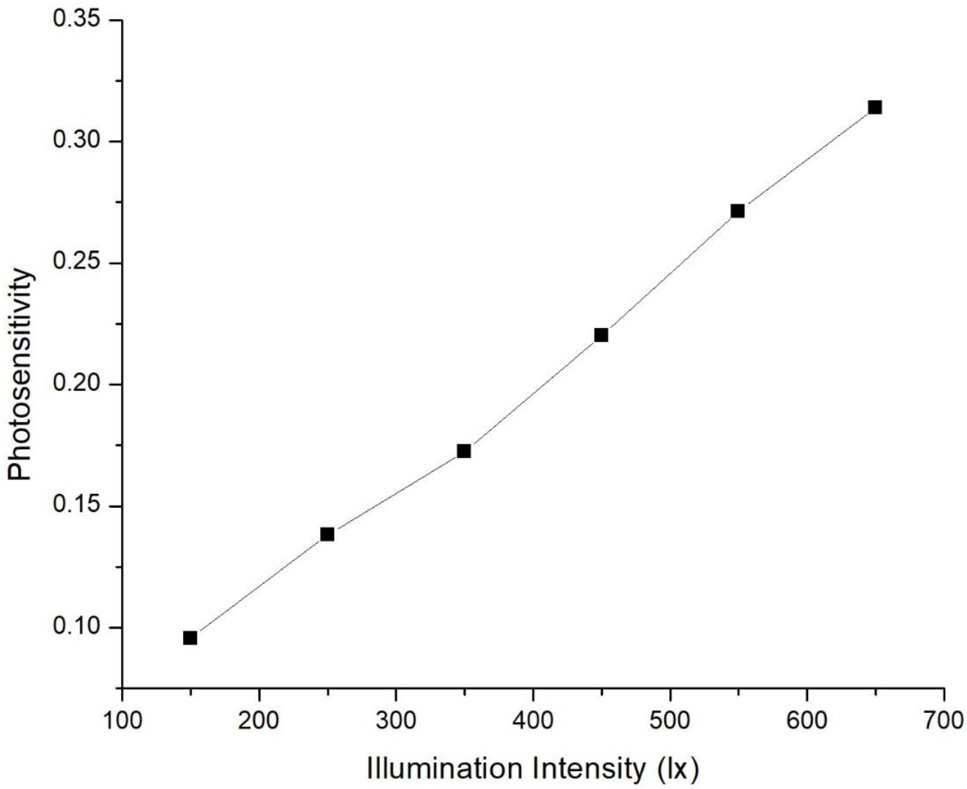

Figure 4: *Variation of photosensitivity with illumination intensities in ZnO film at room temperature*

Transient photoconductivity at various illumination intensity has been measured at temperature 298K on the sample with 5V biasing potential. After turning on light rise in current with time has been recorded. After a certain time of illumination, when steady state achieved, light has been turned off and decay of the photocurrent has been measured. The initial dark current has been subtracted to obtain transient photocurrent. The rise and decay of photocurrent with time for all illumination intensities are shown in Figure 5.

It is evident from Figure 5 that the photocurrent initially rises faster then becomes slow and saturated after 250 seconds. After get saturation current the light has been switched off and the photocurrent starts to decay quite fast initially, and then slows down. As time elapses it reaches steady state value in 600 seconds as shown in Figure 5. The decay process took a total of 350 seconds which seems to be composed of two processes, a faster decay at the onset of transient and a slower decay later on. A persistent photocurrent is observed for for all illumination intensities, which did not decay even after a long time-interval. It is believed that such a large decay cannot be due to carriers trapped in the intrinsic defects [27]. It may be due to defects produce in structure on increasing illumination intensity. To compare the persistent photocurrent effect with illumination intensity, we calculate the quantity Persistent Photoconductivity (PPC) [2], [28], [29] as-

$$PPC = (\sigma_l - \sigma_{dc}) / \sigma_{dc} \quad (4)$$

where σ_l the total photo conductivity of the light induced state after the decay of 350 seconds, and σ_{dc} is the dark conductivity of the ZnO film.

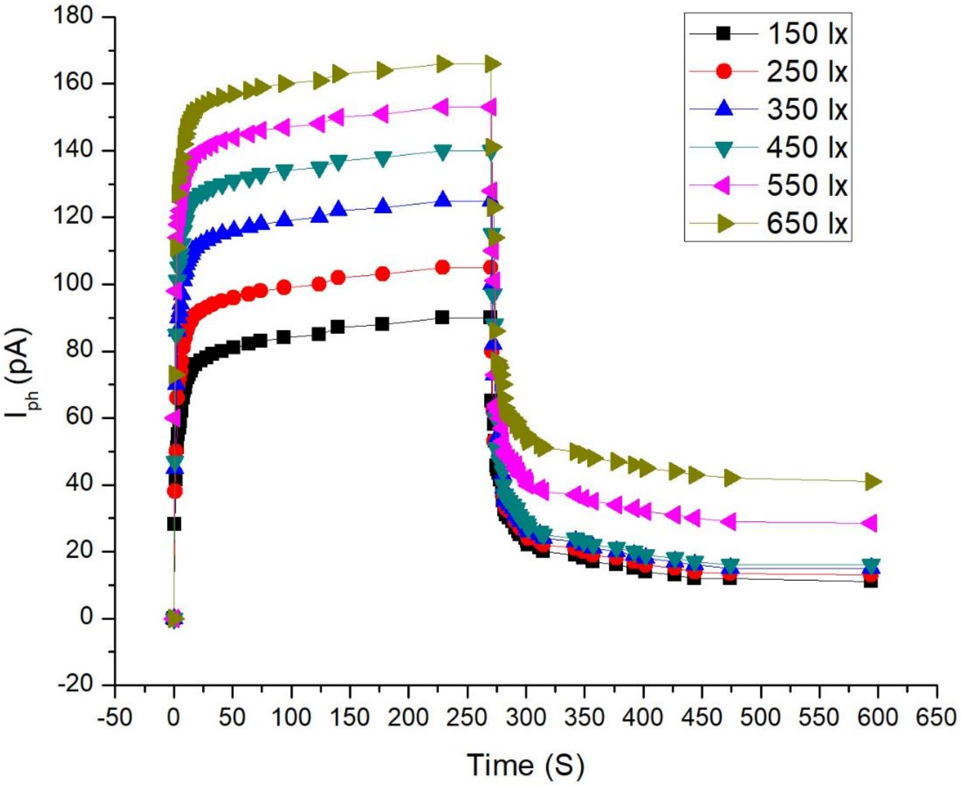

Figure 5: *Variation of photocurrent with time in Zno film for various illumination intensities*

It is found that PPC increases with increasing illumination intensity as given in Table 1. Ho-Hyun Nahm *et al* [21] gives a microscopic explanation for persistent photo-conductivity in ZnO on the basis of bistability of Substitutional hydrogen at oxygen site and suggested that the bistability of the H donor will provide a new way to consider the physics of hydrogen in oxide materials. James C. Moore *et al* [16] have reported a phenomenological model of the PPC observed in ZnO based MSM planar photodetector devices through time-resolved surface band bending. Due to migration of photogenerated holes to the surface, surface band bending decreases during light illumination. To recombine with photogenerated holes at the surface, conduction-band electrons must overcome a relatively low energy barrier immediately just after removing illumination; however, the adsorption of oxygen at the surface in the depletion region increases band bending with increasing time, which results in an increased surface energy barrier that slowed down transport of photogenerated electrons.

4 Conclusion

Illumination intensity dependent photoconductivity in ZnO nanostructured film shows a significant increment in the conductivity with the light intensity which may be utilize in designing a light intensity dependent device. Photosensitivity also found to be increasing with illumination intensity which suggest that ZnO nanostructured film can be useful in fabrication of high sensitive device application to use at higher light intensity. Further, persistent photo conductivity is found to be increases with increasing illumination intensity. A novel application of such intensity dependent ppc is suggested in memory devices, whose "1" state can be triggered by light illumination, maintain due to persistent photo conductivity effect, and returns to "0" state through application of a back-gate voltage. Further study is required for better application-based understanding of intensity dependent photoconductivity in ZnO nanostructured film by considering various optoelectronic parameters.

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