Design and analysis of UV detector using ZnO nanorods on interdigitated electrodes

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Abstract:*ZnO nanorods are widely used as UV detectors. Sensitivity of the UV detectors can be increased by growing the nanorods on an array of interdigitated electrodes. This paper reports a relationship between sensitivity of the UV sensor i.e. the ZnO nanorods and efficiency of the interdigitated electrodes over which the rods are grown.*

Keywords:UV sensor, ZnO nanorods, interdigitated electrodes

1. Introduction

UV photoconductivity is an important feature of few wide band gap semiconductors or materials. This characteristic involves a number of mechanisms, including the absorption of light, carrier photogeneration and carrier transport.[1]

In recent years, there has been increasing interest in ZnO semiconductors as UV detectors due to its large exciton binding energy of 60 meV and wide bandgap energy of 3.37 eV at room temperature [2]. ZnO at nanoscale level produces novel and attractive electrical, optical, mechanical, chemical, and physical properties due to quantum confinement effects. One-dimensional ZnO nanostructures such as nanorods or nanowires have been considered as promising material for UV sensing and detection because of its high surface to volume ratio [3].

In this work, ZnO nanorods arrays were selectively grown on the gap of interdigitated electrodes (IDE) by hydrothermal process and analysis was done to find any possible relation among efficiency of electrodes of different shapes and sizes and UV

detection capability of ZnO nanorods. The geometry of interdigitated electrode plays a major role in increasing the sensitivity of UV sensors. The efficiency of these interdigitated electrodes depends on the overall width X and height Y of the device, the electrode width E, and the serpentine gap width G. The structure is shown in Fig. 1.

2. Experimental

On a Printed Circuit Board, interdigitated electrodes were made by a normal PCB design method as shown in Fig. 2. In this work various IDEs with different metal finger width and space between the fingers were fabricated. ZnO nanorods were located at desired area between the interdigitated

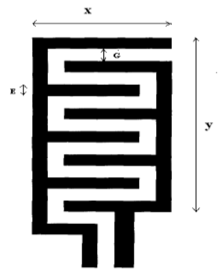

Figure 1: Structure of the inter-digitated electrode

electrodes. When the UV light was illuminating the device, photo generated carriers in ZnO nanorods drifted to the finger electrodes under bias.

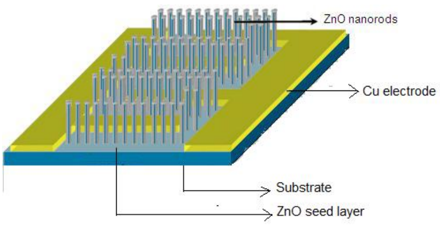

Figure 2: ZnO nanorods on interdigitated electrode

2.1 Fabrication of UV detector

The UV detector was fabricated by growing ZnO nanorods on a Cu interdigitated electrode array. The photocurrent obtained from the photodetector was converted to voltage and then amplified by a photoconductive amplifier. The complete set-up for the UV detector is shown in Fig. 3. The UV sensitive

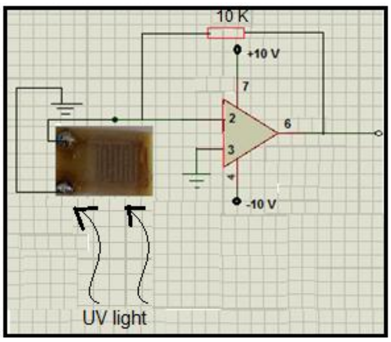

Figure 3: UV detector set-up ZnO nanorods were grown following a chemical synthesis route starting from synthesis of ZnO nanoparticles as explained below.

2.2 Synthesis of ZnO seed nanoparticles

For synthesis of the ZnO nanoparticles, 4 mM zinc acetate dihydrate [$Zn(CH_3COO)_2.2H_2O$, Merck, 99% purity] solution was prepared in 20 ml of ethanol [C_2H_5OH, Merck, 99% purity] with vigorous stirring at 50° C. The solution was then diluted with another 20 ml of fresh ethanol and cooled in the ambient air, following which 20 ml of 4 mM sodium hydroxide in ethanol was added drop-wise to the solution under continuous stirring. The mixture was then kept in a temperature controlled water bath at 60° C for 1 hour and after that cooled to room temperature [4].

2.3 Growth of ZnO nanorods on seeded substrate

The seeding of the particles was done on the substrate containing the Cu electrode by dipping it in the synthesized solution of ZnO nanoparticles for 15 minutes. Three such dipping were required and after each dipping the substrate was washed with deionized water to remove the loosely attached particles and then heated at 150° C for 15 minutes. Preheating of the substrate was done at 100° C and post annealing at 150° C [5].

The growth of ZnO nanorods on the seeded substrate were carried out by hydrothermal method. The substrate was placed inverted in a petri dish containing equimolar (20 mM) solution of zinc nitrate hexahydrate [($Zn(NO_3)_2.6H_2O$), Merck, 99% purity] and hexamine [($C_6H_{12}N_4$), Merck, 99% purity] and then kept in a hot air oven at 90°C oven for 8 hours. In between the solution mixture was changed and the substrate was washed with deionized water. After the completion of the growth of nanorods the substrate was washed thoroughly with deionized water and dried at 150 °C for an hour [6,7,8].

3. Results and Discussion

Fig. 3 (a) shows the TEM image of the as-synthesized nanoparticles and fig.3(b) shows SEM image of the ZnO nanorods grown on the Cu interdigitated electrodes.

The UV response of ZnO nanorods is influenced by the adsorption and desorption of oxygen on its surface during UV illumination. Oxygen molecules from the ambient are adsorbed onto the nanorod surface by capturing free electrons from ZnO, as shown in the following equation.

$$O_2 + e^- \rightarrow O_2^- \quad \text{----------------------->} (1)$$

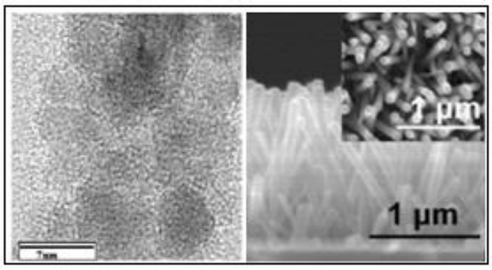

Figure 3: (a) TEM image of ZnO nanoparticles, (b) SEM image of ZnO nanorod

where O_2 is an oxygen molecule, e^- is a free electron, and O_2^- is an adsorbed oxygen on the surface of nanorods. When the UV light is incident on the surface of the nanostructure, electron-hole pairs are photogenerated according to the following equation:

$$h\vartheta \rightarrow h^+ + e^- \quad \text{---------------------->}(2)$$

where hv is the photon energy of UV light, $h^+$is a photogenerated hole in the valence band and $e^-$is a photogenerated electron in the conduction band. Nanorods due to its large surface area facilitates a fast surface reaction process as the photogenerated hole reacts with a negatively charged adsorbed oxygen, as shown by:

$$O_2^- + h^+ \rightarrow O_2 \quad \text{-------------------->} (3)$$

As a result, the electron of the pair is left in the conduction band, which increases the conductivity of the nanostructures. When the UV illumination is turned off, the oxygen molecule recombines with the electron, leading to a decrease in film conductivity.

The efficiency of the different electrode structures can be calculated by using following equation [9] .

$$\varepsilon = \frac{\frac{GY}{G+E}\left(X - 2G - E\right) + G^2 + GE}{XY} \quad \text{--------->} (4)$$

Table I shows the result of the UV detector and also the efficiency of the fabricated electrodes.

Table I: Efficiency of electrode and response to UV for different sizes of the electrode

Size of electrode (mm)				*Efficiency of electrode*	*Response to UV (volt)*
x	Y	E	G		
5	10	1	1	0.24	0.6
7	9	1	1	0.317	0.8
9	12	1	1	0.352	1.6

From table I, it is seen that there is a relationship between efficiency of the electrodes and the response of the sensor i.e. the ZnO nanorods to UV light. It is found that as the x dimension of the electrode increases, the efficiency increases and more efficient the electrode is, more is the response of the ZnO nanorods to UV light.

4. Conclusion

ZnO nanorods grown over interdigitated electrode array have been successfully applied for detecting the presence of UV light. Geometry of electrodes plays an important role in increasing the sensitivity of the UV detector. It was found that ZnO nanorods grown over efficient electrodes work as a better UV detector.

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