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Structural, dielectric and piezoelectric properties of ZnO nanoparticals and its application in liquid crystal based patch antenna

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Abstract: The uniform shape and size of ZnO nanoparticles were grown by wet-chemical method. Powder X-ray diffraction (XRD) technique was used to analyse the crystalline phases and structural properties of the grown sample. XRD study showed that the formation of wurtzite hexagonal crystal system for ZnO nanorods. Transmission electron microscopy confirms that ZnO nanorods were grown in the nano size-controlled morphology. The average diameter (~ 75 nm) of the nanorods was measured using TEM analysis. The effective piezoelectric coefficient (d_{33}) for ZnO nanorods was observed to be 1.2 pC/N. The ZnO nanorods dispersed liquid crystal (LC) patch antenna was simulated at 5 GHz. ZnO nanorods based LC based patch antenna is easily tunable with biased DC voltage.

Keywords: Nanorods, Liquid Crystal, Piezoelectricity, Dielectric, Patch Antenna.

1. Introduction

Nanotechnology proves to be a greater advantageous for various material science applications. The role of nanoscale material is to increase its efficiency by surface to volume ratio. Zinc oxide (ZnO) nanoparticles are the multifunctional materials that have been extensively used by various research groups for optical and piezoelectric applications [1-2]. ZnO exhibits n-type semiconductor behavior due to its native intrinsic defects (oxygen vacancy and zinc interstitials) and also shows the wide bandgap of 3.37 eV with higher exciton binding energy of 60 meV [3-4]. Due to wide bandgap energy, the ZnO matrix has scope for rare earth ion doping [5-6]. Among all the classes of tetrahedrally bonded semiconductors, wurtzite hexagonal ZnO exhibits the largest piezoelectric response [7].

The rectangular patch antenna is widely used for various wireless communication applications. A patch antenna is very attractive due to its simple planer design and ease of fabrication. Nanotechnology improves the application of patch antenna for sensor and energy harvesting applications by using a piezoelectric dielectric substrate. Here, in this work, ZnO nanorods were synthesized and the patch antenna was simulated with ZnO nanorods dispersed LC based rectangular patch antenna. The frequency of patch antenna was tuned by applying DC voltage, which is useful for different resonant frequencies wireless communication.

2. Experimental

ZnO nanorods were synthesized using the wet chemical method. The $ZnCl_2$ and NaOH were taken in 1:5 molar ratio. Firstly, the $ZnCl_2$ was dissolved in distilled water as a solvent. Thereafter, the $ZnCl_2$ solution was dropwise mixed into NaOH solution and a white precipitate was washed using water to remove excess sodium ions. The white precipitate was dried and kept at 150 °C for 4 hours. The structural and morphological properties of the ZnO nanorods have been studied in detail using XRD and TEM analysis. The dielectric and piezoelectric properties of ZnO nanorods were investigated. ZnO nanorods were dispersed in 0.2 Mol % of 4-Cyano-4' –pentylbiphenyl (5CB) LC for dielectric material for patch antenna.

3. Result & Discussion

3.1. X-Ray Diffraction

The structural phase and line broadening of the ZnO has been investigated by X-ray diffraction technique. Fig. 1 displays the diffraction patterns of the pure ZnO nanoparticles. The wurtzite phase of grown ZnO nanorods is confirmed and no additional peaks were observed [8].

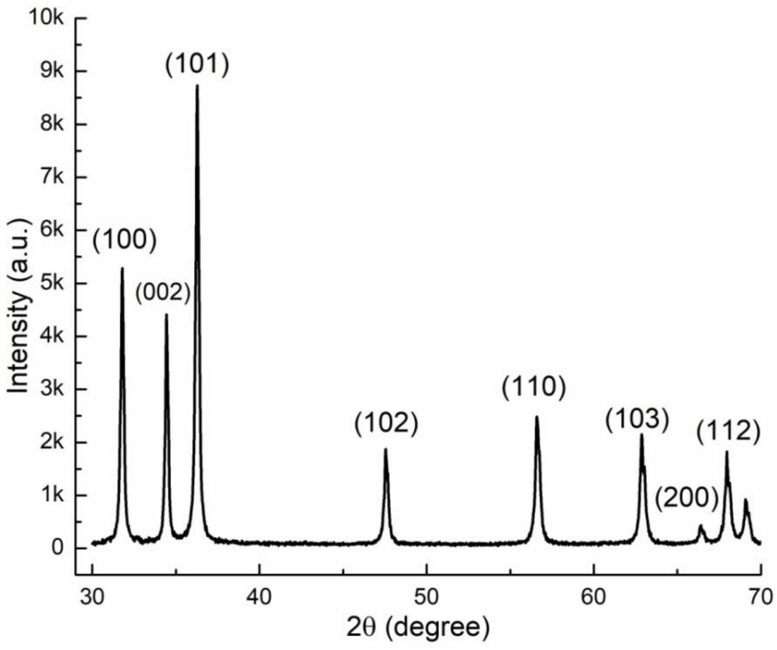

Fig. 1 Powder XRD spectrum of ZnO nanorods.

The refinement of the cell parameters of the ZnO crystal structure was performed using check cell XRD software. Table 1 shows the refined cell parameters of ZnO nanorods.

Table 1.
Refined powder XRD data of ZnO nanorods.

Crystal System	Hexagonal
a (Å)	3.249
b (Å)	3.249
c (Å)	5.204
$\alpha = \beta$ (°)	90
γ (°)	120

3.2. Morphology study

The TEM analysis confirmed that the ZnO nanoparticles were grown in rod-shaped particles with an average length and diameter of 410 nm and 75 nm, respectively. Fig. 2 shows that high quality single crystalline wurtzite structure of ZnO nanorods was developed.

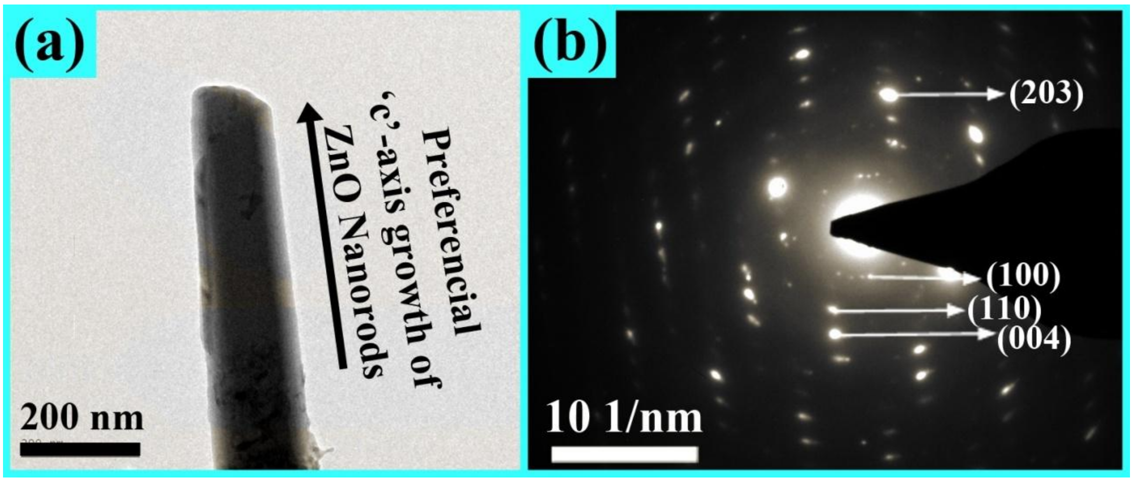

Fig. 2 TEM image of ZnO nanorods

In addition, the SAED image of ZnO nanorods confirmed that the miller indices of diffraction rings match with the wurtzite crystalline structure [9]. The external morphology of grown ZnO nanoparticles belongs to nanorods which are also confirmed by SEM image (Fig. 3).

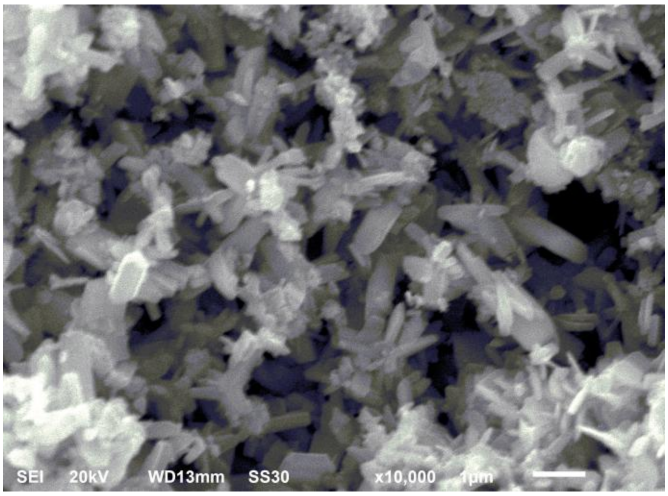

Fig. 3 SEM image of ZnO nanorods

3.3. Piezoelectric properties

Piezoelectric materials can convert the mechanical response to the electric signal and vice-versa. ZnO has largest piezoelectric response among the tetrahedrally bonded semiconductors. ZnO nanoparticles belong to the potential candidate for energy harvesting and sensor applications [10]. The experimental charge coefficient (d_{33}) value of ZnO nanorods was found to be 1.2 pC/N. Therefore, ZnO nanoparticles are widely used for various pressure sensors, position detectors and actuator applications [11-12].

3.4. Dielectric analysis

The dielectric constant of ZnO nanorods dispersed LC decreases with increasing frequency at room temperature. The value of dielectric constant starts to decrease with increasing frequency due to the low contribution of various polarization parameters (ionic, electronic, orientational and space charge [13-14]. Fig. 4 presents the variation of dielectric constant with frequency for ZnO nanorods dispersed LC at DC biasing of 0 V and 10 V. Due to biasing of DC voltage the value of dielectric is increased in ZnO nanorods dispersed LC material [15]. This shift in dielectric constant is used for the tunning in patch antenna application for wireless communication.

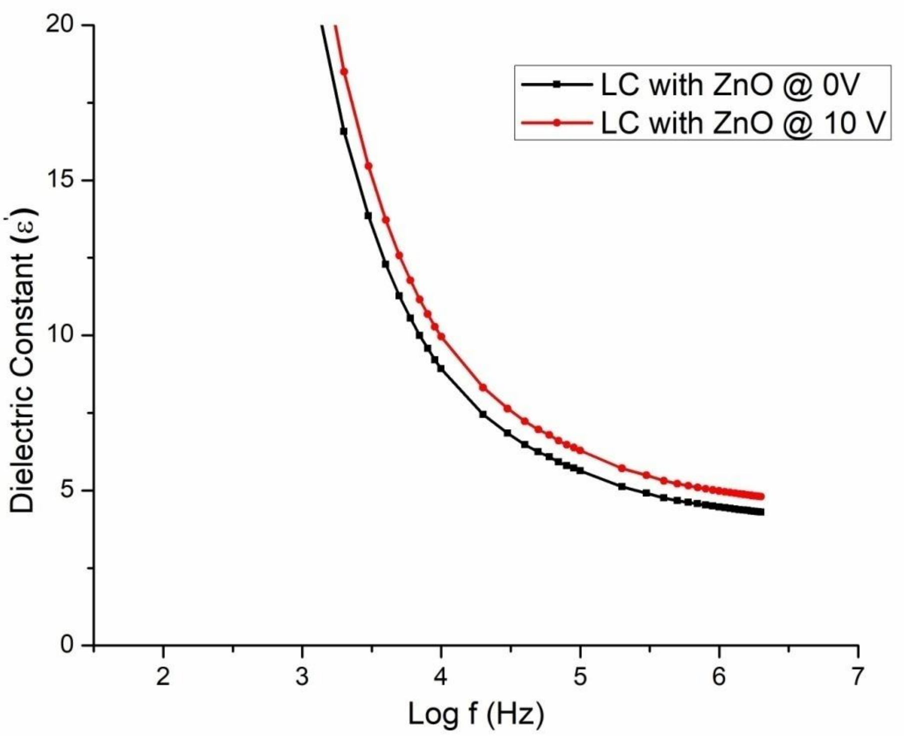

Fig. 4 Dielectric constant of ZnO nanorods dispersed LC with frequency at DC biasing of 0 V and 10 V.

3.5. Patch Antenna Design

LC based patch antenna is very applicative for tunning in the resonant frequency and low-cost fabrication. Patch antennas are attractive due to its simplest planer design, compact size with and low design cost [16]. The low value of dielectric constant of LC is useful for patch antenna with better efficiency [17]. The transmission line model is used to analyze the operating frequency mechanism for patch antenna. The patch antenna was simulated at resonant frequency f_r = 5 GHz and dielectric constant (ε_r) of ZnO dispersed LC at 4. The geometrical width of the patch antenna was evaluated as,

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

and effective dielectric constant was computed as,

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\frac{1}{\sqrt{1 + \frac{12h}{W}}}$$

The geometrical length of the patch antenna is given as,

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}}$$

The length and width of the patch antenna were computed to be 13.97 mm and 18.43 mm, respectively. The tunability of the dielectric constant in the LC is controlled by DC voltage. Table 2 shows the value of dielectric constant of ZnO dispersed LC with DC biasing voltage.

Table 2. The dielectric constant of ZnO dispersed LC at DC biasing voltage

Sample	0 V	10 V
ZnO dispersed LC	4.3	4.8

Simulation of the patch antenna geometry was performed by CST Microwave Studio at 5.0 GHz resonating frequency. The microstrip line (50 Ω) was taken for inset feed. Impedance matching of the LC patch was performed by two slots in the patch antenna. Copperplate as a conducting material for the patch as well as ground plane and standard SMA connector was used for the fabrication for patch antenna [18]. The simulated result of S_{11} parameter for ZnO nanorods dispersed LC patch antenna at DC biasing of 0 V and 10 V are shown in Fig. 5(a-b) The frequency shift was from 5.0 GHz to 4.7 GHZ was observed by applying DC voltage to the dielectric substrate. The shift of 700 MHz was used for tunning applications for patch antenna.

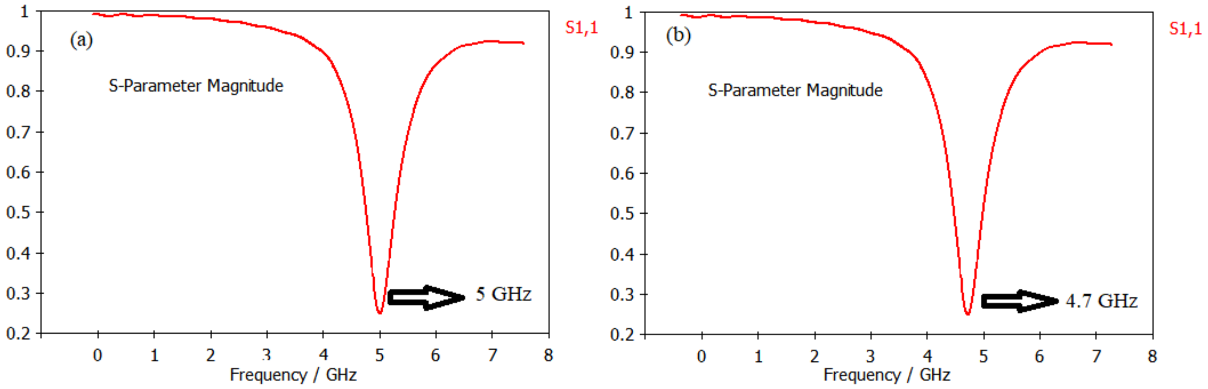

Fig. 5 Simulated S_{11} parameter of ZnO nanorods based LC patch antenna at DC biasing of 0 V and 10 V

Conclusion

ZnO nanorods were synthesized using a low-cost wet chemical route. The powder XRD spectrum confirms the formation of the hexagonal wurtzite crystal system. The average value of crystallite size was found to be 75 nm using TEM analysis. A low dielectric constant of ZnO nanorods dispersed LC is useful for patch antenna design. The piezoelectric coefficient d_{33} was found to be 1.2 pC/N. ZnO nanorods dispersed LC based patch antenna was successfully simulated at 5 GHz resonant frequency. The tuning of rectangular patch antenna was activated by applying DC voltage and a shift of 700 MHz was observed for various wireless communication applications.

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