Investigation of Dielectric Properties of Nanocomposite Junction using Broadband Dielectric Spectroscopy

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ABSTRACT

Metal oxide nanocomposite have gained great attention of research community. The synthesis of nanocomposite junction of CuO and ZnO were done using mechanical milling method. The synthesized nanocomposite were characterized with XRD and UV-Visible spectroscopy. The dielectric properties of synthesized nanocomposite were investigated using Broadband Dielectric Spectroscopy in the frequency range of 10MHz to 100MHz at different temperature. The loss tangent and AC conductivity is also investigated. The result obtained in this study are well in agreement with the earlier study.

KEYWORDS: Metal oxide nanocomposite, XRD, UV-Visible spectroscopy, Broadband Dielectric Spectroscopy.

1. INTRODUCTION

In nanotechnology, nanomaterials and nanocomposites are the foundation stone. This branch of research has potential to revolutionalize the ways in the field of creating materials and products. The properties of nanomaterial are determined by the specific length scale (less than mean free path of the electron), which is usually in nanometer scale. When the length is below 100nm, the material is said to be nanomaterial. Mechanical milling was formerly invented to form small-particle (oxide, carbide, etc.) dispersion-strengthened metallic alloys [1]. In this method high-energy ball milling process is used to develop the nanocomposites. The nanocomposite occurs as a result of recurrent breaking up and linking of the particles [2, 3]. Metal oxides found numerous applications in the field of bioscience, environmental science, and chemical science [4-6] and electronics industries for device fabrications. The CuO and ZnO have excellent morphologies as nanowires, nanorods, nanotubes, nanoflowers, nanoleaves etc which make them useful in optoelecronics devices and sensing applications. In this work, we have used CuO and ZnO analytical grade powder for synthesizing CuO/ZnO nanocomposite PN- junction. CuO is a semiconducting material with a narrow band gap of 1.2–1.9 eV [7-10]. It acts like p-type semiconductor. ZnO is a wide band gap n-type semiconductor material with 3.3 eV energy band gap [11-14]. The combination of CuO/ ZnO semiconductor nano materials forms p-n heterojunction means that, electron donor-acceptor pairs observed in between n-type metal oxide and p-type metal oxide.The CuO/ZnO nanocomposite junction were synthesized [15-17]. The synthesized nanocomposite were characterized by XRD and UV-Visible spectroscopy for confirmation of synthesis of nanocomposite and dielectric characterization is done using Broadband Dielectric Spectroscopy (BDS).

2. EXPERIMENTAL

When the dielectric material is applied with high frequency electric field, dipolar polarization does not reach the equilibrium value fast enough the follow polarizing field. Due to this, as the frequency of applied field is increased, the dipoles per unit volume decreases. Therefore, the permittivity of the material decreases.

The Dielectric spectroscopy (DS) method has occupied a distinct place among the many modern methods used for physical and chemical analysis of materials. It empowers exploration of relaxation processes in an enormously wide range of characteristic time 10^5–10^{13} s. Even though this method does not possess the selectivity of NMR or ESR, it gives important and sometimes exclusive information about the dynamic and structural properties of materials. DS is particularly sensitive to intermolecular interactions, and it is consequently useful processes to be examined. It offers a link between the properties of the bulk and individual constituents of a complex material.

2.1 Materials:

CuO and ZnO research grade powder form material is used.

Zinc oxide (ZnO)

Zinc Oxide is an inorganic compound with the formula ZnO. It is white coloured powder insoluble in water. It acts like n type of semiconductor.

Copper oxide (CuO)

Copper oxide nanoparticles appear as a brownish-black powder. They can be reduced to metallic copper when exposed to hydrogen or carbon monoxide under high temperature. It behaves like p type semiconductor.

2.2 Methods: Mechanical milling

The synthesis of nanoscale composite junction of CuO/ZnO was done by mechanical milling method [18]. It is one of the simplest ways of making nanoparticles of some metals and alloys in the powder form [3-12]. The powder form material of CuO and ZnO was taken in the weight ratio separately mentioned above and milled for 5 hour continuously for each weight ratio.As we know ZuO acts like n-type semiconductor [13-15] and CuO acts like p-type semiconductor [16], the combination of ZnO/CuO semiconductor nano materials forms the nanocomposite. It means that, electron donor-acceptor pairs observed in between n-type metal oxide and p-type metal oxide [17]. The obtained CuO/ZnO nanoscale composite pn-junction materials were characterized by XRD, UV-Visible spectroscopy. The formation of CuO/ZnO nanoscale composite pn-junction was confirmed from this characterization.

2.3 XRD Characterization

Solid matters made up of either amorphous or crystalline material. Atoms are randomly arranged in amorphous material while in crystalline material atoms are arranged regularly or in ordered pattern. The XRD is used to measure the various structural properties of crystalline phases such as crystal size, phase composition etc. [18]. The average size of the crysttalite is given by the Scherrer formula,

$$D = K\lambda / \beta \cos\theta$$

Where, D= average particle size

K= Scherer constant and its value is 0.9

λ = wavelength of the radiation

β = Full Width Half Maximum (FWHM)

θ = Bragg's angle (integral breadth of the peak located at angle θ).

The size obtained from the Scherrer formula gives the average particle size of the nanoscale composite pn-junction. In this work XRD is used to find the crystal size of the CuO/ZnO nanoscale composite pn-junction.

XRD of CuO/ZnO Nanoscale Composite:

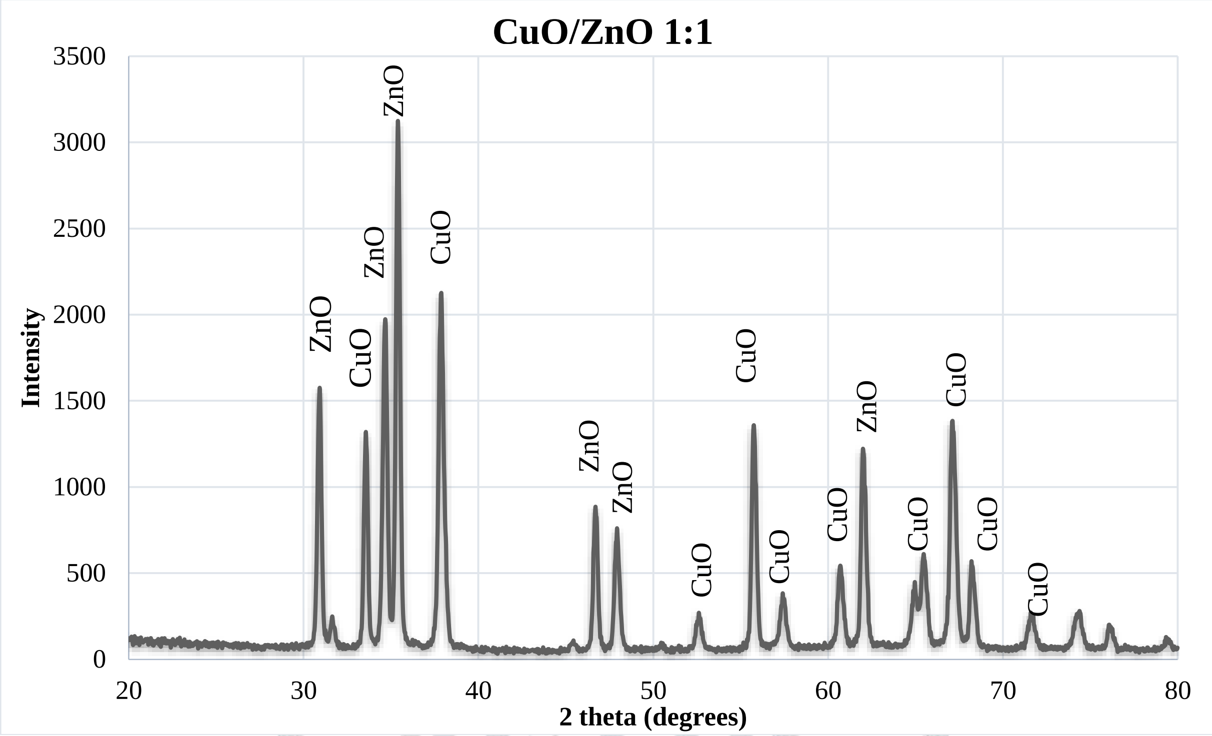

Fig. 1: XRD of CuO /ZnO Nanocomposite

Result of XRD:

CuO/ZnO	FWHM	% crystalinity	% amorphous	Crystal Size A^0	Crystal Size nm
1:1	2.214	88.3	11.7	41.8	4.18

2.4 UV-Visible Spectroscopy:

The UV-Visible spectra is used to find the bandgap energy of the material under test. The UV-Visible spectra of CuO/ZnO nanoscale composites is shown in figure. The absorbance peak occurs at 357nm. The magnitude of band gap energy is estimated by extrapolating absorption peak (linear portion) to zero absorption. The band gap energy is calculated by

$$Eg = \frac{hc}{\lambda}$$

Where, Eg= Band hap energy,

h = Plank's constant 6.626×10^{-34}Jsec.

c = velocity of light 3×10^{8} m/s.

λ = wavelength of absorption peak

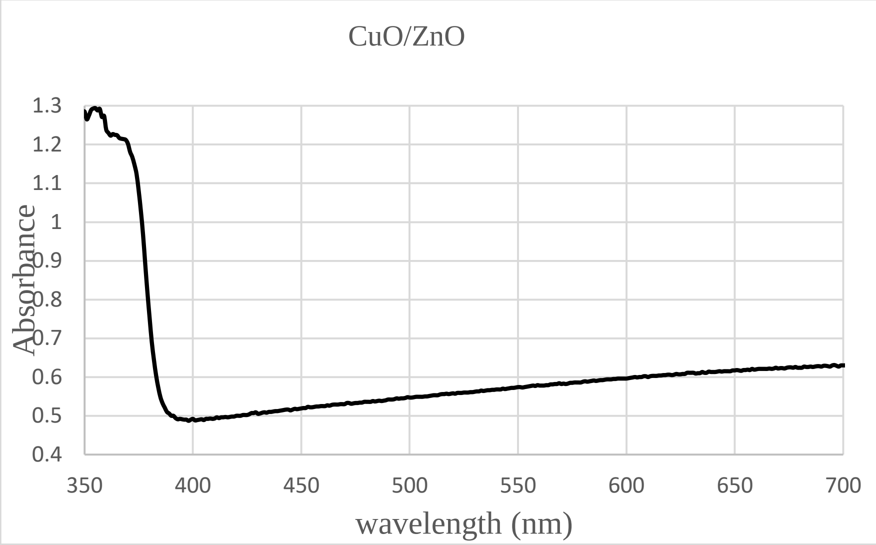

Fig. 2: UV-Visible spectra CuO/ZnO

The Peak wavelength from the plot is357nm. The band gap energy calculated from above formula found to be E_g =3.478eV.

2.5 Frequency dependent dielectric parameters of CuO/ZnO in in 100MHz to 1GHz at 100^0C Temperature

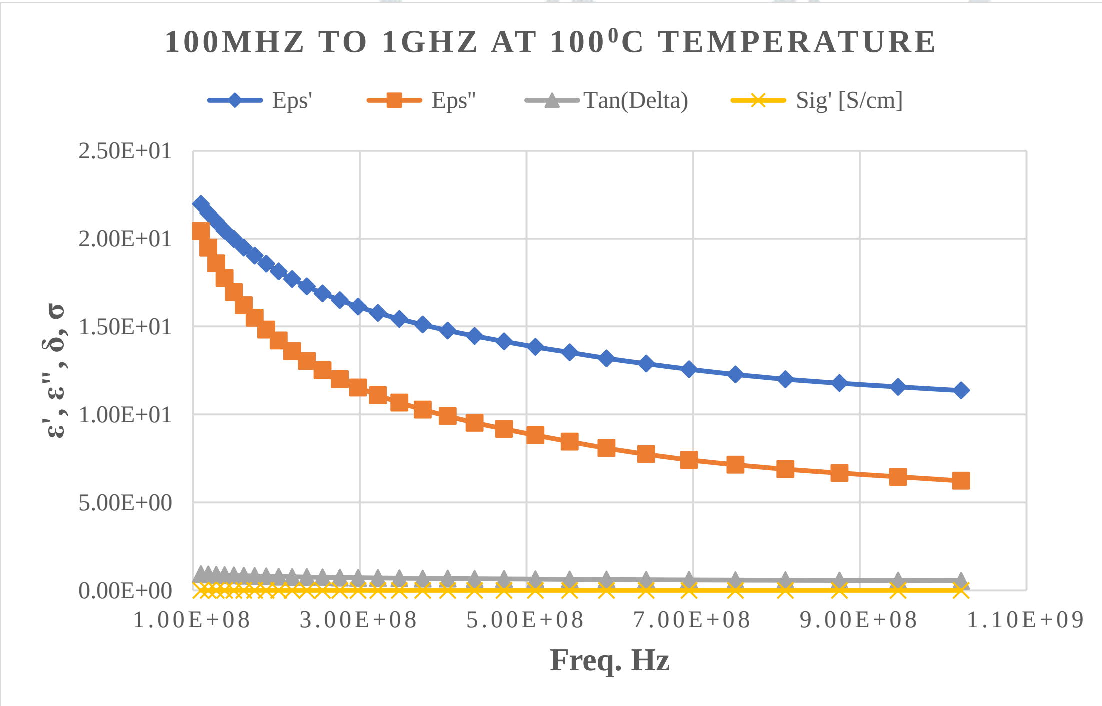

Fig.3: Dielectric constant ε', ε", loss tangent δ and AC conductivity σ as a function of freq. in range 100MHz to 1GHz at 100^0c temp.

The variation of dielectric constant real ε', imaginary ε", was studied as a function of frequency for CuO/ZnO nanocomposite at temperature 100^0C as shown in figure 3.

2.6 Frequency dependent dielectric parameters of CuO/ZnO in 1GHz to 3GHz at 100^0C Temperature

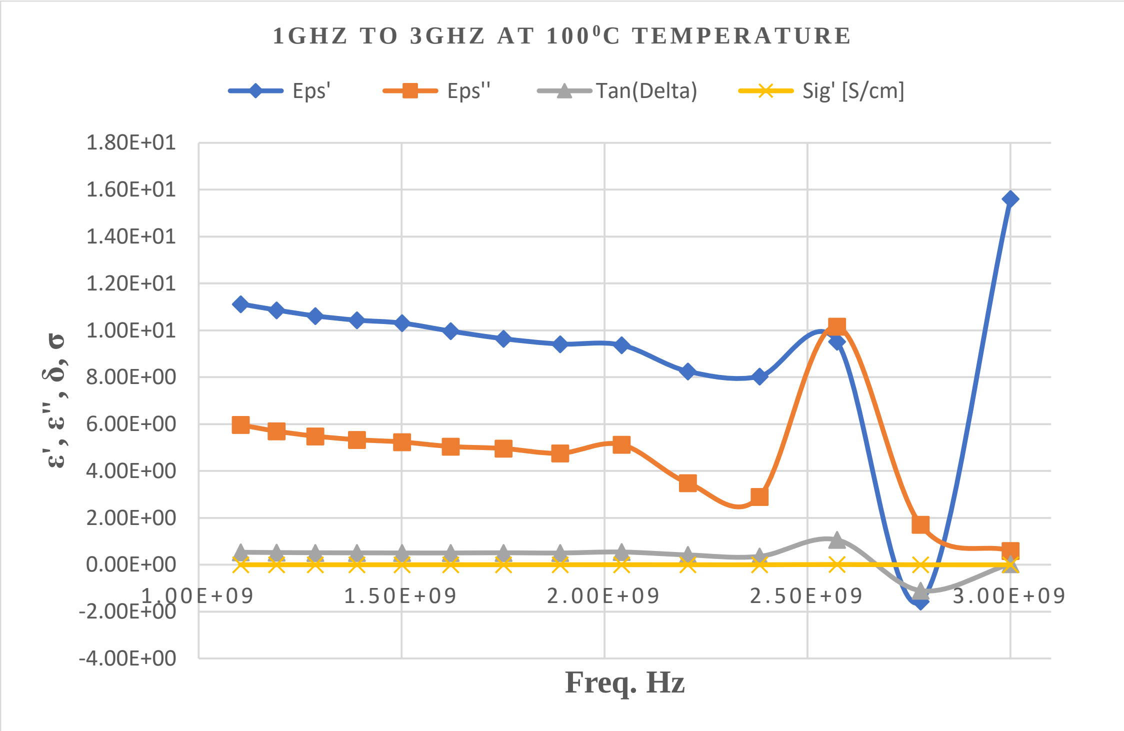

Fig.4: Dielectric constant ε', ε", loss tangent δ and AC conductivity σ as a function of freq. in range 1GHz to 3GHz at 100^0c temp.

The variation of dielectric constant real ε', imaginary ε", was studied as a function of frequency for CuO/ZnO nanocomposite at temperature 100^0C as shown in figure 4.

3. RESULTS AND DISCUSSION

The variation of dielectric constant real ε', imaginary ε", was studied as a function of frequency for CuO/ZnO nanocomposite at temperature 100^0C as shown in figure 3 and 4 at 100MHZ to 1GHz and 1GHz to 3GHz frequency respectively. It can be observed that dielectric constant has high values in the low frequency region. It may be due to existence of different types of polarization [28, 29]. The application of the electric field creates the dipole moment and rotate the atoms in the direction of applied electric field. It can be seen that ε' shows the decreasing tendency with increasing frequency. It is due to increased lagging behind of dipole polarization response with respect to change in electric field at higher frequencies [30].

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