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Synthesis, Structural, and Dielectric Characterization of Cadmium Oxide Nanoparticles

Suresh Sagadevan, A. Veeralakshmi

Abstract**—**Cadmium oxide (CdO) nanoparticles have been prepared by chemical coprecipitation method. The synthesized nanoparticles were characterized by X-ray diffraction analysis (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM), UV analysis, and dielectric studies. The crystalline nature and particle size of the CdO nanoparticles were characterized by Powder X-ray diffraction analysis (XRD). The morphology of prepared CdO nanoparticles was studied by scanning electron microscopy. The particle size was studied using the transmission electron microscopy (TEM).The optical properties were obtained from UV-Vis absorption spectrum. The dielectric properties of CdO nanoparticles were studied in the frequency range of 50 Hz–5 MHz at different temperatures. The frequency dependence of the dielectric constant and dielectric loss is found to decrease with an increase in the frequency at different temperatures. The ac conductivity of CdO nanoparticle has been studied.

Keywords**—**Cadmium Oxide (CdO), XRD, SEM, Dielectric constant and Dielectric loss.

I. Introduction

CADMIUM oxide is attracting remarkable consideration due to its interesting properties like direct band gap of 2.3 eV. CdO is n-type semiconductor used as a transparent conductive material. Cadmium oxide was used in applications such as photodiodes, photovoltaic cells, solar cells, transparent electrodes, liquid crystal displays, IR detectors, gas sensors and antireflection coat [1]-[6]. These applications are based on its specific optical and electrical properties [7]. Improvement of dielectric materials for applications in communication systems such as substrates, cellular phone, etc. has been rapidly progressing in the past few years [8]. Changes in dielectric properties have been associated to changes in particle size, shape, and boundaries [9], [10]. The tailored dielectric properties were used as capacitors, electronic memories, and optical filters [11]-[13]. The high dielectric permittivity and the low loss factors over a wide frequency range are always of a great interest [14]. Dielectric performance can effectively be used to analyze the electrical properties of grain boundaries, since majority of atoms of nanomaterials reside at grain boundaries. The dielectric properties of materials are mainly due to contributions from electronic, ionic, dipolar and space charge polarizations.

Suresh Sagadevan is the Assistant Professor , Department of Physics, AMET University, Kanathur, Chennai-603112, India (Corresponding author, phone: -044-27472905, fax: 91-44-27472804 e-mail: sureshsagadevan@gmail.com)

A. Veeralakshmi is with the in Electronics & Communication Engineering Department, Sree Sastha Institute of Engineering and Technology, Chembarambakkam, Chennai, India (e-mail: veerajyo.lakshmi@gmail.com)

Dipolar or orientation polarization arises from molecules having a permanent electric dipole moment that can change its orientation when an electric field is applied. Space charge polarization arises from molecules having a permanent electric dipole moment that can change its orientation when an electric field is applied. This article deals with the preparation of CdO nanoparticles using the chemical coprecipitation method. The prepared nanoparticles were characterized by powder X-ray diffraction analysis, scanning electron microscopy (SEM), UV-analysis and dielectric studies.

II. Materials and Methods

In this method, aqueous solution of cadmium chloride is prepared in distilled water. As cadmium chloride is soluble in water, it will dissolve completely in distilled water within 30 minutes and yield transparent solution. The ammonium hydroxide was slowly added to this transparent solution. After 3 hour of constant stirring, a whitish cloudy solution is obtained. The precipitate was washed with water and ethanol for several times and dried in oven for 3hrs at 150^{o}C. The prepared nanoparticles were characterized by powder X-ray diffraction analysis, SEM, TEM, UV-analysis, and dielectric studies. The XRD pattern of the CdO nanoparticles was recorded by using a powder X-ray diffractometer (Schimadzu model: XRD 6000 using CuKα with a diffraction angle between 20 and 80°. The crystallite size was determined from the broadenings of corresponding X-ray spectral peaks by using Scherrer's formula. Scanning Electron Microscopy (SEM) studies were carried out on JEOL, JSM- 67001. TEM images were taken using a TEM CM200 with an accelerating voltage of 200 kV. The optical absorption spectrum of the CdO nanoparticles has been taken by using the VARIAN CARY MODEL 5000 spectrophotometer in the wavelength range of 300 – 800 nm. The dielectric properties of the CdO nanoparticles were analyzed using a HIOKI 3532-50 LCR HITESTER over the frequency range 50Hz-5MHz.

III. Results and Discussion

A. Structural Studies

In order to find out the size and to study the structural properties of the synthesized CdO nanoparticles, the powder XRD analysis was performed. Structural identification of CdO nanoparticles were carried out with X-ray diffraction in the range of angle 2θ between 20º and 80º. Fig. 1 shows the XRD patterns for CdO nanoparticles, which were nanocrystalline in nature. The XRD pattern exhibits the prominent broad peaks (1 1 1), (2 00), and (2 2 0) which are attributed to the formation of CdO. The crystallite size was estimated from the broadening of CdO (111) diffraction peak using Scherrer formula,

$$D = \frac{0.9\lambda}{\beta \cos\theta} \quad (1)$$

where λ is the X-ray wavelength, θ is the Bragg diffraction angle, and β is the FWHM of the XRD peak appearing at the diffraction angle θ. The average crystalline size of CdO nanoparticles is calculated from X-ray line broadening using Scherrer equation to be about 28 nm.

B. Scanning Electron Microscopy (SEM) Analysis

Scanning electron microscopy (SEM) is giving morphological examination with direct visualization. The techniques based on electron microscopy offer several advantages in morphological and sizing analysis; however, they provide limited information about the size distribution and true population average. For SEM characterization, nanoparticles solution should be first converted into a dry powder, which is then mounted on a sample holder followed by coating with a conductive metal, such as gold, using a sputter coater. The sample is then scanned with a focused fine beam of electrons. The surface characteristics of the sample are obtained from the secondary electrons emitted from the sample surface. The morphology of the CdO nanocrystallites is shown in Fig. 2. From the image, it is clear that the particles were highly agglomerated in nature. Due to aggregating or overlapping of smaller particles there are some larger particles. The SEM pictures clearly show randomly distributed CdO grains with smaller size. From the SEM analyses, one can conclude the formation of nanoparticles spherical structure. It is very high-density and possessing almost uniform spherical shapes. The image reveals that the average crystal size is 26 nm.

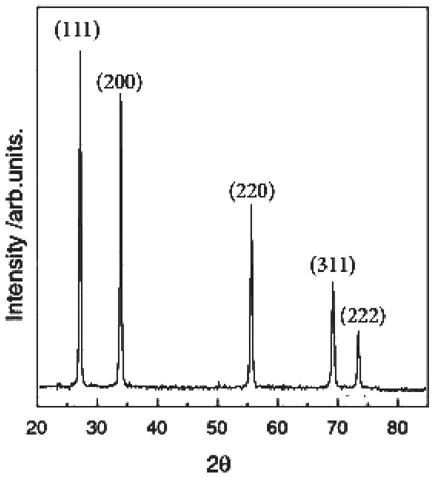

Fig. 1 XRD pattern of CdO Nanoparticles

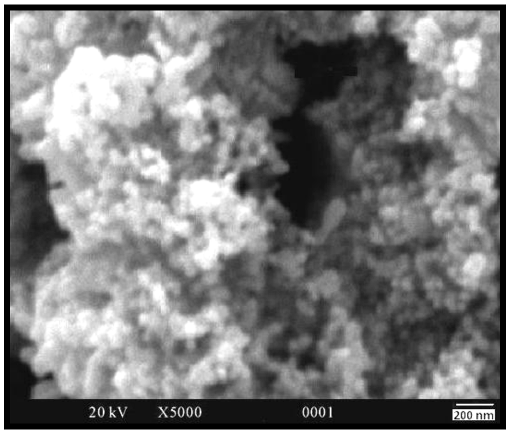

Fig. 2 SEM image of CdO nanoparticles

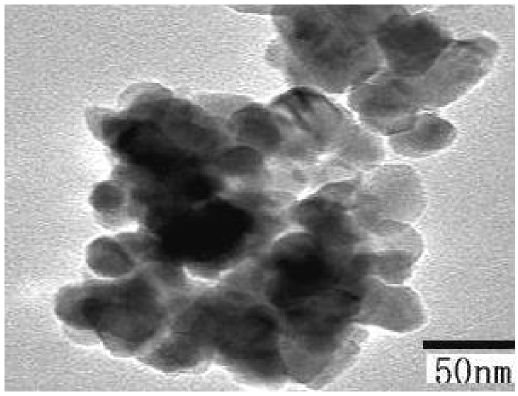

Fig. 3 TEM image of CdO nanoparticles

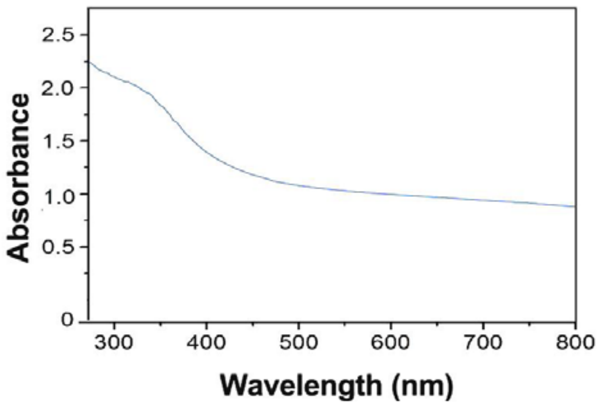

Fig. 4 Optical absorption spectrum of CdO nanoparticles

C. Transmission Electron Microscopy (TEM)

TEM operates on different principle than SEM, yet it often brings same type of data. The sample preparation for TEM is complex and time consuming because of its requirement to be ultra thin for the electron transmittance. The nanoparticles dispersion is deposited onto support grids or films. The surface characteristics of the sample are obtained when a beam of electrons is transmitted through an ultra thin sample, interacting with the sample as it passes through. The transmission electron microscopy (TEM) can yield information such as particle size, size distribution and morphology of the nanoparticles. In particle size measurement, microscopy is the only method in which the individual particles are directly observed and measured. TEM image of the synthesized CdO nanoparticles is shown in Fig. 3. It is clearly observed that the as-prepared CdO nanoparticles are spherical with some aggregated particles, with an average particle size of range ~30-50 nm.

D. UV-Visible Absorption Spectrum

In UV-visible absorption spectrum, the outer electrons of atoms or molecules are absorbed by the radiant energy and undergo transitions to higher energy levels. In this phenomenon, the spectrum obtained due to optical absorption can be analyzed to acquire the energy band gap of the metal oxides. For UV-visible absorption spectrum of CdO nanoparticles is measured as a function of wavelength, which is shown in Fig. 4. The spectrum gives information about the structure of the molecule because the absorption of UV and visible light involves promotion of the electron in the σ and π orbital from the ground state to higher states. The optical absorption coefficient has been calculated in the wavelength range of 300 - 800 nm. The absorption edge has been obtained at a shorter wavelength. The broadening of the absorption spectrum could be due to the quantum confinement of the nanoparticles. The CdO nanoparticles have good crystalline and show strong blue emission, promising for applications in optical devices.

E. Dielectric Constant

The dielectric constant and the dielectric loss of the 10 mm in diameter pellet have been used for the determination of dielectric properties of CdO nanoparticles. The corresponding thickness of the pellet was 1.20 mm was studied at different temperature using a HIOKI 3532-50 LCR HITESTER in the frequency range of 50 Hz to 5 MHz. The variations of dielectric constant with frequency and temperature for CdO nanoparticles are shown in Fig. 5. The dielectric constant of CdO nanoparticles are high at low frequencies that decrease rapidly with the applied frequency at all temperatures. It is seen that the dielectric constant of the CdO nanoparticles is much lower and also there is no much variation with temperature at high frequencies. However, at low frequencies the variation is high. The high values of the dielectric constant in the present study may be attributed to the increased ion jump orientation effect and the increased space charge effect exhibited by nanoparticles. Most of the atoms in the nanocrystalline materials reside in grain boundaries, which become electrically active as a result of charge trapping. The dipole moment can easily follow the changes in electric field, especially at low frequencies. Hence, the contributions to dielectric constant increase through space charge polarization and rotation polarization, which occur mainly in interfaces. Therefore, dielectric constant of nanostructured materials should be larger than that of conventional materials. One of the reasons for the large dielectric constant of nanocrystalline materials at sufficiently high temperature is the increased space charge polarization due to the structure of their grain boundary interfaces. In addition, at sufficiently high temperature the dielectric loss is dominated by the reason for the sharp increase of the dielectric constant at low frequencies and at lower temperatures [15]. As temperature increases, the space charge and ion jump polarization decreases, resulting a decrease in dielectric constant.

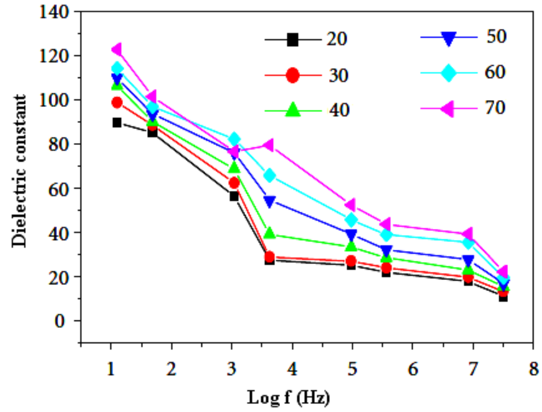

Fig. 5 Variation of dielectric constant with log frequency at different temperature

F. Dielectric Loss

The variations of dielectric loss of CdO nanoparticles of with frequency and temperature are shown in Fig. 6. It can be seen that dielectric loss decreases with increase of frequency and at higher frequencies the loss angle has almost the same value at all temperatures. In dielectric materials, generally dielectric losses take place due to absorption current. The orientation of molecules along the direction of the applied electric field in polar dielectrics requires a part of electric energy to overcome the forces of internal friction. One more part of electric energy is utilized for rotations of dipolar molecules and other kinds of molecular transfer from one position to another, which also involve energy losses. In nanophase materials, inhomogeneities similar to defects and space charge formation in the inter phase layers create an absorption current ensuing in a dielectric loss [16].

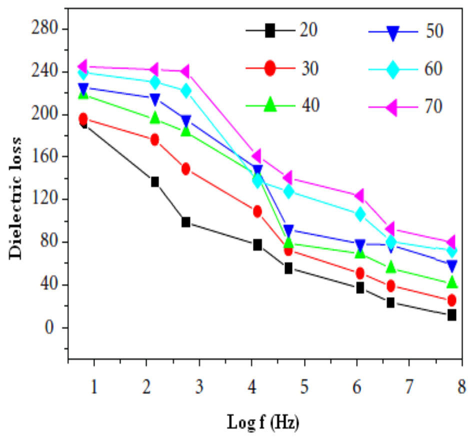

Fig. 6 Variation of dielectric loss with log frequency at different temperature

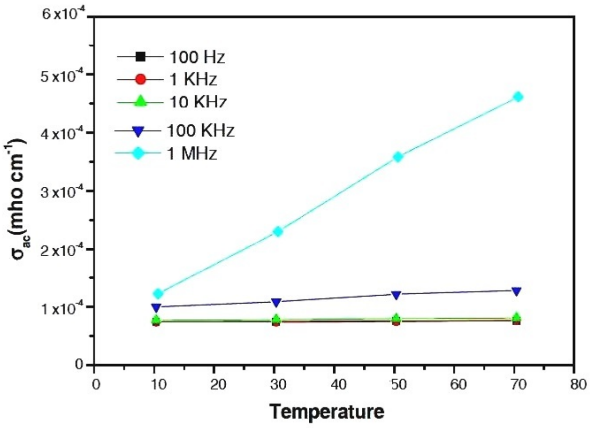

Fig. 7 The a.c conductivities for CdO nanoparticles

G. A.C Conductivity

The temperature dependence of a. c conductivity of CdO nanoparticles are shown in Fig.7. It can be seen that a.c conductivity increases with temperature for CdO nanoparticles. The a.c conductivity was attributed due to bound charges. The a.c. conductivities depend on the particle size, the concentration, and heat treatment of the CdO nanoparticles. The character of temperature dependence of a.c. conductivity of the CdO nanoparticles, suggests an electronic hopping mechanism, exhibited by a large number of nanocrystalline materials. This hopping mechanism is well-suited with the highly disordered or amorphous structure of the grain boundary layers of nanophase materials, having high densities of localized levels. An applied a.c. field will modify this energy difference and produces a net polarization, which lags behind the field. This polarization, which is out of phase with the applied electric field, is measured as a.c. conductivity.

IV. Conclusion

Cadmium oxide (CdO) nanoparticles were prepared by a chemical coprecipitation method. The X-ray diffraction (XRD), scanning electron microscopy (SEM), was used to characterize the structure and morphology of the CdO nanoparticles. The formation of CdO nanoparticles was confirmed by X-ray diffraction (XRD) analysis. The morphology of the CdO nanoparticles was characterized using scanning electron microscopy (SEM). The size of the CdO nanoparticles was characterized using transmission electron microscopy (TEM). The transmission electron microscopic analysis confirms the prepared CdO nanoparticles with the particle size of around 30-50 nm. The optical properties were studied by the UV-Vis absorption spectrum. The variation of dielectric constant, dielectric loss with frequency and temperature for CdO nanoparticles were analyzed. AC electrical conductivity was found to increase with an increase in the temperatures and frequency.

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