Research Article

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Synthesis and Characterization of Copper Oxide-doped CdS Nanoparticles in PVA Matrix Thin Film and Their Application

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ABSTRACT

Cadmium sulphide (CdS) nanoparticles embedded in a polyvinyl alcohol (PVA) matrix were synthesized using a sol-gel technique. Doping was achieved by incorporating copper ions through copper acetate. Comprehensive characterization of the Cu-doped CdS-PVA nanocomposites was performed using particle size analysis (11 nm), UV-Visible spectroscopy (490 nm), Fourier-transform infrared spectroscopy for metal metal bond stretching, X-ray diffraction confirming crystalline nature, energy-dispersive X-ray spectroscopy for composition of elements, scanning electron microscopy, transmission electron microscopy and current-voltage studies.

Keywords: Cadmium sulphide nanoparticles; Polyvinyl alcohol matrix; Band gap; TEM; Current voltage analysis.

1. INTRODUCTION

Material science is a multidisciplinary field concerned with the design, development, and discovery of novel materials, particularly solids. Over time, it has evolved into a distinct scientific discipline by integrating principles from metallurgy, ceramics, solid-state physics, and chemistry (Abdulwahab *et al.* 2013). It exemplifies a modern scientific domain arising from interdisciplinary fusion rather than fragmentation (Akimov *et al.* 1972).

Many key technological advancements have been constrained by the limitations of existing materials, highlighting the critical role of material science in future innovations (Mokari, *et al.* 2004). Historically, breakthroughs in rubber, plastics, semiconductors, and biomaterials stemmed from advancements in material sciences. The field today spans ceramics, polymers, magnetic materials, biomaterials, and nanotechnology. Materials are broadly categorized into ceramics, metals, and polymers (Murray *et al.* 2007).

Material science primarily investigates how internal structures influence material properties, including mechanical, chemical, electrical, thermal, optical, and magnetic characteristics. These properties are governed by fundamental thermodynamic and kinetic principles that define material microstructures (Ashby, 2011).

Thermodynamics plays a crucial role, providing the theoretical foundation for chemical reactions, magnetism, elasticity, and phase stability. Solid materials, based on their bonding types (metallic, ionic, covalent and van der Waals), exhibit varied physical and chemical behaviors. Further, solids may be crystalline or amorphous, a structural difference that significantly affects their properties such as conductivity, strength, and transparency. Materials are broadly categorized into ceramics, metals, and polymers (Cahn *et al.* 1996)

2. METHODOLGY

2.1 Synthesis of CdS Nanoparticles

A 0.1 N cadmium acetate solution was prepared by dissolving cadmium acetate in 50 mL of distilled water and stirring for one hour. Separately, a 0.1 N thiourea solution was similarly prepared and stirred. The thiourea solution was added dropwise into the cadmium acetate solution, and the mixture was stirred for approximately 12 hours at 40°C, during which the colour changed to pale yellow, indicating CdS formation.

Subsequently, 5 g of copper acetate was dissolved in 25 mL of distilled water to prepare a 0.03 N solution. This copper acetate solution was mixed with polyvinyl alcohol (PVA), and the resultant solution was combined with the pale yellow CdS solution. The

mixture was stirred for an additional two hours at 40 °C until it turned black, signifying successful doping. The resulting gel was coated onto a glass substrate for further analysis.

3. RESULTS AND DISCUSSION

3.1 Particle Size Analyser

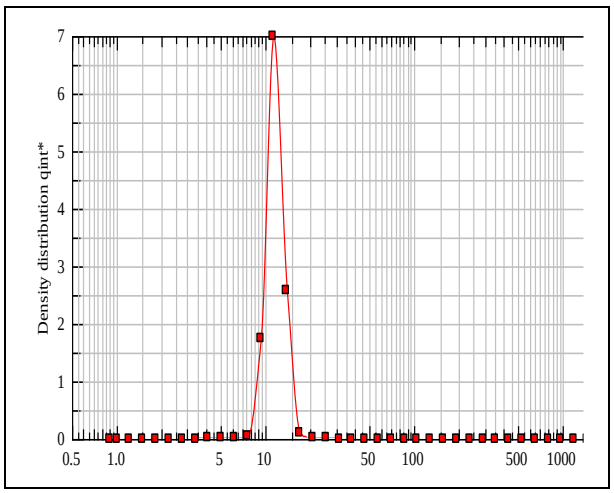


Fig. 1: PSA spectra of copper oxide-doped CdS in PVA matrix thin film

Fig. 1 shows the particle size analysis of the prepared copper oxide-doped CdS in PVA matrix thin film. The particle size ranged from 9-14 nm (×10 = 9.54 nm; ×50 = 11.51 nm; ×90 = 14.61 nm) at the scattering angle of 90°. It is the evident from the observed PSA spectra that the average particle size of the prepared nanoparticles is 11 nm. This range clearly indicated uniform distribution of particles in the copper-doped CdS in PVA matrix thin film.

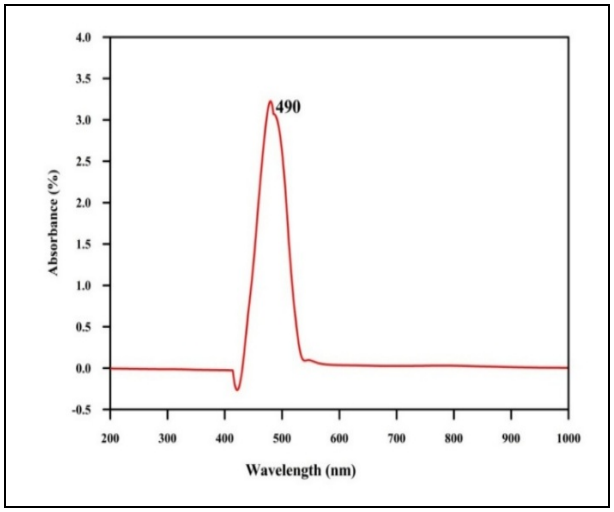


Fig. 2: UV-vis spectra of copper oxide-doped PVA matrix thin film

3.2 UV-visible Spectral Analysis

Fig. 2 shows maximum absorption of 490 nm corresponding to the absorption maxima of thin film.

3.3 Band Gap Analysis

A graph between hν and $(\alpha h\nu)^2$ was plotted (Fig. 3). The extrapolation of straight line gives the value of the energy band gap of the film. The band gap of the synthesized copper oxide-doped CdS in PVA matrix is determined to be 2.37 eV.

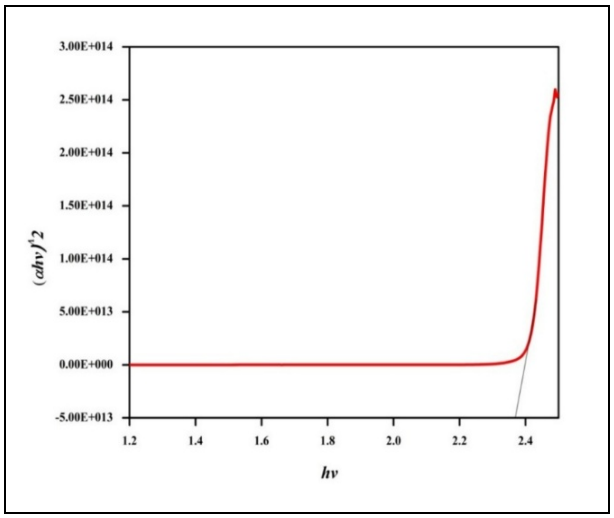


Fig. 3: Plot of hν *vs* $(\alpha h\nu)^2$ of copper oxide-doped CdS in PVA matrix

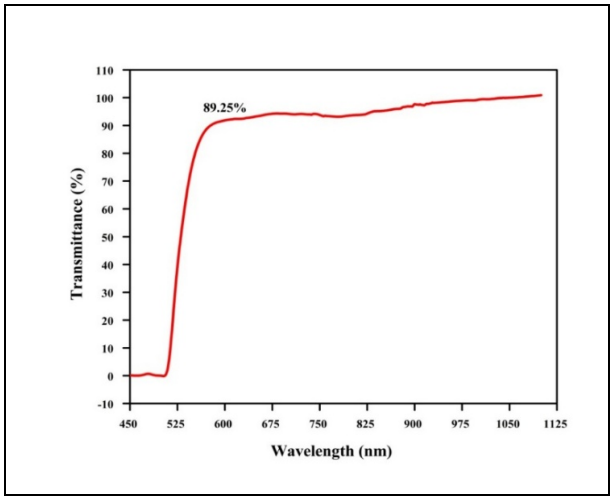


Fig. 4: Transmittance spectrum of copper oxide-doped CdS in PVA matrix

3.4 Transmittance Spectral Studies

The optimum transmittance of the synthesized copper oxide-doped CdS in PVA matrix was obtained at 89.25% at a wavelength longer than 490 nm (Fig. 4).

3.5 Reflectance Spectral Studies

Fig. 5 shows a plot of reflectance versus wavelength of CdS:CuO in PVA matrix which has the least reflectance, almost highly negative value. This low reflectance value makes cadmium sulphide nanoparticle an important material for antireflection coating.

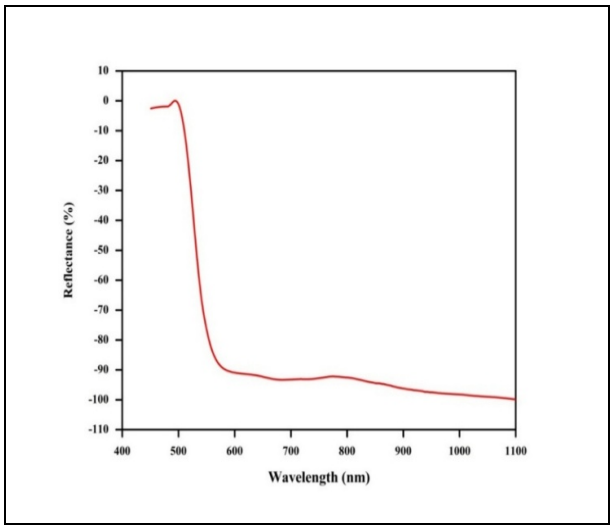


Fig. 5: Reflectance spectrum of copper oxide-doped CdS in PVA matrix

3.6 Absorption Coefficient Spectral Studies

The absorption coefficient of CdS:CuO in PVA matrix indicates a strong absorption range between 2.49 to 2.69 eV (Fig. 6).

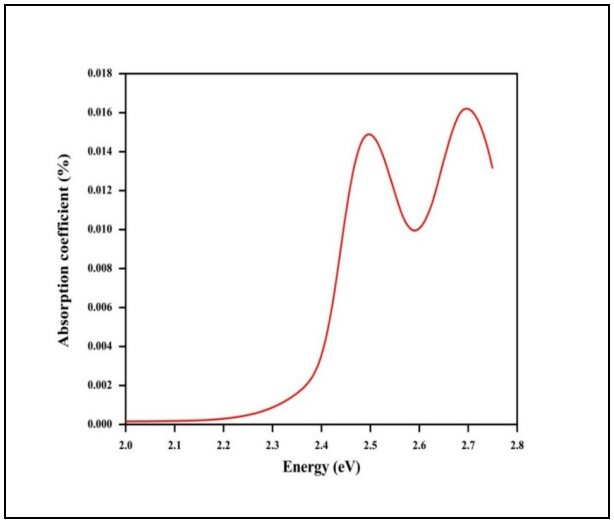


Fig. 6: Absorption coefficient spectra of copper oxide-doped CdS in PVA matrix thin film

3.7 Refractive Index Spectral Studies

Plot of refractive index against photon energy of the CdS:CuO in PVA matrix thin film was in the range of 1.3 (Fig. 7). The refractive index, n is the range of frequency in which synthesized nanoparticles are weakly absorbed. High refractive index makes it suitable for antireflection coating.

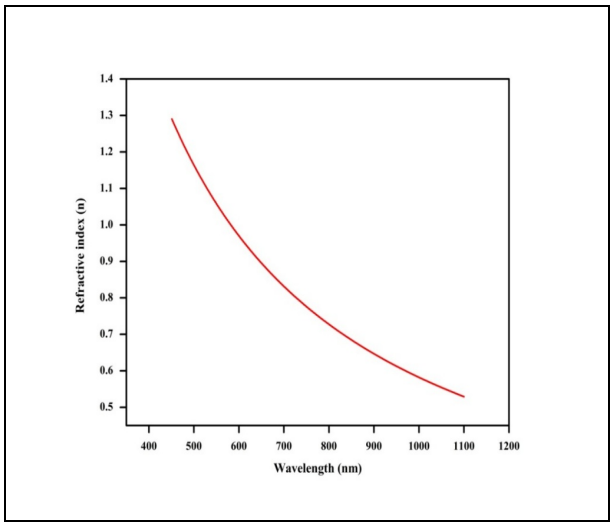


Fig. 7: Refractive index spectrum of copper oxide-doped CdS in PVA matrix

3.8 Fourier Transform Infrared Spectroscopy (FT-IR)

From the data obtained, the peak observed at 3460 cm^{-1} can be assigned to the –OH stretching. The sharp and medium band at 669 cm^{-1} is assigned to be the Cd-S stretching in the synthesized thin film. The sharp peak at 1020 cm^{-1} represents the C-O-C bond in the acetyl group of poly vinyl alcohol. The fine sharp peak at 1410 cm^{-1} is assigned to be the doped metal copper oxide in the cadmium sulphide in PVA matrix.

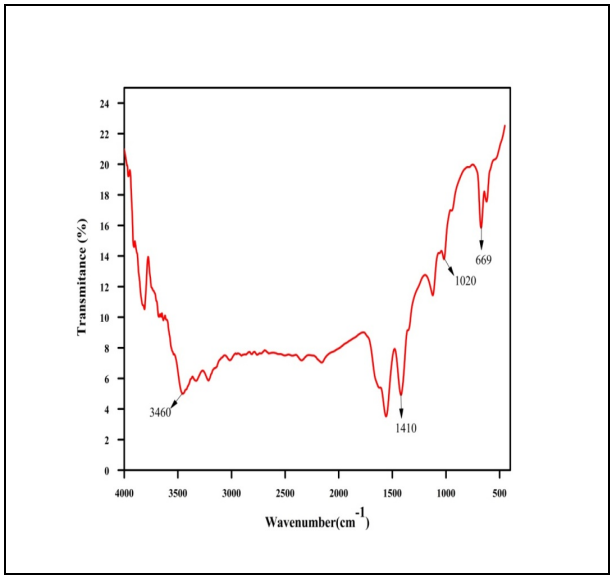


Fig. 8: FT-IR spectrum of copper oxide-doped CdS in PVA matrix

3.9 Powder X-ray Diffraction Profile

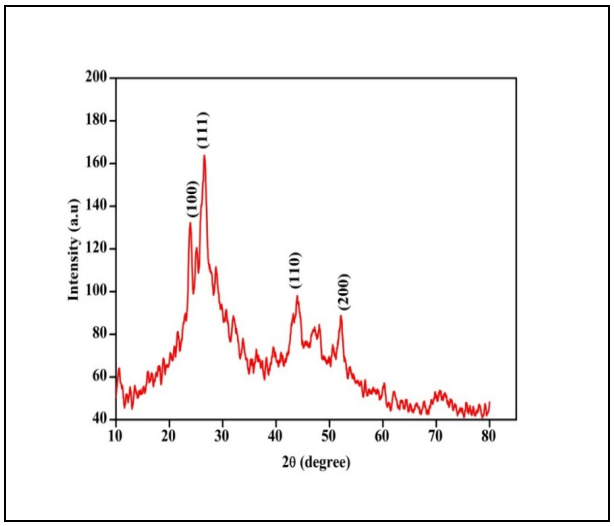


Fig. 9: XRD profile of copper oxide-doped CdS thin film

3.10 Scanning Electron Microscope (SEM) Analysis

Fig. 10 shows the SEM image of the synthesized CuO-doped CdS nanoparticles embedded in the PVA matrix. The particles exhibited a uniform spherical morphology with sizes ranging from 80-150 nm and an average diameter of approximately 60 nm.

Table 1. Percentage composition of elements in CdS:CuO in PVA matrix

S. No	Elements	Energy (keV)	Percentage (%)
1	Cadmium	2.32	46.45
2	Sulphur	3.14	28.02
3	Copper	8.02	13.63
4	Oxygen	0.96	11.90

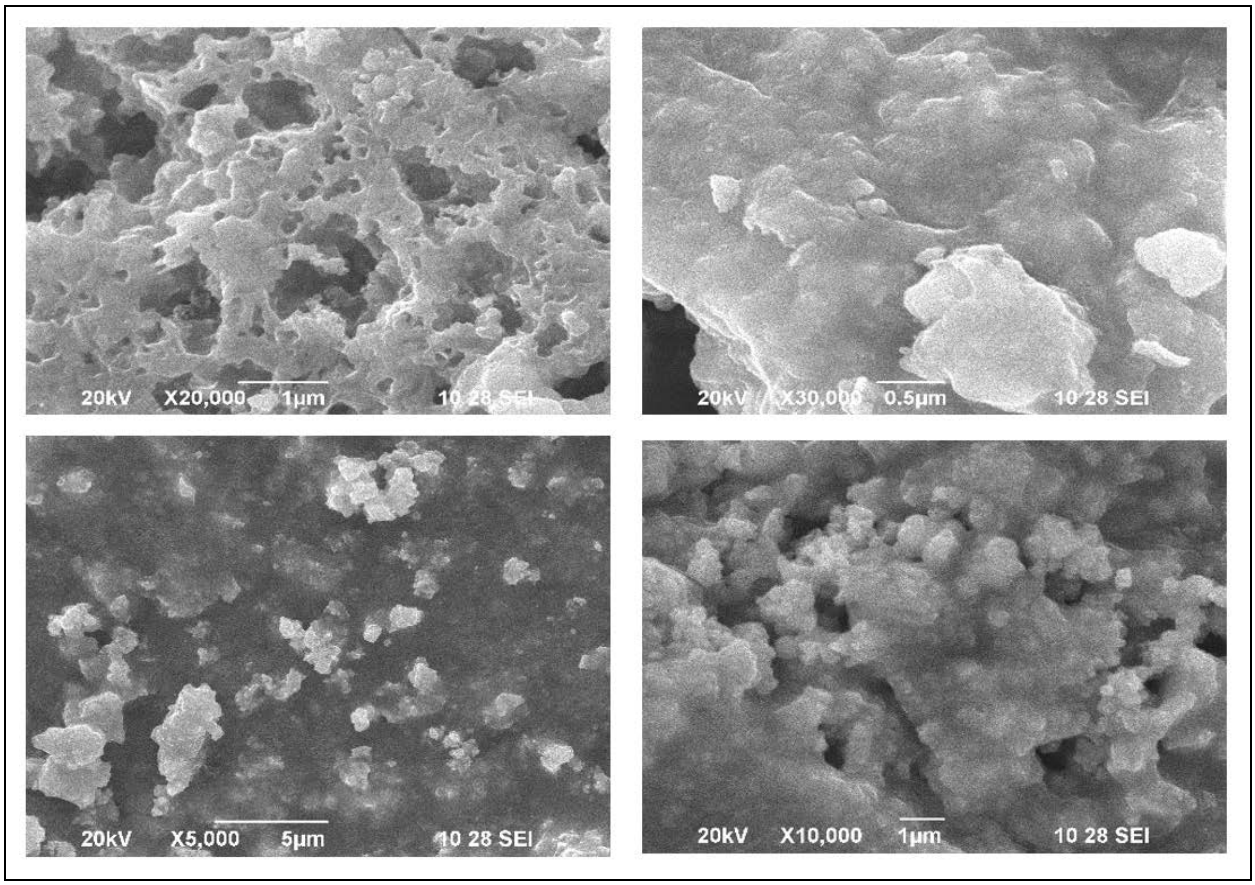


Fig. 10: SEM images of copper oxide-doped CdS in PVA matrix

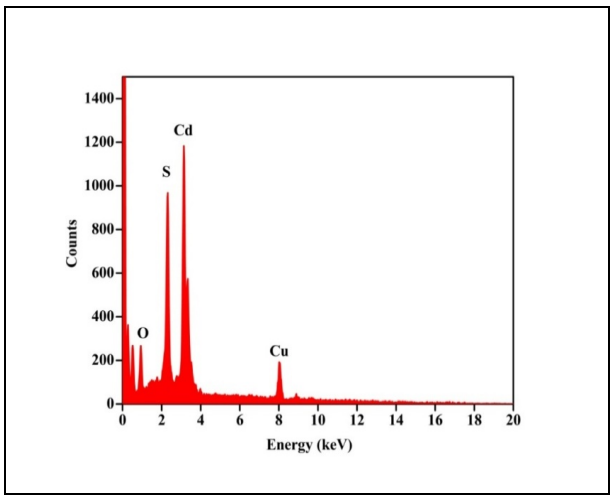


Fig. 11: EDAX spectrum of copper oxide-doped CdS in PVA matrix

3.11 Energy Dispersive X-ray Spectroscopy

Fig. 11 shows the EDAX spectra of CuO-doped CdS in PVA matrix. Table 1 shows cadmium 46.45%, sulphur 28.02%, Copper 13.63% and oxygen 11.90%.

3.12 Current-voltage Characteristics

From the above results we conclude that the synthesized cadmium sulphide doped with copper is nano sized, crystalline in nature and has the maximum absorption with blue shift. The synthesized CdS:CuO nanoparticles have low band gap value which results in the conduction of solar energy. They have high transmittance and negative reflectance. This property makes the material a good candidate as a transparent window layer in solar cell.

3.13 High Resolution-Transmission Electron Microscopy (HR-TEM)

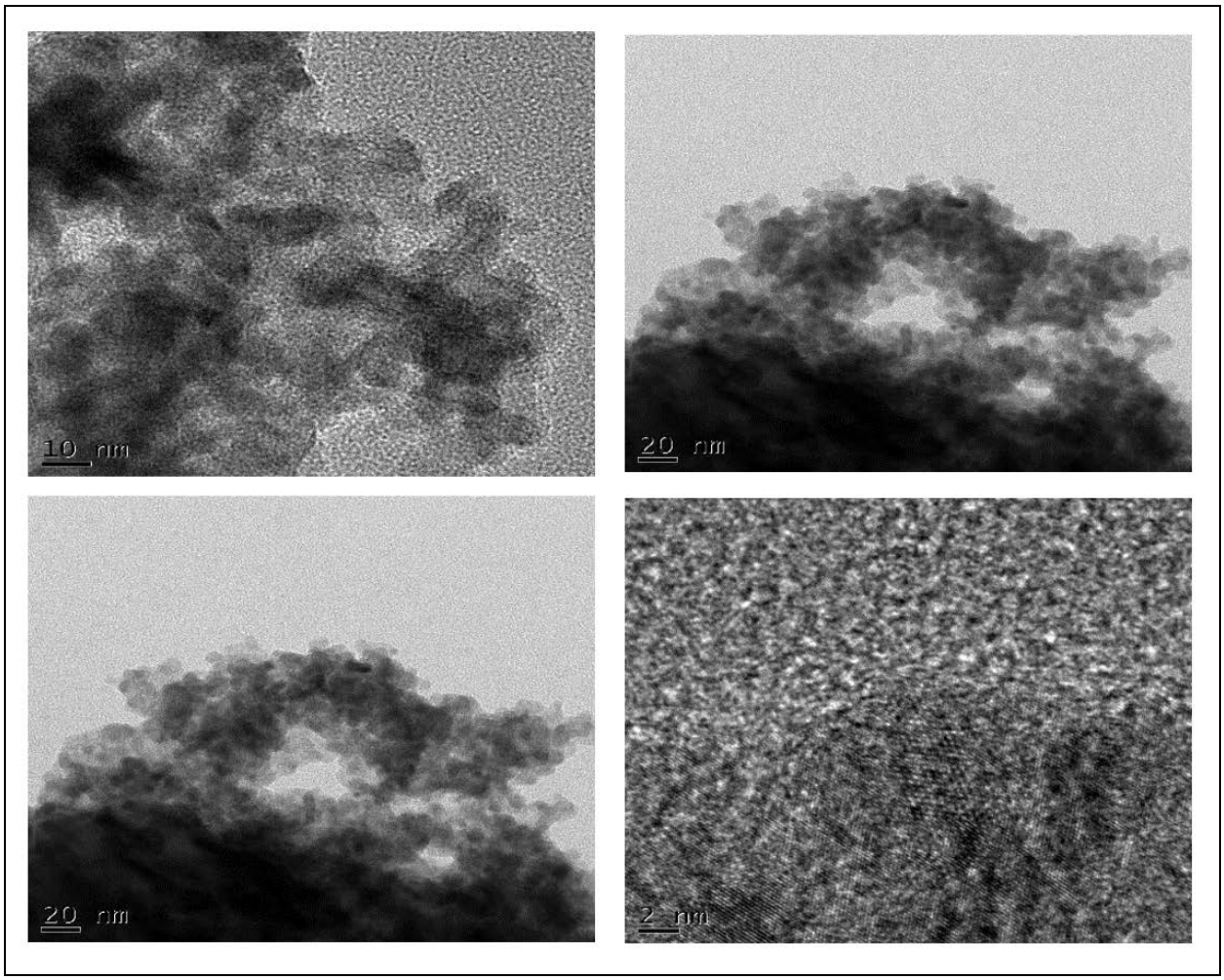


Fig. 12: TEM image of copper oxide-doped CdS in PVA matrix thin film

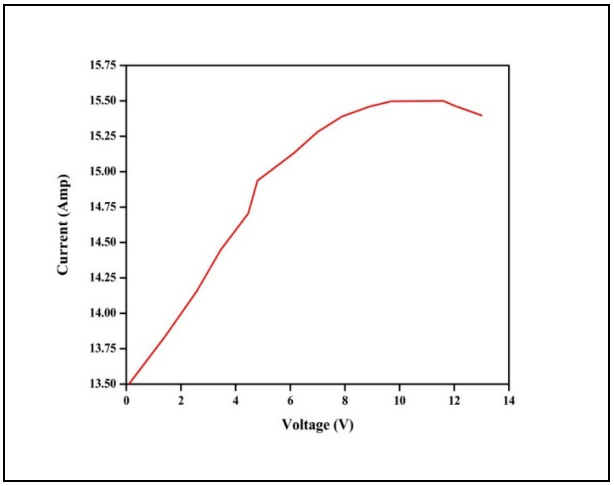


Fig. 13: Current-voltage characteristics of CdS-doped with copper oxide

4. CONCLUSION

In this work cadmium sulphide nanoparticles in PVA matrix were prepared by sol-gel method. particle size analysis of the prepared copper oxide-doped CdS in PVA matrix thin film. The particle size is 11 nm. Maximum absorption of UV-Vis spectroscopy is 490 nm. The band gap is 2.37ev. In FT-IR spectroscopy 3460 cm^{-1} can be assigned to the –OH stretching. The sharp and medium band at 669 cm^{-1} is assigned to be the Cd-S stretching in the synthesized thin film. The sharp peak at 1020 cm^{-1} represents the C-O-C bond in the acetyl group of poly vinyl alcohol. The fine sharp peak at 1410 cm^{-1} is assigned to be the doped metal copper oxide in the cadmium sulphide in PVA matrix, X-ray difractometer confirm crystalline in nature, Energy Dispersive X-ray Spectroscopy shows cadmium 46.45%, sulphur 28.02%, Copper 13.63% and oxygen 11.90%. In scanning electron microscope the particles exhibited a uniform spherical morphology. The CV property makes the material a good candidate as a transparent window layer in solar cell.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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