Study of Optical Properties of Cobalt - Doped Cadmium Sulfide Nanomaterials

Rahul Pratap Singh[1], Santosh Kumar[2]

Department of Physics, Faculty of Engineering and Technology, V. B. S. Purvanchal University, Jaunpur - 222003, U. P., India

Abstract: ***Pristine and Co - doped cadmium sulphide (CdS) nanoparticle was prepared by the hydrothermal method. The optical properties were studied with the help of UV - Visible spectroscopy. The effect of the cobalt doping on optical and electrical properties was investigated. The doping of cobalt reduces the bandgap of cadmium sulphide from 2.42 to 2.10 eV.***

Keywords: Nanoparticle, Cadmium sulphide, Band gap

1. Introduction

Nanotechnology has revolutionized various scientific fields, offering unprecedented opportunities to engineer materials with tailored properties at the nanoscale. Semiconductor nanoparticles, especially those with controlled doping, have garnered substantial attention due to their remarkable optoelectronic and catalytic properties [1]. Among these, cadmium sulphide (CdS) is one of the most intriguing binary semiconducting materials because it can be easily synthesized, and has good electrical properties. Furthermore, CdS has a large (2.2–2.5 eV) and straight band gap, making it ideal for optoelectronic devices. It belongs to the II–IV compound group and was the first semiconductor used in thin - film transistors (TFT) [23]. Because of their high optical transparency and electrical conductivity, they are excellent for transparent conductive coatings used in displays, touch screens, thin film transistors, integrated circuits, and other applications. CdS is chemically inert and corrosion and oxidation - resistant. Its nanostructured forms have garnered considerable interest over the last decade. They are ideal materials for the components of practical nano - devices such as sensors, photovoltaic devices, light - emitting diodes, photodetectors, and field - effect transistors, among others [3–7]. It is a well - known fact that even minor modifications in the synthesis method, annealing temperature, doping, etc. can drastically change the characteristics of a nanostructured material. Doping of manganese (Mn), iron (Fe), and cobalt (Co) into semiconductors adds magnetic characteristics and opens up new avenues of investigation. These materials are known as diluted magnetic semiconductors (DMS), and their resistance can be altered by applying a magnetic field to them. The diluted magnetic semiconductors could be used in spintronic devices. DMS materials based on cadmium sulphide have garnered a lot of attention due to their simultaneous magnetic, semiconducting, electromechanical, and optical properties. Magnetic field sensors and memory technology make use of these properties [8].

CdS nanoparticles easily combine with transition metal ions such as cobalt without changing the crystal structure. By d - orbital hybridization, co - doping can create impurity levels between the conduction and valence bands of CdS nanoparticles [9].

In recent years, significant efforts have been directed towards enhancing the performance of CdS nanoparticles through intentional doping with various transition metals. One such compelling dopant is cobalt (Co), which introduces a range of intriguing functionalities to the CdS matrix. The incorporation of Co into the CdS lattice not only enables fine - tuning of the electronic structure but also facilitates the manipulation of optical, magnetic, and catalytic properties. This has led to the emergence of Co - doped CdS nanoparticles as promising materials with enhanced capabilities, opening avenues for breakthroughs in fields such as solar energy conversion, environmental remediation, and advanced electronic devices [10].

This paper delves into the effects of Co doping on CdS nanoparticles optical properties. As the demand for high-performance materials with tailored properties continues to grow, understanding the synthesis, properties, and applications of Co - doped CdS nanoparticles becomes pivotal. This exploration not only enriches our fundamental knowledge of nanoscale systems but also provides a platform for harnessing their unique attributes to address pressing technological and societal needs.

2. Experimental Method

Cobalt - doped cadmium sulphide nanomaterials based on CoxCd1 - xS (x = 0, 5, 10, and 15 at. %) were synthesized by the hydrothermal method. To prepare pure CdS nanoparticles, an aqueous solution of (0.02 M) cadmium acetate, thioacetamide, and cobalt nitrate hexahydrate was dissolved separately in 50 ml of de - ionized water under magnetic stirring. The mixed solution was transferred into a 100 - ml autoclave reactor for hydrothermal treatment (170 °C for 12 h). When it cooled down to room temperature, the resultant solution was washed several times using de - ionized water and ethanol. Subsequently, the Co doped CdS nanoparticles were obtained by drying at 60 °C for 10 h. UV - visible spectra were recorded by Motras Double Beam UV - Vis Spectrophotometer Model: UV Plus with a resolution of 0.1 nm.

3. Results and Discussion

The optical properties of synthesized nanomaterials were investigated using UV - Visible spectroscopy, and the obtained spectra are shown in Figure 1. Material absorption was seen in both the ultraviolet and visible ranges. It is obvious from Fig.1 that synthesized nanomaterials exhibit optical characteristics. The absorption spectra of the synthesized nanomaterial suggest that the material is photoactive. TheTauc plot corresponding to the above absorption spectra is plotted in Figure 2. The Tauc plot relation is used to calculate the band gap of synthesized nanomaterials:

$$\alpha = B (h\nu - Eg)^{n/h\nu}$$

where α represents the absorption coefficient, ν is the irradiation frequency, h is Planck's constant, B is a constant, Eg is the band gap, and n is also a constant that depends on the behaviour of the semiconductor. The value of n = 2 for indirect transition, and n = ½ is for direct transition. The band gap (Eg) was estimated by extrapolation of the linear part of the curves of $(\alpha h\nu)^2$ against energy (hν), as displayed in Fig.2 [11]. The values of the indirect band gap of synthesized pristine and Co - doped CdS nanomaterials are 2.42 eV to 2.1 eV. The doped samples

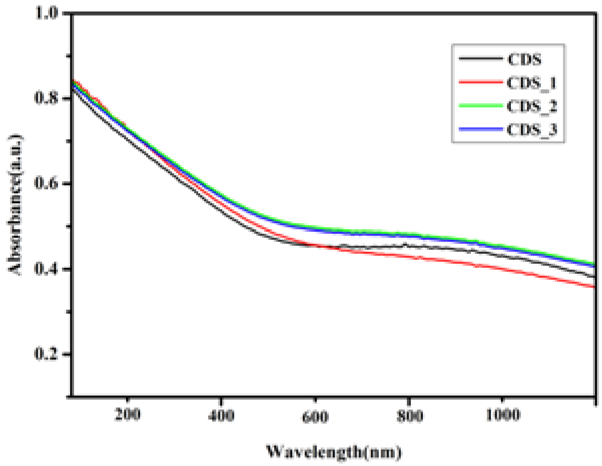

Figure 1: Absorption spectra of CdS and Co/CdS

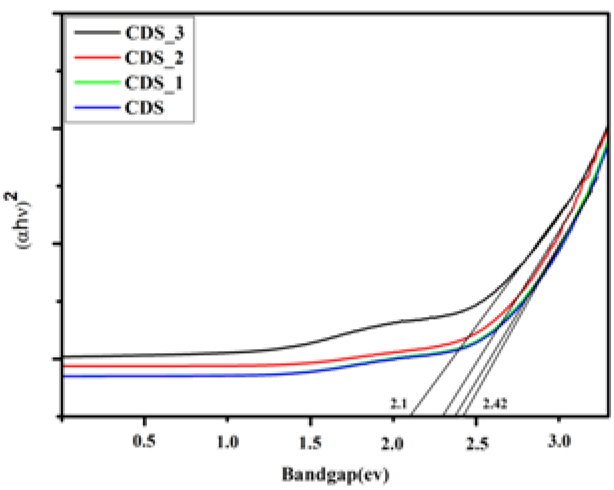

Figure 2: Bandgap of CdS and Co/CdS

absorb more visible light than pristine This study reveals that the incorporation of cobalt in cadmium sulphide reduces the band gap. The reduction of the bandgap of Co doped CdS makes them fascinating materials for their applications in remote control devices, optical communication, display technologies, multi - junction solar cells for space and concentrated photovoltaic systems, power generation from waste heat, portable power sources, night vision cameras, thermal imaging devices, motion sensors, faster transistors, microwave devices, gas sensors, environmental monitoring, etc.

4. Conclusion

This study reveals that the doping of cobalt in cadmium sulphide reduces the bandgap from 2.42 eV to 2.1 eV. The reduction of bandgap by the introduction of cobalt makes them more intriguing for their application in numerous fields of science and technology.

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