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Effect of doping on structural, optical and electrical properties of nanocrystalline CdO thin films, Review

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Abstract

This review shows the effect of doping on structural, optical and electrical properties of Cadmium oxide thin films by different dopants. CdO is one of the promising n-type semiconductor with direct energy gap and has great potential for optoelectronic. Various methods are used to synthesis pure with doped CdO nanoparticles. The structure of doped CdO nanoparticles are polycrystalline and cubic structure. CdO thin films have high carrier concentration, low resistivity and wide direct energy gap. It has many uses in various aspect such as solar cells, optical heaters, transparent electrodes gas sensing and other optoelectronic devices.

Keywords: CdO, Nanoparticles, thin films, doping.

1. Introduction

Nanoparticles are motes of matter tens of thousands of times smaller than the width of a human hair. Because of their small size, nanoparticles have a huge number of atoms on their surfaces rather than in their interiors. This shows that surface interactions dominate nanoparticle behavior. As a result, they frequently differ from bigger pieces of the same material in terms of traits and qualities [1]. Nanoparticle Technique is a method for creating, characterizing, processing, and using nanoparticles that is predicted to become one of the most important technologies for commercializing nanotechnology applications. Nanosized particles are important in the development of commercial nanotechnology applications because of their unique functional capabilities [2]. (NP) can be synthesized either by breaking down the bulk materials into smaller dimensions or by joining up atoms, molecules or clusters. This is known as the Top- down approach"a block of a bulk material is broken down to get the nanosized particles", whereas the latter is referred to as the Bottom-up method" the individual atoms and molecules are placed or self assembled precisely where they are needed. Here the molecules or atomic building blocks fit together to produce nanoparticles", Fig.1 [3].

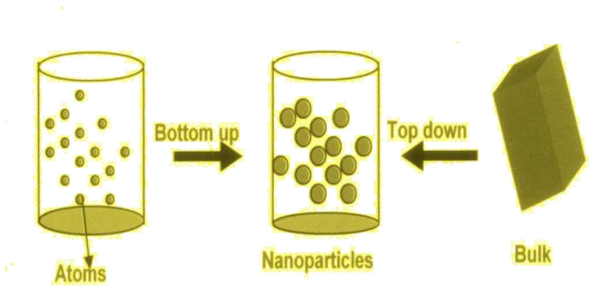


Fig. 1.The techniques of nanoparticles synthesis [3].

Quantum-confined nanoparticles such as quantum dots, wires, and sheets are generating a lot of research attention because of their unique optical properties [4]
CdO is important n-type semiconductor [5], and has direct energy gap (2. 197-2.95) eV [6,7]. Pure and doped CdO thin films have been prepared on various substrates by several techniques such as SILAR [8] spray pyrolysis technique [9], sol-gel [10], pulsed laser deposition [11], thermal evaporation [12], simple soft chemical method [13], chemical bath deposition [6,7], pulse laser deposition [14]. To expand the band gap, several dopants including as In, Ti, Al, Sn, F, and Zn have been added to CdO [15]. CdO is a promising semiconducting oxide with a high carrier mobility that has a lot of applications in optoelectronics [16].

Table 1. Some values of D_{111} and E_g of some prepared undoped and doped CdO films

Ref.	Materials	Crystallite size of D_{111} (nm)	Synthesis method	Energy gap E_g (eV)
17	CdO	188	spray pyrolysis technique	2.36
	CdO:Al (3 wt.%)	146		2.53
18	CdO	32.6	vacuum evaporation method	2.25
	CdO:Eu (0.4 wt.%)	34.7		1.78
	CdO:Eu (0.5 wt.%)	34.7		1.65
	CdO:Eu (0.8 wt.%)	34.7		1.61
	CdO:Eu (1.1 wt.%)	41.7		1.44
19	CdO	8.23	sol–gel	2.49
	CdO:Cu (2%)	11.25		2.5
	CdO:Cu (3%)	8.8		2.56
20	CdO	23.92	sol–gel	2.2
	CdO:Au (2%)	28.75		1.52

21	CdO	37	sol–gel	2.35
	CdO:Al (1at.%)	17		2.82
	CdO:Al (5at.%)	11		2.5
22	CdO	18.12	SILAR	2.36
	CdO:Pb (0.5%)	18.65		2.44
	CdO:Pb (1%)	16.08		2.49
	CdO:Pb (1.5%)	14.92		2.53
	CdO:Pb (2%)	14.32		2.57
	CdO:Pb(2.5%).	14.44		2.61
23	CdO	30	sol–gel	2.99
	CdO:Al (1 at.%)	52		3.03
	CdO:Al (3 at.%)	45		2.82
	CdO:Al (5 at.%)	26		2.77

In general, table 1 shows when the doping concentration increases, the size of CdO particles decreases.

2. Structural properties

The effect doping concentration and dopant type on the grain size (*D*) of CdO in table 1.varis between increasing in *D* such as Eu, and decreasing such as Pb and Cu(CdO:Cu (3%) with minimum value of (*D*) is 8.8 nm), but the effect of Al dopant is uneven to make increasing and decreasing of (*D*).

2.1 Patterns of XRD of prepared CdO thin films

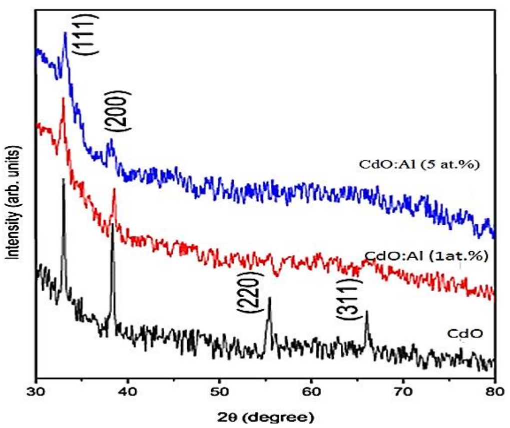


Fig. 2. XRD of the CdO thin films pure and with various Al concentrations [21]

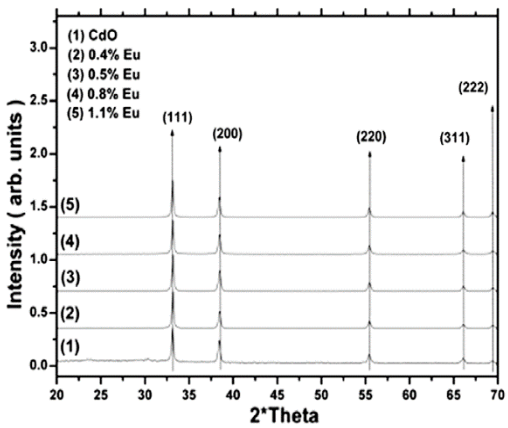
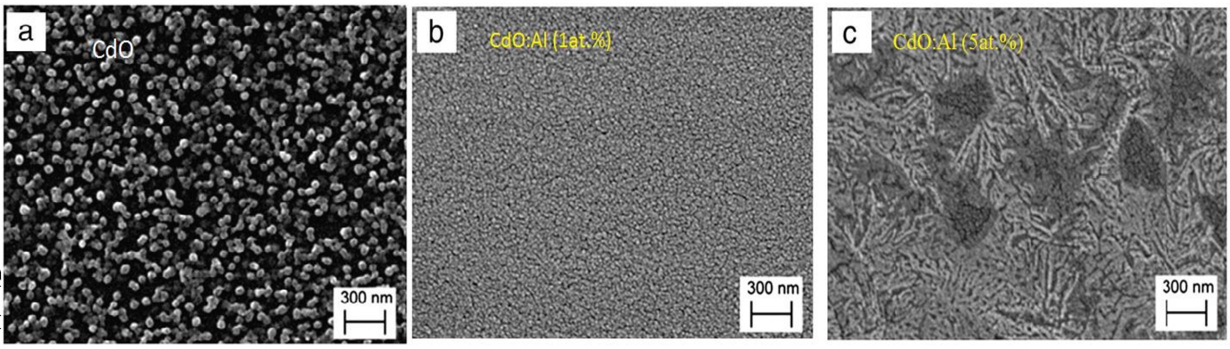


Fig. 3. XRD of the CdO thin films pure and with various Eu concentrations [18]

The X-ray diffraction (XRD) of the prepared pure and doped CdO films in Fig. 2 and Fig. 3. The patterns reveal that films are polycrystalline of cubic face-centered CdO structure, and the peaks associated to planes (1 1 1), (2 0 0), (2 2 0) and (3 1 1).

2.2 Pattern of SEM of prepared CdO thin films



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smooth grain surface and a single mode size distribution of grain. In general, samples with low doping showed a porous microstructure and spherical crystalline surface particles. Fig. 4c shows 5 at.% Al doped sample with an uneven surface and dense microstructure [21].

3. Optical properties

From values's energy gap (E_g) in Table 1. The effect of doping on CdO thin films energy gap is not big different for increasing or decreasing. Moreover, the effect of the dopants and doping concentration varies between an increase and a decrease from one dopant to another. The widest energy gap (E_g) is 3.03 eV at CdO:Al (1 at.%).

3.1 Pattern of direct energy gap of prepared CdO thin films

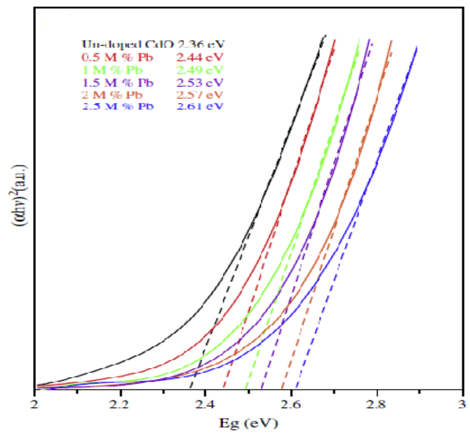

Fig. 5. $(\alpha h\nu)^2$ vs. E_g of pure and Pb doped CdO films [22]

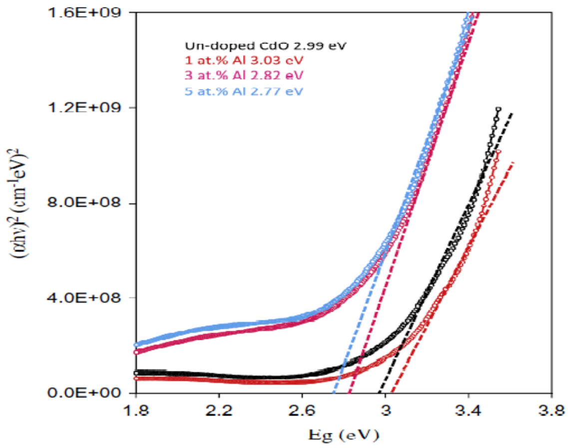

Fig. 6. $(\alpha h\nu)^2$ vs. E_g of pure and Al doped CdO films [23]

Fig.5. shows the effect of Pb concentration on the optical band gap. It is seen that the E_g values of the films were increased with increasing Pb concentrations The variation crystal

structure of the CdO nanostructure could explain the change in optical band gap values. Changes in the optical band gap in nanostructured materials can also be explained by the quantum size effect [22].

Fig.6. shows the effect of Al concentration on the optical band gap. The decrease in the optical band gap can be explained by an increase in the degree of disorder in the films. Localized energy levels expand when there is a lot of content. As a result, the optical band gap narrows due to the large number of localized states. This means that when the localized states expand, the CdO sheets' optical band gap diminishes. The optical transmittance of CdO films is also reduced due to free hole absorption and disorder in the films caused by Al doping [23].

4. Electrical properties

Table 2. The N, μ, and ρ of sample prepared pure and doped CdO films

Ref.	Materials	Carrier concentration N (cm^{-3})	Mobility μ (cm^2/Vs)	Resistivity ρ(Ω cm)
14	CdO	0.35×10^{20}	88.01	20.03×10^{-4}
	CdO:Sn (2.9 at.%)	4.53×10^{20}	47.31	1.59×10^{-4}
17	CdO	8.67×10^{19}	68	1.05×10^{-3}
	CdO:Al (3 wt.%)	4.12×10^{20}	55	3.4×10^{-4}
18	CdO	4.42×10^{19}	7.03	20.1×10^{-3}
	CdO:Eu (0.4 wt.%)	27.88×10^{19}	20.9	1.072×10^{-3}
	CdO:Eu (0.5 wt.%)	32.93×10^{19}	18.63	1.018×10^{-3}
	CdO:Eu (0.8 wt.%)	48.68×10^{19}	24.42	0.525×10^{-3}
	CdO:Eu (1.1 wt.%)	44.5×10^{19}	20.8	0.68×10^{-3}
21	CdO	1.7×10^{19}	46.8	0.78×10^{-3}
	CdO:Al (1at.%)	3.5×10^{19}	4	44×10^{-3}
	CdO:Al (5at.%)	2.2×10^{19}	6.64	42×10^{-3}

Generally, Table 2.shows the effect doping concentration on carrier concentration (N), mobility (μ), and resistivity (ρ) for pure and doped CdO film. The increasing in carrier concentration and decreasing of mobility and resistivity. The maximum value of (N) is 4.12×10^{20} for CdO:Al (3 wt.%). In comparison to an undoped CdO film, the 0.8 % Eu-doped CdO film has a 3.5 times improvement in mobility, a 40 times increase in conductivity, and an 11times increase in carrier concentration. As a result, the role of Eu dopant is similar to that of other common metallic dopants. [18].

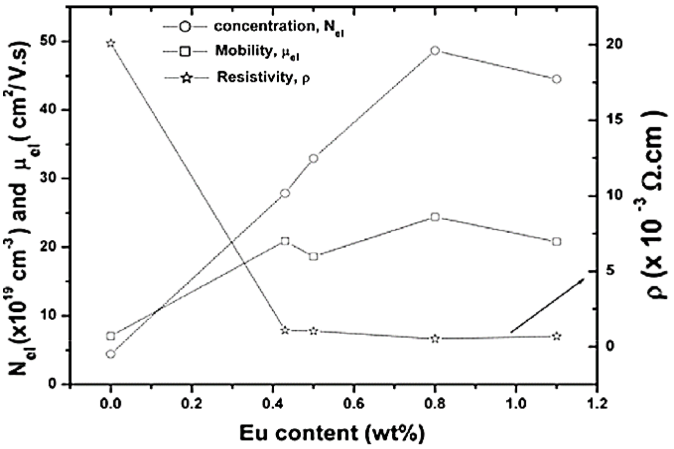

Fig.7. Variation of N, μ, and ρ, for pure and Eu doped CdO film [18].

Fig.7. shows the relation between carrier concentration, mobility and resistivity with Eu concentration dopant. The decrease in the resistivity and the increase to carrier concentration and mobility with increasing Eu concentration.

5. Applications

CdO has some application as:

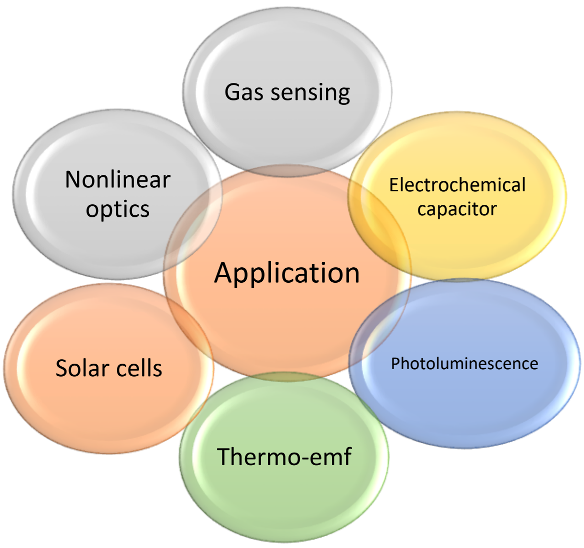

Fig. 7.CdO applications characterization [24].

J. Santos-Cruz *et. al*. proposed the heterostructure design Au–Cu/p–CdTe:Sb/n–CdO:F /glass for the photovoltaic (PV) solar cell. The values of the parameters J_{sc} = 28.6mA/cm^2, and V_{oc}= 522.3 mV,With low resistivity approximately 4.5x10^{-4} Ω-cm and an optical transmission higher than 85% [25].

6. Conclusion

The effect of doping on the structural, optical and electrical properties of CdO films as:

1. XRD measurements revealed that all the CdO films are polycrystalline and with cubic structure.
2. CdO thin films have wide energy gap. For their improved optical and electrical properties, for future optoelectronic devices.
3. CdO films have high carrier concentration and low resistivity.

The difference of *D, Eg, N, μ, ρ* among prepared pure and doped CdO thin films refers to synthesis method, substrate type, dopant concentration, dopant type.

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