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Synthesis and Characterization of PbS:Cd, Cu, Co Nano composites Prepared by Pulsed Laser Deposition For Gas Sensor Applications

A Thesis

Submitted to the Council of the College of Science- University of Diyala in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy of Science in Physics

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

قَالُواْ سُبْحَانَكَ لاَ عِلْمَ لَنَا إِلاَّ مَا عَلَّمْتَنَا
إِنَّكَ أَنتَ الْعَلِيمُ الْحَكِيمُ

البقرة [32]

صدق الله العظيم

Dedication

My PhD is dedicated to…

My parents.

My lovely wife.

My Son.....Mohammed.

My brothers and sister.

My uncle Dr. Mohammed

My supporters Friends

Nawar T. Mohammed

2022

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I certainly cannot mention the names of everyone who contributed towards the success of this research, but as they have always known, I am very grateful.

Nawar T. Mohammed / 2022

Supervisors Certification

We certify that this thesis entitled **" *Synthesis and Characterization of PbS:Cd, Cu, Co Nano composites Prepared by Pulsed Laser Deposition For Gas Sensor Applications* "** for the student (**Nawar Thamer Mohammed**), was prepared under our supervisions at the Department of Physics, College of Science, University of Diyala in partial fulfillment of requirements needed to award the degree of ***Doctor of Philosophy (Ph.D.) of Science in Physics.***

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Abstract

In this work , lead sulfide PbS thin films deposited on a glass substrate were mixed with (30, 50, and 70%) of cadmium, copper, and cobalt at room temperature. by use a pulsed laser deposition (PLD) technique, The laser energy was 600 mJ, and wave length 1064 nm. The number of laser pulses was fixedly set to 100 pulses for each ablation . The effect of mixing ratios on the structural and optical properties of PbS films were studied.

Using X-ray diffraction method, the structures of (PbS, PbS:Cd, PbS:Cu, and PbS:Co) thin films were investigated. X-ray analysis of the structure showed that it is polycrystalline and that the film's crystal system is the cubic system. also shows that the high intensity appeared at ($2\theta^{\circ}$ =53.48886 and 69.14403) and that the dominant trend of growth is (2 2 2) and (3 3 1), respectively and that the crystal size of the Pure PbS sample is (17.74 nm) and that the size of the crystal grows with the mixed ratio of (Cd, Cu, and Co).

The surface morphology of pure and mixed thin films deposited on a glass substrate by laser induced plasma technique at room temperature was examined by Field Emission Scanning Electron Microscope (FESEM).

FESEM micrographs for pure lead sulphide (PbS) and mixed (PbS: Cd, Cu, and Co) films deposited on glass substrates at various ratios it was noticed that the mixing of Cd ,Cu and Co exhibits some changes in the PbS surface morphology in which the surface was found to be densely packed with crystallite.

For pure PbS thin film, it was observed that the film was dense, smooth, non-homogeneous with pinholes. Also, it was noted that the grains have a mixture of nano cauliflower and spherical-like shapes with different sizes. In addition, it was noted that PbS thin film formed was highly agglomerated.

FESEM micrographs of PbS thin film deposited with 30% of Cd,Cu,Co showed large clusters of spherical or semispherical shaped grains on some parts

of the images indicating an irregular growth rate of the grains. The images exhibited a dense compact of the grains covering the entire surface without any defects like cracks or pinholes. While the mixing ratios (50% and 70%) it was clearly observed that the mix ratio of cadmium increased the loss of the grain their sharp-edged nature and becomes smaller in size.

AFM measurements, which demonstrate that the films created using the PLD process, have In every instance, a dense surface for the thin films was achieved. The stacked grains made up the thin films.

From result of optical measurement by UV-ViS spectrophotometer showed that the thin films of (PbS, PbS:Cd, PbS:Cu, and PbS:Co) exhibit direct transit energy gap transitions. The absorbance of the films rises with the rising mixing ratio. The optical constants have been determined, including the absorption coefficient (α). As the mixing ratio is increased, the energy gap narrows.

Hall effect measurement showed that all the samples of (PbS , PbS:Cd , PbS:Cu and PbS:Co) were p- type conduction.

The gas sensor measurements showed that the resistivity of p- type gas sensor increases and return decreases by NO_2 Oxidization gas and decreases by high operation temperature . The sensitivity of all the samples decreased with increasing of mixing ratio because decreases the surface area with increase the grain size and the best sensor for NO_2 gas was the sample with a percentage of X = 30% Cu with a sensitivity of 355% at 150 ^{o}C .

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Symbol	Meaning	Unit
Eg	Optical energy gap	eV
λ	The wavelength of the incident rays	(nm)
θ:	Brack diffraction angle in units.	degree
d_{hkl}	The distance between two successive levels in a crystal (hkl).	A
a	Lattice constants	A
hkl	Miller's coefficients	
K	shape factor	
β	Full Width at Half Maximum (FWHM)	radial
(Tc)	Texture Coefficient	
I (hkl)	Relative intensity of the plane (hkl).	
I_o (hkl)	Standard intensity of the level (hkl) taken from the ICDD card	
t	Thickness.	A^o
k	Space wave vector	
Ei	Initial energy of the electron in the valence	e.v
Ef	Final energy of the electron in the conduction bands	e.v
hυ	Photon energy.	e.v
k_i	initial wave vector of the electron in the valence bands	
k_f	final wave vector of the electron in conduction bands	
q	Photon wave vector.	
r	An exponential parameter that specifies the type of transition	
B_o	A constant that depends on the nature of the substance	
α	Absorption coefficient.	
hν	The energy of a photon in units	e.v
r	An exponential coefficient that depends on the nature of the transition	
T	Transmittance	
n_o	Represents the true refractive index.	

K_o	Represents the damping factor.	
n_o	Refractive Index ()	
ε	Complex dielectric constant.	
ns	Refractive index of glass.	
Tc	Transmittance of glass.	
(VH)	Hall voltage	
(RH)	Hall coefficient	
(B_Z)	Z-directional magnetic field	
μH	Mobility	
S%	Sensitivity (S)	

List of abbreviations

abbreviation	Meaning
PLD	Pulsed laser deposition
XRD	X-ray diffraction
CBD	chemical bath deposition
FE-SEM	Field-Emission Scanning Electron Microscopy
AFM	Atomic Force Microscope
FWHM	Full Width at Half Maximum
UV	Ultra Violet

Chapter One

Introduction and Literature Review

1.1.Introduction

Depending on the material's fixation ranges and the magnitude of the energy gap between the conduction band and the valence band, solids are categorized as conductors, insulators, or semiconductors. When the temperature rises from zero Kelvin (0K), when they are an insulating material, semiconductors exhibit great electrical conductivity. Because they are affordable, easily available, and influenced by magnetic, thermal, and light fields, semiconductors are widely used in electronic applications[1,2].

Chalcogenide semiconductors are regarded as Nano scale in part of nanotechnology due to its physical and chemical properties, which are mostly governed by their shape and size [3]. It is evident that the semiconducting nanomaterials' characteristics are controlled by their chemical composition, shape, and size [4]. Due to quantum size effects brought on by a predominate number, the semiconductor's nanostructure shows excellent electrical, photo magnetic, and photochemical characteristics that are distinct from those of micro-bulk materials. of atoms on surfaces of nanoscale materials [5]. Metal chalcogen transition compounds are important semiconductor materials, especially at their nanoscale, due to their excellent photo electronic transformation properties, potential applications in physics, chemistry, biology, medicine, materials science, and their various fields in fabrication of solar cells, sensitive sensors, and photon computers[6]. A few examples of the physical and chemical variables that sensors may detect or measure are temperature, pressure, sound, and concentration. and it transforms the information into an electrical signal that alerts us to the presence of anything, such as a harmful chemical or a high gas concentration[7].

1.2 Thin Film Phenomena

Thin film technology are very significant methods that has advanced the study of semiconductors. The study of materials in general and semiconductors in particular is the focus of the significant and distinctive field of thin-membrane physics, which is a subfield of solid state physics. Thin film technology has greatly aided the development of thin film manufacturing methods by providing a thorough understanding of its physical and chemical properties[8].

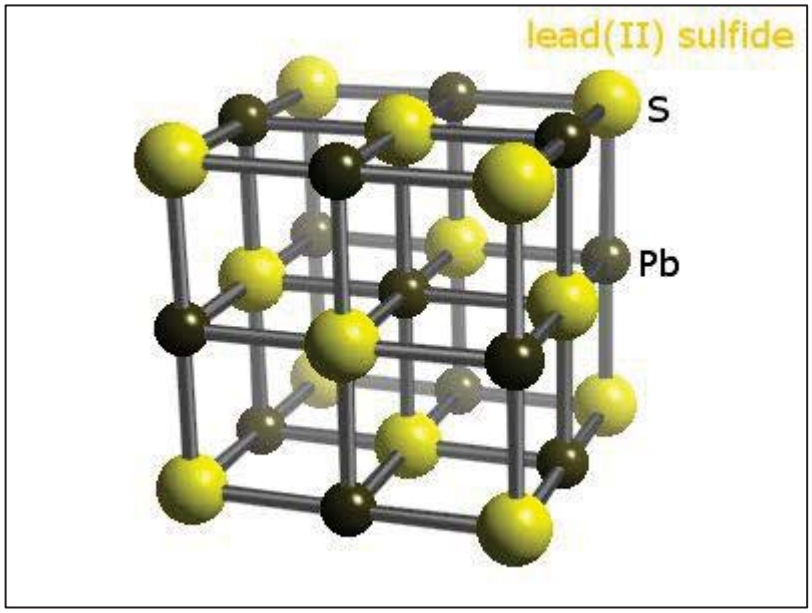
Thin films are composed of atoms in one or more layers with a maximum thickness of (one micrometer). According to the nature of the study, it must be placed on solid bases of glass, silicon, polymer, and other materials because it is thin and delicate (easily broken) [9].

1.3.Thin Film Applications

Resistors, capacitors, transistors, and other electronic components are made of thin films. Because of this character , these materials have a wide range of industrial uses. Advances in the thin film sector have largely been responsible for the accuracy and intelligence of all technologies that people utilize in electronic gadgets[10]. The development of thin films, namely those utilized in nanotechnology, allowed for their entry into the field and the examination of the properties of materials at the nanoscale scale[11].

1.4. Lead Sulphide (PbS)

Lead Sulphide is an IV-VI compound a class of semiconductor, materials that dominated in research and solid state technologies. The crystal structure of PbS is a cubic and as the figure (1-1) [12, 13].



Figure(1-1) crystal structure of Lead Sulfide [3]

1. 5. Lead Sulphide applications

Thin film polycrystalline semiconductors have gained a lot of attention recently and used in a variety of electrical devices. The cheap cost of manufacture is the primary driver of this interest [14]. Infrared detectors, transistors, photoconductive cells, high temperature lubricants, and earthenware glazing all make use of this substance. In order to remove mercaptans from petroleum distillates, it is also utilized as a catalyst in the refinement of petroleum [15].

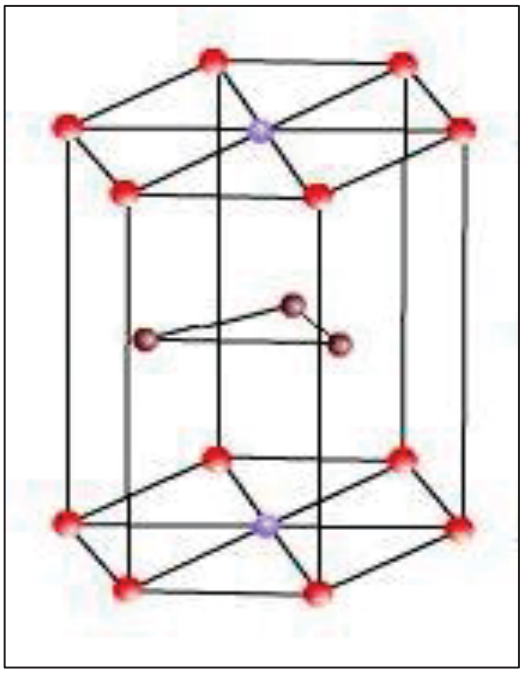
Table(1-1): physical and chemical properties of of Lead Sulphide[15]

Symbol.	PbS
Color	Black
Crystal structure	FCC
Moh's hardness	2.5
Molecular Wight (amu)	239.266
Density (g/cm^3)	7.60
Melting Point (°C)	1118
Boiling Point(°C)	1749
Lattice constant	5.936

By altering the grain size, the band gap of PbS may be changed dramatically. According to some reports, reducing the grain size to a nano domain can cause a rise in band gap from its bulk value by as much as 2.5 eV [16]. Additionally, the optical band gap of PbS thin films may be controlled (to 1.5 eV) and electrical resistivity can be reduced by altering various preparation conditions [17,18]. These features could be linked to substrate characteristics and growth circumstances. Due to these factors, several research teams have expressed a strong interest in creating and studying this material using a variety of deposition techniques, including electrode position, spray pyrolysis, photo-accelerated chemical deposition, microwave heating, and chemical bath deposition (CBD) [19], One of the most advanced and contemporary techniques for thin film deposition is pulsed laser deposition (PLD) .

1.6. Cobalt element

Close-packed hexagonal (Cph) and face-centered cubic crystal structures of cobalt have long been recognized (fcc). Both phases are capable of coexisting at ambient temperature, although the fcc structure is favoured thermodynamically at 450^{o}C while the hcp phase is preferred at lower temperatures. The fcc form, however, seems to be favoured even below ambient temperature for tiny particles. Hull first discovered fcc and hcp cobalt in 1920 after studying the diffraction patterns of powders made using a variety of methods, but it observed new diffraction lines in samples made by spark erosion of bulk cobalt surfaces, but the structure was never fully established. It also noticed several new lines in the diffraction pattern of cobalt nanoclusters made by plasma evaporation and the subsequent condensation of the metal, but attributed these new lines to chance and the figure (1-3) showed the crystal structure of Cobalt and table (1-2) showed the physical and chemical properties of Cobalt [20].



Figure(1-2): crystal structure of Cobalt[20]

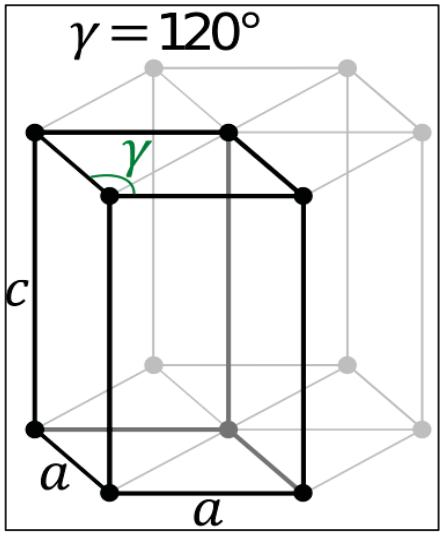
Table (1-2): physical and chemical properties of Cobalt [21]

Symbol.	Co
Color	silver-grey
Crystal structure	Fcc , hcp
Atomic number	27
Atomic Wight (amu)	58.933195
Density (g/cm^3)	8.9
Melting Point (°C)	1495
Boiling Point(°C)	2927
Atomic radius(Pm)	125

1.7. Cadmium element (Cd)

Cadmium is silvery-white, metal glossy, soft and ductile with a moderately high vapour pressure. Cadmium is produced during the miming of zinc metal ores include Cd, a divalent metal that is chemically similar to zinc and is present there due to isomorphous replacement. This metal is less prevalent than zinc and is frequently present in zinc ores as an impurity. It results from the mining of zinc. It is accessible in free form as soft, malleable, ductile, and moderately active similar to other stable metals Zinc and Mercury due to its oxidation state of +2 like Zinc and low melting point feature. In the Earth's crust, cd is a rare and equally distributed element with an average concentration of 0.15 to 0.2 mg/kg. The degree in which Cd is soluble in water depends on the acidity of the medium. As the acidity of the solution increases, more cadmium that is suspended or bonded to sediment will dissolve. In unpolluted fresh water, the

average Cd concentration is less than 0.001 mg/L, while in saltwater, it is 0.00015 mg/L. The figure (1-4) the image displayed the crystal structure of cadmium, and table (1-3) displayed its physical and chemical characteristics. Cadmium may enter plants through the roots or be aerosolized onto plant surfaces [22].



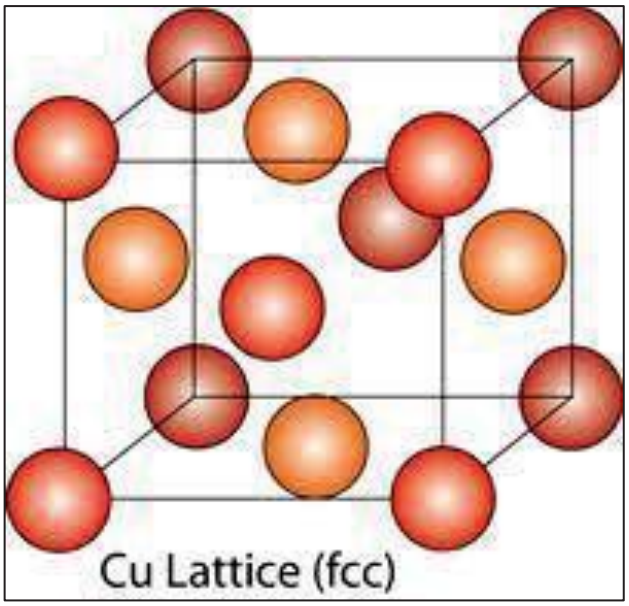
Figure(1-3) crystal structure of Cadmium[22]

Table(1-3) :physical and chemical properties of Cadimum [15]

Symbol.	Cd
Color	metallic
Crystal structure	closed–packed hexagonal
Atomic number	48
Atomic Wight (amu)	112.41
Density (g/cm^3)	8.69
Melting Point (°C)	321
Boiling Point(°C)	767
Atomic radius(Pm)	154

1.8. Copper element(Cu)

Copper, a reddish brown, malleable, ductile, highly electrically conductive, and corrosion-resistant metal, is typically present in metal ores that contain sulfides, arsenides, chlorides, and carbonates. Plumbing and electrical conductors are the principal uses for copper. It is typically has a +2 oxidation state. The black form of copper (II) oxide, known as CuO, may also be found in +1 state. Cu2O is the chemical name for red copper (I) oxide. Copper functions as co-enzyme and is needed to life in trace levels. However it could be poison at high concentrations . Figure (1-5) shows the crystal structure of Copper and table (1-4) shows the physical and chemical properties of Copper[22] .



Figure(1-4) crystal structure of Copper [22]

Table (1-4) :physical and chemical properties of Copper [23]

Symbol.	Cu
Color	brown
Crystal structure	FCC
Atomic number	29
Atomic Wight (amu)	63.54
Density (g/cm^3)	8.94
Melting Point (°C)	1083
Boiling Point(°C)	2595
Atomic radius(Pm)	128

1.9.Literature review

Laxmi J. Tomar et. al. (2014) Synthesized PbS Nano crystals with rod shaped structure by chemical bath deposition process. The structure PbS was located using X-ray diffraction studies.The development of the cubic phase of PbS with the preferred orientation was indicated by the XRD data (2 0 0). The size of the typical crystallite was determined to be 7.82 nm. PbS nanorod production is verified by SEM pictures. By capturing absorption spectra in the wavelength range of 200-900 nm, the optical characteristics were investigated. The refractive index and optical band gap were discovered to be 1.47eV and 2.97, respectively. The electrical resistance was measured by four-probe way and determined to be 0.67MΩ [24].

Rajesh Kumar et. al. (2014) Synthesized nano crystalline PbS doped by Sb thin films were prepared by CBD method. The films were annealed for one hour at 673 K in the air after deposition. The X-ray diffraction (XRD) pattern of the films reveals the formation of well-crystallized PbS with a face-centered cubic structure and the preferred orientation (200). The average crystallite size was discovered to be between 40 and 43 nm. The average grain size, as determined by AFM surface research, is 52.3 nm with smooth surface. As a function of doping, the optical characteristics, absorbance, and transmission of the films have all been measured. A blue shift of the absorption edge in nanostructured thin films is satisfied by a decrease in the band gap Eg from 1.69 eV to 1.59 eV caused by increasing Sb doping in PbS thin films. The electrical resistivity of the films at room temperature ranged from 1.29 to 3.7 X 10^6 cm [25].

Mosiori et. al.(2014) synthesized Lead sulphide [PbS] thin films deposited by the [CBD] method on glass slide substrates for 120 minutes at room temperature. It is possible to model transmittance data in the 260–2000 nm wavelength range in order to derive additional optical and solid state parameters after using a spectrophotometer to assess the thin films' optical properties. The OJL model, the Drude model, and the Kronig Kramer Relation [KKR] model were three optical simulation models that were used by the software. As variables of wavelength and photon energy, the complex dielectric function, band gap, refractive index, absorbance, extinction, and absorption coefficients were examined. According to a study, PbS thin films were discovered to have a band gap of 0.88 eV, optical transmittance below 55% near infrared region, with significant absorption in visible range. It was made ideally for solar cells manufacturing [26].

S. SAGADEVAN et. al.(2014) synthesized lead sulphide (PbS) were Used the spin coating method, lead sulphide (PbS) was placed on a glass substrate while it was still warm. SEM is used to examine the particle size and shape, X-ray diffraction (XRD) was utilized to determine the structure and crystallite size of the films. In diverse frequency range of 50Hz-5MHz at various temperatures, the dielectric characteristics of PbS thin films were investigated. At various temperatures. Additionally, the electrical characteristics of the PbS thin films, such as their electronic polarizability and average energy gap or Penn gap, are computed [27].

Sanjeev Kumar et. al.(2015) studied the effect of substrate temperature on the structural and optical characteristics of PbS thin films produced by pulsed laser deposition. The main goal of this study was to raise many standards for high-caliber movies. At a substrate temperature of just 200°C, the experiment demonstrates the optimal orientation of the (200) reflection plane under compressive stress (-0.31211 GPa). However, an atomic force microscope can also be used to find the area of the film with the least amount of roughness. To calculate the band gap of these films in the weak absorption region, only reflectance spectra are used [28].

C. Rajashree et. al.(2015) investigated Cd doped PbS thin film properties by spray pyrolysis method. Glass substrates were doped with Cd at various concentrations (0, 2, 4, 6 and 8 at-%), and their characteristics were assessed. The X-ray diffraction (XRD) experiments revealed that all of the films exhibit face-centered cubic structure with a preferential orientation along the (2 0 0) plane, regardless of the Cd doping concentration. Optical tests show that when Cd concentration increases, the band gap of doped films shifts between 1.96 and 2.12 eV, and the film coated with 6 % Cd dopant has a maximum transmittance

of nearly 77%. Electrical measurements revealed a maximum conductivity of the 6 %Cd dopant-coated material. The PbS:Cd film coated with 6 %Cd dopant, as a consequence, enhanced the structural, morphological, optical, and electrical properties [29].

Yasmeen Z. Dawood et. al.(2015) studied the nano Lead sulfide PbS thin films' structural characteristics. The samples created via pulse laser deposition and applied on glass using laser intensity of 800mj at a 1064nm wavelength. By studying the impact of changing substrate temperature on these parameters. X-ray diffraction was used to identify the structural attributes of films. The films are highly crystallized, adhering to the substrate, and have a centered cubic structure with the preferred orientation (111), (200). When the film was deposited at a substrate temperature of 70 ^{o}C, the grain size was at its smallest value of 16.5 nm. The optical analysis revealed that direct transitions in the range of 1.55-2.45 eV were permitted depending on the substrate temperature [30].

F. Gode et. al.(2015) synthesized Lead sulfide thin films by Chemical bath deposition and utilized to deposit synthesized Lead sulfide thin films on glass substrates for two hours at room temperature. Different techniques were used to identified the thin films included X-ray diffraction, scanning electron microscopy, atomic force microscopy, optical absorption spectroscopy, and Hall effect measurements. Also, they studied the structure, surface morphology, optical, and electrical properties of these films. The produced films demonstrate the development of well-crystallized PbS with a cubic rock salt structure and the desired orientation (111) plane. The information of X-ray reflectivity from the atomic force microscopy image, showed that the lattice parameter and crystallite size of the films are a = 600 and 62 nm, respectively. The films' band

gap is thought to be 2.84 eV. The films' extinction coefficient, real and imaginary dielectric constant portions, and refractive index were assessed. According to the Hall measurements[31].

M. Chavez Portillo et. al.(2016) studied Li ion-doped PbS thin films' structural, electrical, and opto-electronic characteristics were researched. The Li inclusion in PbS led the crystal size to change from 36 nm to 12 nm, which was a substantial effect of the Li doping on crystallite size. The optical band gap in the range of 1.5e2.3 eV was changed as a result of Li inclusion. It was found that the Urbach energy depends on how much Li is incorporated and that there is Urbach tailing in the band gap. In SEM images, Li doping induced a discernible shift in grain size, although the morphology shifted from large grains to agglomerations of smaller grains. The electric conductivity of the films varied with the quantity of Li doping, reached a peak, and subsequently decreased for films with additional Li. Samples that have been doped showed greater photosensitivity[32].

Kadhim A. Aadim et. al.(2017) Used the pulsed laser deposition (PLD) method, to prepare thin films of lead sulfur (PbS) at room temperature and annealed at various temperatures (573, 673, and 773) K. PbS thin film structural measurements reveal face-centered cubic structure. The PbS surface was examined using atomic force microscopy (AFM). More uniformity may be seen in the movies. After annealing, the root mean square, average particle size, and surface roughness all increased. PbS thin films' optical characteristics are investigated in relation to wavelength in the range of (375 - 1100) nm. PbS thin films' optical transmittance showed that the transparency reduces as annealing temperature rises. Due to the formation of the crystallites, the direct energy gap for PbS thin films decreased with increasing annealing temperatures for all

samples. Calculations were also made for the optical constants such as the refractive index, extinction coefficient, and dielectric constant [33].

S. Ravishankar et. al.(2017) synthesized PbS and PbS with Fe doping were applied to glass substrates. On glass substrates, artificial PbS and Fe doped PbS thin films were created by spraying them with a perfume atomizer. This work investigates and reports on the effects of Fe doping concentration on the structural, morphological, optical, photoluminescence, and magnetic properties of PbS thin films. The changes in Fe concentration are 0, 1, 2, 3, and 4 wt%. Structural investigations reveal that the films all have a face-centered cubic crystal structure with a strong (200) preferred orientation. The Scherrer formula's projected crystallite size decreased with Fe doping, going from 55.73 nm to 31.97 nm. The elemental analysis result that the undoped and doped PbS thin films lack sulfur is considerably confirmed by the presence of an emission peak at 485 nm in the photoluminescence spectra. The optical band gap is blue-shifted by Fe doping. Doped PbS thin films had enhanced magnetic properties. The findings show that Fe2+ ions greatly enhanced the optical and magnetic properties of pure PbS thin films [34].

S. HOROZ et. al.(2018) synthesized PbS by chemical bath deposition (CBD) technique. X-ray diffraction (XRD), energy dispersive x-ray (EDX), and absorption measurements were used to investigate PbS which was produced via chemical bath deposition (CBD) method on glass substrates at ambient temperature. Although both thin films have the same structure, it was found that the particle size of the PbS:Ni (3%) thin film was smaller than that for PbS in the presence of Ni as additive material (cubic phase). Using the information gathered as a consequence of the optical measurements, a comparable outcome

was attained. Additionally, a bigger energy band gap was seen in the PbS thin film when Ni was added to it [35].

Hariyadi Soetedjo et. al.(2018) synthesized Cu-doped PbS thin films were prepared using a DC sputtering technique. The Cu dopant plate material was introduced directly onto the PbS sputtering target plate's surface to achieve the doping. According to SEM-EDX measurements, the Cu content in the PbS film was inversely correlated with the diameter of the Cu plate. The film was in crystalline cubic shape, according to the XRD pattern. According to the Hall effect test, Cu doping results in a considerable reduction in electrical resistivity and an increase in the carrier concentration to 3.55 1019 cm 3. The lowest resistivity measured was 0.13 at 18.5% Cu content. During deposition, (1 1 1) and (2 0 0) were oriented preferentially [36].

Omer Şahin et. al.(2019) studied the synthesized PbS and PbS:Mo(3%) thin films deposited using chemical bath deposition (CBD), a technique for producing pure PbS and PbS:Mo(3%) thin films on glass substrates. The major goal of this study was look at how the additional metal, Mo, can affect the optical energy band gap, photovoltaic characteristics, and crystallite size of the PbS semiconductor thin film. Even though the structure of the PbS:Mo(3%) thin film was the same as pure PbS, it was discovered to have a smaller crystallite size (24.12 nm) (25.97 nm). PbS and PbS:Mo(3%) thin films were found to have band gaps of 1.89 eV and 1.91 eV, respectively. The integration of Mo6+ ions into the PbS lattice is one potential explanation for the rise in the energy band gap of the PbS:Mo(3%) thin film. Via IPCE and J-V measurements, the photovoltaic characteristics of PbS and PbS:Mo(3%) thin films produced on Zn2SnO4 coated on FTO conductive glasses using CBD method were examined. At 400 nm, the pure PbS and PbS:Mo(3%) thin films' IPCE (%) values were 35% and 41%, respectively. For thin films constructed of pure PbS

and PbS:Mo(3%), the power conversion efficiency values were found to be 2.02% and 2.11%, respectively. It was found that the doped metal considerably enhanced the photovoltaic qualities of PbS thin films [37].

Mengting Liu et. al.(2019) prepared lead sulfide (PbS) thin films with Zn doping concentrations range from 0% to 5% by chemical bath deposition from previously investigated lead sulfide (PbS) thin films with Zn doping values ranging from 0% to 5%. According to X-ray diffraction, the predicted crystallite size reduced from 20.6 nm to 16.7 nm when zinc doping concentration rose (XRD). The PbS nanocrystals on the surface of the films had a pyramidal form, and FESEM images show that the grain size decreased as the doping concentration increased. The AFM measurements show that Zn doping has decreased the root mean square roughness of the PbS sheet. Using a UV-spectrophotometer in the 400-2400 nm range, PbS films' optical bandgap grew from 1.14 eV to 1.74 eV when their optical properties were investigated. All the films were p-type semiconductors at the time of deposition. [38].

Ahmed K.Abbas et. al.(2021) synthesized Lead sulfide Using laser-induced plasma. have been investigated by analyzing the laser-produced PbS plasma spectra at different energies (200, 300, 400, 500, 600mJ). The item was subjected to Nd: YAG laser light at a wavelength of 1064 nm. The electron temperature (Te), electron density (ne), Debye length (D), and plasma frequency were determined using optical emission spectroscopy (fp). The analysis of this air mixture's spectra is a method that used to calculate the electron temperature by Boltzmann plot method and the electron density using the Stark broadening of Pb lines. The results showed the significance of electron temperature in the range of (1.465-1.599 eV) and electron density in the range of (1.11-1.47)1018 cm^{-3} at a wavelength of (1064) nm [39].

1.10. The Aim of the Work

1- Study the effect of (cadmium, Copper, and Cobalt) in different mixing ratio on the (structural , optical and electrical) properties of PbS thin films prepared on glass substrates.

2- Manufacturing and preparing gas sensors from (PbS , PbS:Cd , PbS:Cu and PbS:Co)