Examining Impacts of Acidic Bath Temperature on Nano-Synthesized Lead Selenide Thin Films for the Application of Solar Cells

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Received 22 October 2021; Revised 2 December 2021; Accepted 22 December 2021; Published 10 January 2022

Academic Editor: Wilson Aruni

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The influence of bath temperature on nano-manufactured PbSe (lead selenide) films was successfully generated by utilizing CBD on the acid solution’s metal surface tool. Pb(NO₃)₂ was employed as a lead ion source as a precursor, while Na₂O₄S was used as a selenide ion source. The XRD characterization revealed that the prepared samples are the property of crystalline structure (111), (101), (100), and (110) Miller indices. The scanning electron microscope indicated that the particles have a rock-like shape. There was a decrement of energy bandgap that is from 2.4 eV to 1.2 eV with increasing temperature 20°C–85°C. Thin films prepared at 85°C revealed the best polycrystal structure as well as homogeneously dispersed on the substrate at superior particle scales. The photoluminescence spectrophotometer witnessed that as the temperature of the solution bath increases from 20°C to 85°C, the average strength of PL emission of the film decreases. The maximum photoluminescence strength predominantly exists at high temperatures because of self-trapped exciton recombination, formed from O₂ vacancy and particle size what we call defect centres, for the deposited thin films at 45°C and 85°C. Therefore, the finest solution temperature is 85°C.

1. Introduction

Currently, the world is in trouble with air and water pollution released from nonrenewable energy sources such as coal, natural gas, fossil fuels, and fabrics [1]. The fuels released from fabrics flow out to the rivers and cause water pollution. This polluted water is directly consumed by a person and cause diseases like cholera, amoebic dysentery, and typhoid. Generally, it harms human safety health in the world. Photovoltaic technology connects solar power renewable and sustainable energy. This renewable energy originates from natural assets that are continuously replaced. These include the sunlight,
ocean, and the power of wind [2]. This technology of energy is
deliberately unpolluted and does not contain carbon since it
does not emit greenhouse gases [3]. Since it is a clean energy
source, it has no influence on the atmosphere other than the
energy coming from fossil coals. When they are burned, they
release dangerous carbon toxic radiations into the environment
[4]. To reduce these hazardous wastes and pollutions from the
world, the production and fabrication of solar cells from
compound semiconductor thin films is the only solution.
Because currently, the existing elemental semiconductor is very
expensive and anybody cannot use it [5]. A wide-ranging
investigation has been dedicated to produce numerous kinds of
semiconductor thin films which are applicable in renewable
sources of energy like solar cells [6]. This is because of their
potential uses in the production of photovoltaic materials,
optical-electronic devices, and sensor and infrared indicator
instruments [3]. The lead selenide thin films appeal consider-
ation of many scholars because they involve low cost, exist in
abundance, and retain semiconducting material goods [7].

The production of films like lead selenide has been
discovered via so many methods. These include electrode-
deposition, CBD, electrochemical atomic layer, photochemical,
and molecular beam epitaxial deposition method [6]. The
films synthesized via solution techniques are generally in-
expensive than films produced via the concentrated somatic
methods. In the present work, the CBD technique was
carefully chosen because of its many benefits like the in-
expensive, wide scope of fabrication, and straightforward-
ness during the installation.

Present, chemical bath preparation techniques are used
to synthesize many semiconductors films, including [8] zinc
sulfide (ZnS), lead selenide (PbSe), cadmium selenide(CdSe),
zinc selenite (ZnSe), Cu2S (copper sulphide), CuInS (copper
indium sulfide), and CuBiS2 (copper bismuth sulfide) on
glass substrates [9], and they have no longer quality.

There are very few chemically prepared PbSe films reported
by using glasses substrates in an alkaline base. But this can
make deletions of films and affect the quality of prepared films.
Even they release toxic hydroxide chemicals during their de-
positions [10]. For the present work, we have used metallic
substrates to grow lead selenide films via the CBD method in an
acidic medium (pH = 4) for the applications of solar cells.

2. Instruments and Methodology
PbSe films were grown on a metallic substrate (30 × 70 × 1 mm
by means of CBD techniques. Proceeding to preparations, the
metal substrate was inserted in ethanol for about 15 min,
tracked via ultra-sonically washed in deionized water again for
20 min, and lastly desiccated in warm condition. The solution of
lead nitrate was used as a metallic precursor source that is
lead, sodium selenite as the sulphide ion source, and
[(HOC2H4)3N] as a complexing agent for synthesis of lead
sulphide thin films [10, 11]. All compounds were analytically
graded before the deposition, and the bath solutions were
equipped with deionized seawater. Stepwise deposition, 25 ml
of 0.2 M of lead nitrate was complexed with 15 ml of trietha-
nolamine. Next, 15 ml of 0.2 M of sodium selenite was dropped
step by step to the reaction. The pH values of the resultant
solution were controlled by using droplet sulfuric acid [12] and
then with continual stirring. The cleaned metal substrate was
bought from a shop prepared to grow nanoparticles of lead
selenide, with varying temperatures as 20°C, 45°C, and 85°C. As
preparation time required, 95 min ended; we fetched the water
from the chemical solution by using a syringe. The bottom of a
glass of bath solution is left with molten lead selenide nano-
particles. Next, the metal substrates were coated with molten
lead selenide, and it was dried in the air, splashed with
deionized seawater and kept in an oven for further analysis.

Crystalline structures of nano-synthesized PbSe films
were studied by using XRD, PANalytical, US [13]. The
diffraclometer is kept with CuK sources to operate at 35 kV
and 23 μA; the scanning was taken in a 2θ range from 20° to
85°. An optical absorption measurement was executed using a
Janeway 6850 UV/visible spectrophotometer in the range of
226–2250 nm. The surface morphology study of nano-
particles size was characterized via scanning electron micro-
scopy on a Hitachi SU5000 with an operating voltage of
20 kV. Photoluminescence of the prepared material was
analyzed by using a photoluminescence spectrophotometer.

3. Results and Discussion
3.1. Structural Characterization. The X-rays diffraction
patterns of the PbSe thin films deposited at different tem-
perature bath solutions are shown in Figure 1. Thin films
deposited at 45°C observed with four peaks at 2θ = 26° and
30.6°C. When bath solution temperature rises to 85°C, the
intensity of the peaks attributable to PbSe is revealed. The
position of the peak along the (111), (101), (100), and (110)
Miller indexes reveals the saturated intensity with well-
deﬁned sharp indicating high crystallinity of the material
prepared. This means that the grain size of the grown thin
ﬁlm increases with the temperature of the bath. The number
of peaks of PbSe films also increased when bath temperature
increased. These witnesses show that the deposited structure
has a cubic phase, matching with earlier reported data [12]. The
three lattice constant values are equal to 6.13 Å. In this case,
the presence of iron dioxide peaks in the XRD is be-
cause of the metallic substrate used to prepare films. The
observed four peaks are at 26 values, 40.2, 52.8, and 67.3. The
peaks via solid triangles are related to the cubic shape of lead
selenide, and those striking with undefended diamonds
attributed to the orthorhombic crystal of iron dioxide. This
result is witnessed with scanning electron microscope analysis homogeneous and cubic structure; this result agrees
with a reported study [13]. Comparison of evaluated and
standard “d” and 2θ values for nano-synthesized PbSe thin
films with varying bath temperatures (20°C, 45°C, and 85°C)
deposition time 95 min is given in Table 1.

The size of the particle was premeditated by using
Scherer’s formula; it is given by

$$D = \frac{0.9λ}{β \cos \theta}$$

where λ shows the wavelength, β stands for the FWHM in
rad, and θ represents the angle diffraction (Bragg angle).
3.2. Surface Morphology Characterization of PbSe Thin Films. The scanning electron microscope micrographs of PbSe thin films deposited at different temperatures are shown in Figure 2. Variation of temperatures shows a significant influence on the surface morphology of the thin films. All micrographs samples were taken at 10.00 kV and 20.71x magnification. Scanning electron microscopy reveals that lead selenide films grown at all temperatures fully covered the metal substrates. The synthesized films that had cracks were very small in size with well-covered grain borders. As the researcher, well-defined grains were observed for the film deposited at all temperatures, but the grains were decreasing with temperature increases from 20°C to 85°C. As it was observed in XRD analysis, the shape of PbSe films was cubic, and fully covered crystals on the metal substrate were investigated. Increasing temperature raises the smoothness of the films; the grain amounts were observed to rise slowly. Additionally, there is a material which just likes soil which decreases in size as shown in Figures 2(a)–2(c) with increasing bath temperature from 20°C to 85°C that shield over cadmium sulphide thin films in some amounts of the apparent. The impact of temperature on the surface morphology of nano-synthesized lead selenide films was observed; this is in good agreement with a reported study [14].

3.3. Optical Properties. The optical immersion of the nano-synthesized lead selenide films prepared from different temperatures was measured in the wavelength range of 226–2250 nm, which is in the visible region photocatalyst, as shown in Figure 3. The absorbance of the films expressively increased when the bath temperature increased within the deliberated range of wavelength. The highest absorption of thin films was witnessed in the visible wavelength (λ) range. The absorption coefficient of PbSe films was evaluated by using Lambert’s equation:

$$\alpha = \frac{A}{t},$$

where $A$ is the absorbance, $\alpha$ is the absorption of coefficient, and $t$ stands for the thickness. The band gaps ($E_g$) of films were calculated from Tauc’s relation [15]:

$$(ahv)^n = k(hv - E_g),$$

where $h$ is Planck’s number, $v$ stands for the frequency, $k$ expresses the optical transition constant number, $E_g$ is the energy of bandgap, and $n$ is transition type, and it is varying either 2 or 2/3 for direct allowed and forbidden transitions or 1/2 or 1/3 for indirect allowed and forbidden transitions, correspondingly [16]. Best linear fit for equation (3) is given for $n = 2$ in the main absorption edge, representing that the thin films have direct optical band gaps. The $(ahv)^n$ axis intercept attained by extrapolating the linear portion of the $(ahv)^2$ vs. $(hv)$ curve gives the $E_g$ of the films as shown in Figure 3. The $E_g$ of the nano-synthesized PbSe thin films declined from 2.4 eV to 1.2 eV with the temperature of the solution increasing from 20°C to 85°C. The bandgap decrement could be because of increment of crystal size with temperature; this result is the same as reported [17]. The maximum absorbance observed in visible light section and band gaps of thin films within the range of 2.6–1.2 eV in all PbSe thin films provides the application materials as the absorber layer in photovoltaic thin film solar cells as well as well-organized visible light photocatalyst [18–21].

3.4. Photoluminescence Property (PL). Inappropriate to discover the optical study of deposited PbSe nanoparticles, photoluminescence was similarly used. In the λ range from 350 nm to 600 nm at different temperatures, the PL spectrum of nano-synthesized films was reported. When solution bath temperature increases from 20°C to 85°C, the average strength of PL decreases. The maximum photoluminescence strength is predominant because of the self-trapped exciton recombination, formed from O$_2$ vacancy and particle size what we call defect centres, for the deposited thin films at 45°C and 85°C. The photoluminescence intensity rises sequentially with all temperatures.
Figure 4 shows the absorption of nano-synthesized lead selenide films deposited at various temperatures; all samples reveal a gradual rising absorbance in the visible area, which provides the potential for these tools to be applicable in a photovoltaic solar cell. The plotted figure shows that the samples synthesized at a greater temperature of the solution have greater absorption values related to other solution bath temperatures. Because these are nano-synthesized, thin films have the maximum uniform surface and well crystallinity compared with other reported samples.
Nanocrystalline lead selenide films are successfully prepared using an easy, inexpensive method. Chemical solutions made from lead nitrate and sodium selenite compounds are used as sources of lead and selenide ions. The triethanolamine was used as a complexing mediator through the deposition procedure. The X-ray diffraction pattern tells the creation of a cubic crystalline structure with very sharp peaks defined as (111), (101), (100), and (110) Miller indices plane. PL confirmed that photoluminescence emission of the deposited thin films increased with increasing bath temperature. The deposited film at 85°C indicated the best crystallite and is homogeneously formed on a substrate with larger crystal sizes. Bandgap energy was declined from 2.4 eV to 1.2 eV with temperature increases from 20°C to 85°C, and this is suitable for photovoltaic solar cells.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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