

Original Article

Structural, Optical, Electrical and Photoconductive Properties of Pbs Thin Film Synthesized Via a Three-Step Cation-Anion Exchange Process

A. S. Gayakwad¹, R. D. Ladhe², K. B. Deore³

¹Department of Physics, S.S.M.M Arts, Science and Commerce College, Pachora Maharashtra, India

²Department of Physics, D.N.C.V.P.S Shirish Madhukarrao Chaudhari College, Jalgaon Maharashtra, India

³ Department of Physics, JET's Z.B. Patil College, Dhule Maharashtra, India

Manuscript ID:
IJERSD-2026-020307

ISSN: 3067-2325

Volume 2

Issue 3

Pp. 32-37

June 2026

Submitted: 12 May 2026

Revised: 19 May 2026

Accepted: 12 June 2026

Published: 30 June 2026

Correspondence Address:

A. S. Gayakwad
Department of Physics, S.S.M.M
Arts, Science and Commerce
College, Pachora Maharashtra,
India
Email: asgayakwad@gmail.com

Quick Response Code:



Web: <https://rlgjaar.com>

DOI: 10.5281/zenodo.23057686

DOI Link:
<https://doi.org/10.5281/zenodo.23057686>



Attribution-NonCommercial-
ShareAlike 4.0 International



Abstract

The semiconductor thin films have been synthesized through a chemical process and studied for their physical, optical, and photoelectrical characteristics. Based on the X-ray diffraction patterns, the material is found to be crystalline, with clear peaks that correspond to specific crystallographic planes such as (111), (200), (220), (222), and (420). When it comes to the optical properties of the thin films, the material shows strong absorption in the UV-visible range. Using the Tauc plot, the optical band gap of the material is calculated to be approximately 1.85 eV. From the electrical measurements, a linear relationship between current and voltage is observed, indicating that the material exhibits ohmic conductivity. The significant increase in photocurrent compared to the dark current suggests that the generated charge carriers are efficiently transported through the material.

Keywords: Lead sulphide thin film, XRD analysis, FESEM, optical properties, electrical properties, photoconductive properties.

Introduction

PbS thin-film semiconductors have gained significant attention because of their wide applications in optoelectronics, including detectors, solar cells, sensors, and energy conversion systems [1–4]. The performance of these materials is strongly influenced by their structural, morphological, optical, and electrical properties [5]. Understanding how the microstructure of these materials affects charge transport can help in improving the performance of semiconductor-based devices. Furthermore, PbS has high carrier mobility and a significant Bohr exciton radius (~18 nm), which support effective charge transport and exciton separation in nanoscale applications [6–9]. Field emission scanning electron microscopy (FESEM) is a common technique used for characterizing thin film morphology and grain sizes. The structural parameters of the thin films such as grain boundaries, surface roughness, and particle agglomeration play an important role in optical and electrical properties. Grain structure influences the charge transport properties, and a connected uniform grain structure will enhance electrical conductance properties by minimizing scattering and recombination.

Apart from morphology, the current-voltage (I-V) characteristics help in investigating the electrical conductance properties of materials. The I-V graph provides information regarding whether the material exhibits ohmic or non-ohmic conduction and also about electrical contact characteristics. In addition, conducting I-V analysis under both dark and light conditions will enable investigation of photocurrent generation and transport characteristics of the material. The optical characteristics, including the absorption characteristics and energy bandgap, influence the interaction capability of the substance with light and production of charge carriers. Substances that have energy gaps in the visible spectrum range are more appropriate for the conversion of solar energy and photodetector applications. The structural features derived through XRD studies add value to such investigations by ensuring phase formation and crystallization. This paper explores the fabrication and characterization of semiconductor PbS thin film based on a chemical process and utilizes techniques such as XRD, UV-Visible spectroscopy, FESEM, electrical and photoconductive properties.

Creative Commons

This is an open access journal, and articles are distributed under the terms of the [Creative Commons Attribution NonCommercial-ShareAlike 4.0 International](https://creativecommons.org/licenses/by-nc-sa/4.0/). The Creative Commons Attribution license allows re-distribution and re-use of a licensed work on the condition that the creator is appropriately credited.

How to cite this article:

Gayakwad, A. S., Ladhe, R. D., & Deore, K. B. (2026). Structural, Optical, Electrical and Photoconductive Properties of Pbs Thin Film Synthesized Via a Three-Step Cation-Anion Exchange Process. *International Journal of Engineering Research for Sustainable Development*, 2(3), 32–37. <https://doi.org/10.5281/zenodo.23057686>

Experimental Methodology

PbS nanostructures were synthesized via a three-step chain reaction process using a chemical bath deposition technique at room temperature ($\sim 27^\circ\text{C}$). Initially, $\text{Cd}(\text{OH})_2$ nanoparticles were deposited on clean glass substrates by immersing them in a 0.1 M CdCl_2 aqueous solution, followed by controlled addition of ammonia to maintain an alkaline pH (~ 12). The substrates were kept inclined ($\sim 45^\circ$) in the bath for 16 hours, then rinsed and air-dried. Subsequently, cation exchange was carried out by immersing the $\text{Cd}(\text{OH})_2$ coated substrates in 0.15 M lead acetate solution for 10 hours, resulting in the formation of $\text{Pb}(\text{OH})_2$. After washing and drying, the substrates were further treated in a 0.1 M sodium sulfide (Na_2S) solution for 21-24 hours, leading to the conversion of $\text{Pb}(\text{OH})_2$ into PbS.

Characterization Techniques

To study the synthesized PbS thin films, several analytical techniques were used to examine their structural, physical, optical, and electrical properties. X-ray diffraction (XRD) was performed using $\text{Cu-K}\alpha$ radiation (wavelength of $1.5406 \text{ \AA}$) to identify the crystal structure and the different phases present in the PbS film. A Field Emission Scanning Electron Microscope (FESEM) was used to examine the surface morphology and structure of the film.

To determine the optical properties, UV-Visible spectroscopy was conducted over a wavelength range of 350 to 1000 nm. The optical band gap was calculated using the Tauc plot method. Electrical properties were assessed through I-V measurements to understand the material's conductivity. Additionally, resistivity was measured at various temperatures. To investigate the photoconductivity of the PbS thin film, photoconductivity tests were carried out using an external light source such as a halogen lamp.

Results & Discussions

1. Diffraction (XRD) Analysis

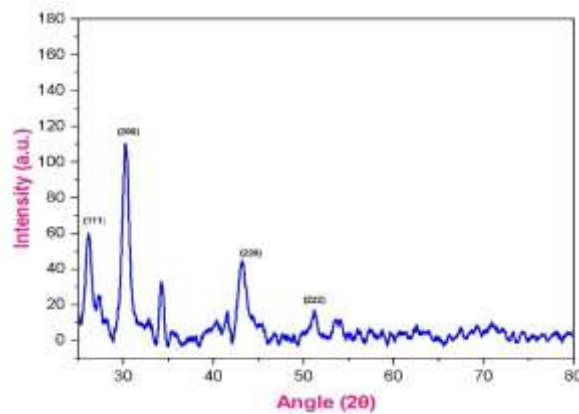


Figure 1: XRD graph of synthesized PbS thin film.

The structure of the PbS thin film was studied using X-ray diffraction (XRD). The diffraction pattern, measured in the angular range of about 20° to 80° , showed several clear peaks, indicating that the sample has a crystalline structure. These peaks correspond to the crystal planes with Miller indices (111), (200), (220), and (222), as listed in JCPDS Card no. 05-05092 [10,11]. The strongest peak, corresponding to the (200) plane, suggests that the crystals grow preferentially in that direction, indicating anisotropy in the structure. The presence of several strong peaks with very little background noise shows that the film is well crystallized and has a pure structure. No extra peaks due to impurities were observed in the diffraction pattern. The crystallite size of the thin film was calculated using the Scherrer equation [12]:

$$D = 0.9\lambda / \beta \cos(\theta)$$

Where, D is the crystallite size, λ is the wavelength of $\text{Cu-K}\alpha$ radiation ($1.5406 \text{ \AA}$), β is the full width at half maximum (FWHM) of the diffraction peak, and θ is the Bragg angle. The calculated crystallite size was 9.25 nm , which shows that the film has a nanocrystalline structure. The narrow width of the peaks also suggests better crystallinity and fewer lattice defects.

2. Surface morphology

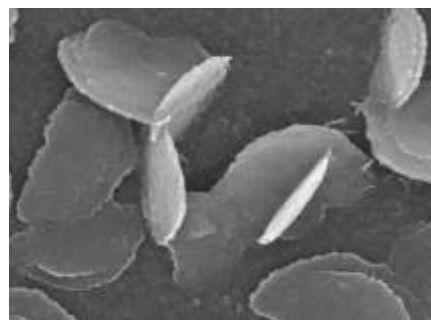


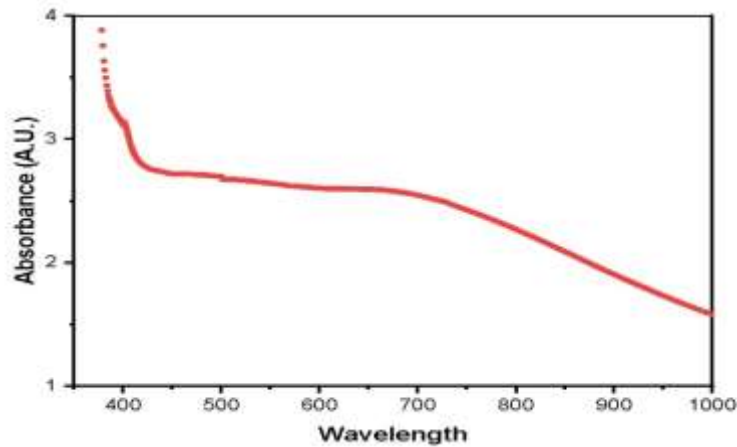
Figure 2: FESEM image of synthesized PbS Thin Film

The surface morphology of the synthesized PbS thin films was investigated using field emission scanning electron microscopy (FESEM), as presented in Fig. X. The micrograph reveals that the film consists predominantly of platelet-shaped nanostructures distributed uniformly over the substrate surface.

The grains exhibit irregular geometries with relatively smooth surfaces and well-defined boundaries, indicating controlled nucleation and growth of PbS crystallites. The nanoplate are found to be closely packed and partially overlapped, resulting in a continuous and compact film with good surface coverage. The absence of noticeable cracks and pinholes suggests that the deposited films possess high uniformity and structural integrity.

In addition, a layered arrangement of the nanoplate is observed, which can be attributed to anisotropic crystal growth during the deposition process. Such morphological features are commonly reported in PbS thin films synthesized via low-temperature or solution-based techniques [18]. A slight degree of agglomeration is also evident, which is typical for nanocrystalline materials due to their high surface energy.

3. Optical Absorption and Bandgap Analysis



Absorbance Spectrum

Figure 3: Absorbance spectra of the PbS thin film

Optical analysis of the synthesized PbS thin film was carried out using UV-visible spectroscopy, ranging from 350–1000 nm. In the absorbance curve, the maximum absorbance occurs at lower wavelength values, i.e., UV-visible range, followed by a gradual decrease in the absorbance value as the wavelength increases. This high absorbance in the UV region implies that the thin film is capable of efficiently absorbing photons through electronic transition between the valence and conduction bands.

In addition, there is a sudden absorption edge in the visible part of the spectrum, implying fundamental absorption related to bandgap absorption of the material. In addition, there is a gradual decrease in the absorbance value beyond this region, indicating weak interaction of photons beyond the absorption edge. There is no abrupt change in absorbance, which implies uniformity in film formation without any defects.

Bandgap Determination

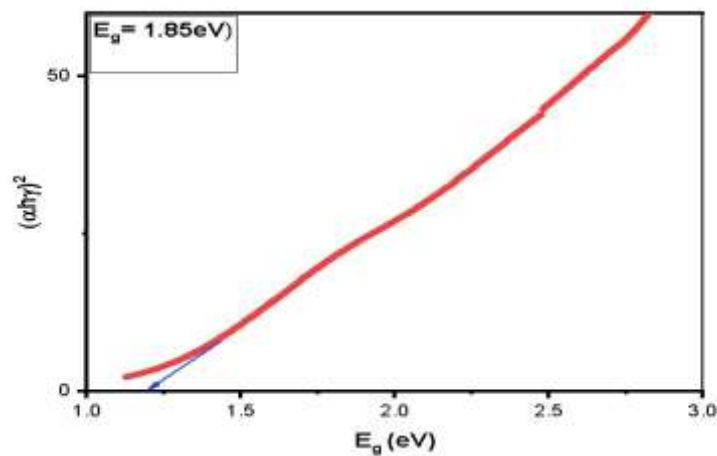


Figure 4: $(\alpha h\nu)^2$ against photon energy ($h\nu$)

The optical bandgap of the thin film was calculated based on the Tauc equation for a direct allowed transition. The graph plotted between $(\alpha h\nu)^2$ and the energy of the photon ($h\nu$) reveals a straight-line segment close to the absorption threshold. From this graph, the optical bandgap is obtained by extrapolating the straight-line segment to the energy axis.

$$\alpha h\nu = A(h\nu - E_g)^{1/2}$$

From the extrapolation of the graph, the optical bandgap energy (E_g) is estimated at about 1.85 eV. It can be noted that the energy gap falls within the visible spectrum range of electromagnetic radiation [13].

The straight-line shape of the Tauc graph indicates a direct allowed transition characteristic of the material. The small bandgap implies strong optical absorption capability and high charge carrier generation efficiency [14-15].

4. Current–Voltage (I–V) Characteristics of PbS Thin Films

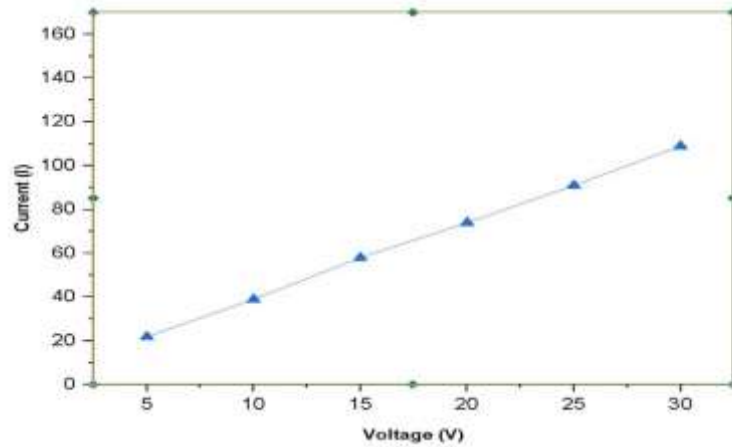


Figure 5: I-V graph of synthesized PbS thin film

Current–voltage (I–V) characterization of the synthesized sample was conducted over the voltage range of 5–30 V. As depicted in Figure X, there is a linear rise in current when the applied voltage varies over the studied range, showing that the current and voltage have a proportional relationship. This linear relationship proves that the sample adheres to the principle of Ohm's law, which can be expressed as

$$I = V/R$$

The linear relationship of the plot implies that there is no deviation from ohmic contacts on the part of the electrodes and the sample since this indicates low contact resistance and effective charge carrier transfer. The slope of the I–V curve shows that the resistance of the sample hardly changes with voltage, showing that the electrical conduction is stable and does not deviate due to the phenomenon of Joule heating and trap-controlled conduction. Also, there are no non-linear sections implying that barrier-controlled transport does not occur in this sample.

Ohmic conductivity is usually characteristic of samples having homogeneous morphological structure and good crystallinity because charge carriers experience fewer barriers during transport through the sample.

5. Temperature-Dependent Resistivity

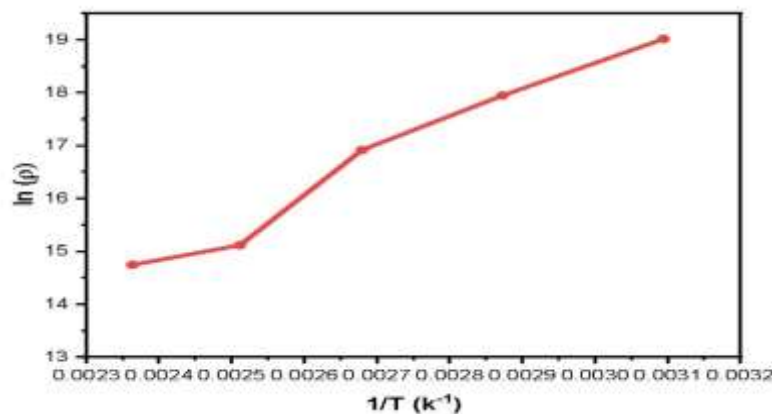


Figure 6: $\ln(\rho)$ Vs $1/T$

Temperature-dependent resistivity values of the prepared thin film show that the samples exhibit semiconductor-like behavior. Resistivity decreases as the temperature rises in accordance with the negative temperature coefficient of resistivity (NTCR). Such behavior indicates that the electron transport mechanism in this system takes place by means of thermally activated electrons.

In case of low temperatures, resistivity values are relatively high since the number of charge carriers is not sufficiently large. An increase in temperature leads to adequate thermal excitation of electrons to the conduction band from localized states or from the valence band, respectively. No abrupt changes observed in the resistivity versus temperature plot suggest that no phase transition processes are involved and indicate uniform crystalline structure of the prepared sample.

Moreover, resistivity values obey Arrhenius equation:

$$\rho = \rho_0 e^{E_a/kBT} \quad [16].$$

In summary, the electrical behavior of the material synthesized clearly shows that it exhibits thermally activated conductivity with stable transport properties. These properties make it very useful in electronic applications where thermal properties are critical.

6. Photoconductivity Studies

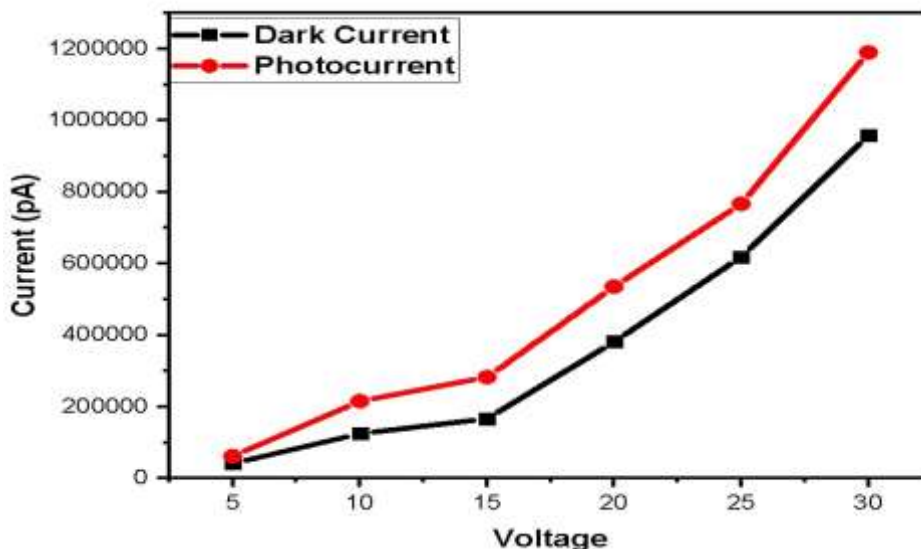


Figure 7: I-V graph of PbS thin film (I_d– Dark current and I_p– Photocurrent)

Photoconductivity of the fabricated PbS thin films was studied under illumination with halogen lamp serving as light source. From the I–V plots obtained, the current-voltage relation shows nearly linear relation, indicative of the ohmic conduction property and excellent electrode-film contact.

In terms of the experiment results, there is a significant increase in the measured current when subjected to illumination. The change in current is illustrated by the measured current increasing from $\sim 10^3$ at low voltages to $\sim 10^5$ when voltages are increased. There is an immense increase in the conductivity of the thin film due to illumination [17]

The increase in the photocurrent measured is attributed to the absorption of light whose photon energy is almost equal to that of the bandgap (~ 1.85 eV). This energy causes the valence electrons to be excited to the conduction band, resulting in the generation of electron-hole pairs which conduct electricity. The absence of saturation in the I–V curve indicates minimal recombination losses and stable carrier dynamics within the material. The high magnitude of photocurrent reflects strong light absorption capability, efficient photocarrier generation and good charge carrier mobility and transport

In general, the obtained results demonstrate that the PbS thin film has excellent properties of light responsiveness and stability under light illumination, and can be applied to produce optoelectronic devices such as photodetectors and optical sensors.

Conclusion

The PbS films were successfully prepared through a chain reaction process using a chemical bath deposition approach in room temperature conditions. The result from the X-ray diffraction measurement showed the presence of a polycrystalline form of PbS with well-resolved diffraction peaks. From the FESEM image analysis, there were well-distributed grains within the film surface, suggesting that charge transport would be easy. From the optical property analysis, there was a good absorbance of the light by the sample material, and the optical bandgap was determined to be 1.85 eV, which made it a promising light harvesting material. The electrical measurements indicated that it was a semiconductor material because its resistivity decreased with increasing temperatures.

The photoconductivity study under the illumination of the halogen lamp showed that the current significantly increased to the order of 10^3 to 10^5 pA.

Acknowledgment

The authors express their sincere gratitude to the Director, School of Physical Sciences, Kavayitri Bahinabai Chaudhari North Maharashtra University (KBCNMU), Jalgaon, for providing the necessary research facilities and technical support. The authors also extend their heartfelt thanks to the Principal and the Department of Physics, S.S.M.M. Arts, Science and Commerce College, Pachora, and D.N.C.V.P.S. Shirish Madhukarrao Chaudhari College, Jalgaon, for their continuous support, encouragement, and cooperation throughout this research work.

Financial support and sponsorship

Nil.

Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

References

1. S. A. McDonald, P. W. Cyr, L. Levina, E. H. Sargent, Appl. Phys. Lett. 85, 11 (2004). Appl. <https://doi.org/10.1063/1.1792380>.
2. M. M. Abbas, A. A. M. Shehab, A. K. A. Samuraec, N. A. Hassan, Energy Procedia 6, 241 (2011).
3. G. Nabyouni, P. Boroojerdian, K. Hedayati, D. Ghanbari, High Temp.Mater. Proc. 31, 723 (2012). DOI:10.1515/htmp-2011-0155.
4. M. C. Weidman, M. E. Beck, R. S. Hoffman, F. Prins, W. A. Tisdale, ACS nano 8, 6363(2014).
5. DOI:10.48550/arXiv.1603.02547.
6. Y.F. Nicolau, Applications of Surface Science, 22/23(1985) 1061.
7. [https://doi.org/10.1016/0378-5963\(85\)90241-7](https://doi.org/10.1016/0378-5963(85)90241-7).
8. K. K. Nanda, F. E. Kruis, H. Fissan, J. Appl. Phys. 95, 9 (2004)
9. <https://doi.org/10.1063/1.1691184>.
10. Z. Huang, G. Zhai, Z. Zhang, C. Zhang, Y. Xia, L. Lian, X. Fu, D. Zhang, J. Zhang, Cryst.
11. Eng. Comm. 19, 946 (2017). <https://doi.org/10.1039/c6ce02471h>.
12. J. R. Caram, S. N. Bertram, H. Utzat, W. R. Hess, J. A. Carr, T. S. Bischof, A. P. Beyler, M. W. B. Wilson, M. G. Bawendi, Nano Lett. 16, 6070 (2016). DOI: 10.1021/acs.nanolett.6b02147
13. S. B. Pawara, J. S. Shaikh, R. S. Devanc, Y. R. Mac, D. Haranathd, P. N. Bhosalea, P. S. Patil, Applied Surface Science 258, 1869 (2011).
14. S.I. Sadovnikov, A.I. Gusev, Journal of Alloys and Compounds, Volume 573, 2013. DOI: 10.1016/j.jallcom.2013.03.290.
15. Vu, Le & Doanh, Sai & Nga, Le & Nguyen Ngoc, long. (2011. e-Journal of Surface
16. Science
17. and Nanotechnology. 9. 494-498. <https://doi.org/10.1380/ejsnt.2011.494>.
18. Danye Liu, Linlin Xu, Jianping Xie, Jun Yang, Nano Materials Science, Volume 1, Issue
19. 3, 2019. DOI: 10.1016/j.nanoms.2019.03.005.
20. B.R. Sankapal, et al., J. Alloys Compd. (2011), doi: 10.1016/j.jallcom.2011.08.036.
21. Yuehui Chen, Ligang Ma, Yan Yin, Xu Qian, Guotai Zhou, Xiaomin Gu, Wenchao Liu, Xiaoshan Wu, Fengming Zhang, Journal of Alloys and Compounds, Volume 672, (2016). <https://doi.org/10.1016/j.jallcom.2016.02.135>.
22. A.N. Chattarki, S.S. Kamble, L.P. Deshmukh, Role of pH in aqueous alkaline chemical bath deposition of lead sulfide thin films, Materials Letters 67 (2012) 39-41. <https://doi.org/10.1016/j.matlet.2011.08.105>.
23. Jiamin Qiu, Shizhen Zhi, Peng Zhao, Jian Wang, Xiaojing Ma, Sheng Ye, Chenhao Lin 1, Xuanhe Zhang 1, Zuoxu Wu 2 et al, Phys. Rev. B 111, 045203. DOI: <https://doi.org/10.1103/PhysRevB.111.045203>.
24. K. C. Patel, Journal of ELECTRONIC MATERIALS, 2016 The Minerals, Metals & Materials Society, DOI: 10.1007/s11664-016-4364-1.
25. Jhelai Sahadevan, Esakki Muthu S, Kulathuraan K, Arumugam S, Ikhyun Kim, Baby Sri
26. Pratha G, Materials Today Proceeding, <https://doi.org/10.1016/j.matpr.2022.06.311>.