REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 25, No.1s(2024)
http://www.veterinaria.org
Received: Revised: Accepted:

Study of DC Conductivity, Complex Impedance, and Photodetection Characteristics of $CsPbI_3$

Hiral Patel[1*], Piyush Vyas[2]

[1*]Chemistry Department, Amity University, Gwalior-474005, Madhya Pradesh, India,
E-mail: hiralpatela16@gmail.com
[2]Chemistry Division, Sheth M. N. Science College, Patan-384265, Gujarat, India

ABSTRACT
Cesium lead iodide ($CsPbI_3$) is an inorganic halide perovskite that has attracted significant attention due to its excellent optoelectronic properties and potential applications in photovoltaic and photodetection devices. In the present work, $CsPbI_3$ was synthesized and systematically investigated through DC electrical conductivity, complex impedance spectroscopy, and photodetection studies. Structural and morphological analyses confirmed the formation of the perovskite phase with well-defined crystalline features. The DC conductivity measurements were carried out over a wide temperature range to understand the charge transport mechanism. The conductivity was found to increase with temperature, indicating semiconducting behavior and thermally activated charge carrier transport. Complex impedance analysis revealed the contribution of grains and grain boundaries to the overall electrical response, while the temperature-dependent impedance spectra demonstrated a decrease in bulk resistance with increasing temperature. The frequency-dependent dielectric and impedance parameters further supported the enhanced mobility of charge carriers at elevated temperatures. Photodetection measurements under light illumination showed a significant increase in photocurrent compared to the dark current, confirming the excellent photoresponsive nature of $CsPbI_3$. The material exhibited high photosensitivity and stable photoresponse, highlighting its suitability for photodetector applications. The combined electrical and optoelectronic investigations demonstrate that $CsPbI_3$ is a promising candidate for next-generation semiconductor and optoelectronic devices.

Keywords: $CsPbI_3$, Perovskite, Dielectric properties, Impedance spectroscopy, Optoelectronic properties, Photo detector.

Introduction

In recent years, inorganic halide perovskites have emerged as promising materials for a wide range of optoelectronic applications owing to their exceptional optical absorption, tunable band gap, high charge-carrier mobility, and excellent defect tolerance. Among these materials, cesium lead iodide ($CsPbI_3$) has attracted considerable attention because of its superior thermal stability compared to hybrid organic–inorganic perovskites and its remarkable electronic and optoelectronic properties. The all-inorganic nature of $CsPbI_3$ makes it a suitable candidate for photovoltaic devices, light-emitting diodes, photodetectors, and other semiconductor applications requiring long-term operational stability.1-3
The crystal structure and electronic properties of $CsPbI_3$ contribute significantly to its performance in optoelectronic devices. The material exhibits strong light absorption in the visible region and possesses favorable charge transport characteristics, enabling efficient generation and separation of photogenerated charge carriers.4 These features have motivated extensive investigations into the structural, optical, and photovoltaic properties of $CsPbI_3$. However, a detailed understanding of its electrical transport behavior and impedance response remains essential for optimizing device performance and improving charge carrier dynamics.5
DC electrical conductivity studies provide valuable information regarding the charge transport mechanism, activation energy, and semiconducting nature of materials.6 Temperature-dependent conductivity measurements help elucidate the role of thermally activated charge carriers and the influence of defects, grain boundaries, and crystal structure on electrical conduction.7,8 Furthermore, complex impedance spectroscopy is a powerful technique for distinguishing grain and grain-boundary contributions, analyzing relaxation phenomena, and understanding the electrical response of materials over a wide frequency range. Such studies are crucial for correlating microstructural features with electrical performance.9
In addition to its electrical characteristics, the photodetection behavior of $CsPbI_3$ has become a subject of significant interest due to its high absorption coefficient and efficient photoresponse.10 Under light illumination, the generation of electron–hole pairs can lead to a substantial increase in conductivity, making $CsPbI_3$ a potential material for high-performance photodetectors. Investigating the photocurrent response and photosensitivity is therefore important for evaluating its suitability in optoelectronic sensing applications.11, 12
In the present work, $CsPbI_3$ was synthesized and systematically investigated through DC electrical conductivity, complex impedance spectroscopy, and photodetection measurements. The temperature-dependent electrical properties

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 25, No.1s(2024)
http://www.veterinaria.org
Received: Revised: Accepted:

were analyzed to understand the conduction mechanism, while impedance studies were employed to examine relaxation processes and charge transport behavior. Furthermore, the photodetection characteristics were evaluated under light illumination to assess the optoelectronic performance of the material. The results provide valuable insights into the electrical and photoresponsive properties of $CsPbI_3$ and demonstrate its potential for future semiconductor and optoelectronic device applications.

Experimental

The synthesis of CsPbI3 was carried out via a solution-based method, ensuring phase purity. Structural analysis was performed using XRD, followed by morphological characterization via FESEM. Elemental composition was verified using ED-XRF spectroscopy. Optical properties were studied using UV-Vis spectroscopy and photoluminescence (PL) measurements. Dielectric behavior was analyzed through impedance spectroscopy across different temperatures and frequencies. Finally, the optoelectronic properties were evaluated using a two-probe method under varying light intensities.

Synthesis Of Cesiumleadiodide (Cspbi3)

In this work CsPbI3 was successfully synthesized via solution proceed method using dimethyl formamide (DMF) as a precursor solvent, represents chematically in Figure 1 In this typical synthesis process, 3 mM lead iodide was first dissolved in 30 ml DMF under constant magnetic stirring for 50 minutes in open atmosphere top repare ahomogeneous lead iodide precursor. Next, 3mM Cesium iodide (CsI) was added with the above lead iodide (PbI2) solution under vigorous magnetic stirring for1hour at ambient temperature to form ahomogeneous mixture. To remove the unreacted reagents the CsPbI3 precursor was filtered the nisopropylalcohol(IPA) was added very slowly until the occurrence of precipitation of CsPbI3.The precipitate sample was washed several times by using ethanol (EtOH). Thenth esample was collected and dried in vacuum for over night. Finally, the dried sample was further rannealed at 300 0C in vacuum for halfanhour. Thus, the CsPbI3 micro wire was synthesized by following method for further scharacterization (Figure 1).

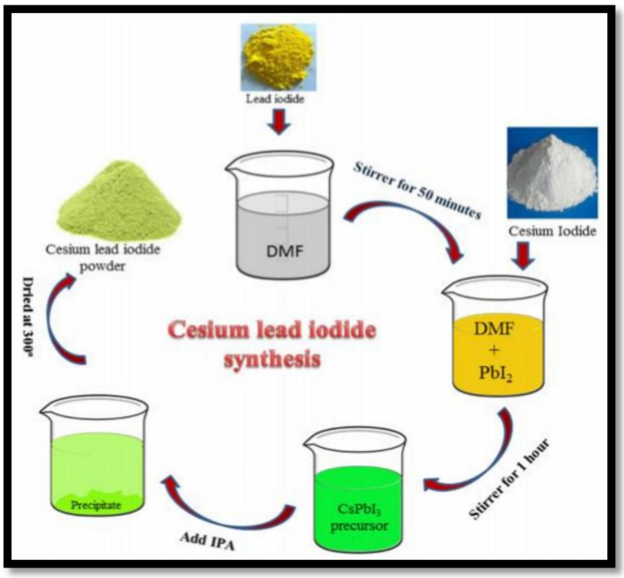

Figure 1: Schematic Representation Of Synthesis Process Of Cspbi3

Results And Discussin

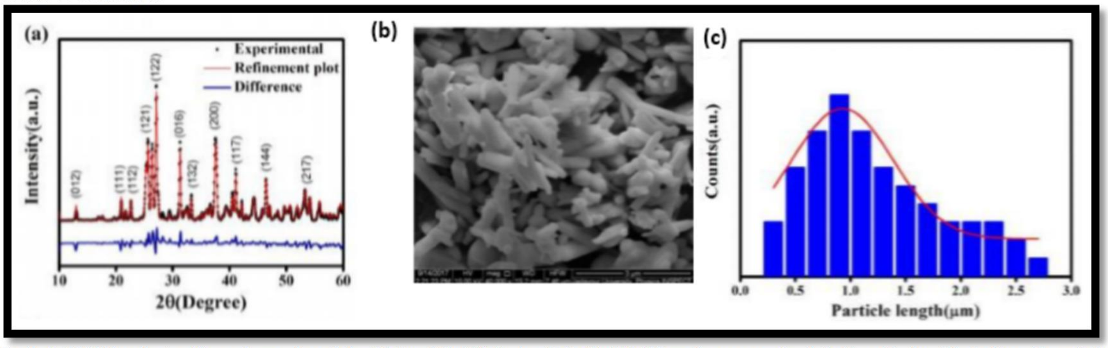

Figure 2: (a) XRD plot of cesium lead iodide ($CsPbI_3$,); (b) CsPbI3 micro-rod; (c) Particle distribution histogram

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 25, No.1s(2024)
http://www.veterinaria.org
Received: Revised: Accepted:

The X-ray diffraction (XRD) pattern of the as-synthesized $CsPbI_3$, shown in (Figure 2a) confirms the formation of an orthorhombic phase (Pmnb). The prominent diffraction peaks observed at 13.05°, 20.95°, 22.65°, 25.66°, 27.12°, 31.33°, and 37.46° correspond to the (012), (111), (112), (121), (122), (016), and (200) crystallographic planes, respectively, matching JCPDS card No. 74-1970. Rietveld refinement using the MAUD package shows excellent agreement between the experimental and calculated patterns, indicating phase purity and the absence of detectable impurities. The refined structural parameters, including lattice constants, crystallite size, and microstrain, are listed in Table 1. The elemental composition of $CsPbI_3$ was analyzed using energy-dispersive X-ray fluorescence (ED-XRF) spectroscopy. The mass percentages of Cs, Pb, and I were determined from the intensities of their characteristic X-ray lines. The measured elemental ratios are in good agreement with the expected stoichiometric composition, confirming the successful formation of $CsPbI_3$ (Figure 2b/c). A slight deviation from the theoretical values may be attributed to the presence of lattice defects, such as iodide vacancies. Overall, the ED-XRF analysis verifies the elemental purity and composition of the synthesized material.

Table 1:Structural parameter computed from Rietveldre finement

parameter	Computedvalue
Celllengtha(nm)	10.46
Celllengthb(nm)	4.8
CelllengthC(nm)	17.76
Sigma	1.28
crystallitesize(nm)	675.2
Microstrain(x10-4)	7.251

The AC conductivity of $CsPbI_3$ was studied in the temperature range 373–673 K to understand its charge transport mechanism. The conductivity spectra exhibit a frequency-independent plateau at low frequencies, corresponding to DC conductivity, followed by a dispersive increase at higher frequencies due to carrier hopping. The observed behavior follows Jonscher's power law. The frequency exponent (n) increases with temperature, indicating a small polaron hopping mechanism. The hopping frequency follows Arrhenius behavior, yielding an activation energy of 0.294 eV. This value suggests that similar charge carriers are involved in both conduction and relaxation processes.

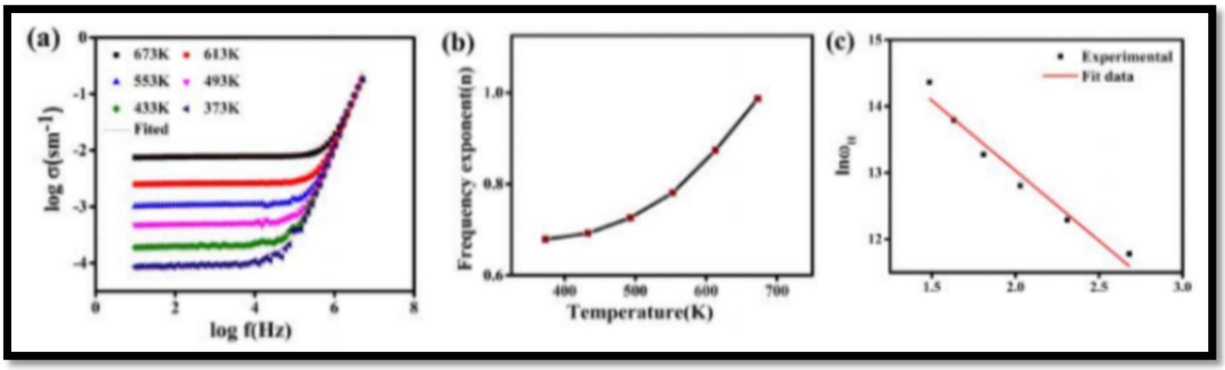

Figure 3: (a) Frequency dependent ac conductivity; (b) Variation of frequency exponent (n) with temperature; (c) Arrhenius plot of hopping frequency

Conclusion
In this work, $CsPbI_3$ was successfully synthesized and systematically investigated for its structural, electrical, and optoelectronic properties. The material exhibits thermally activated DC conductivity, confirming semiconducting behavior and temperature-dependent charge transport. Complex impedance analysis revealed the contributions of grains and grain boundaries, with a decrease in resistance at higher temperatures indicating enhanced charge carrier mobility. AC conductivity behavior followed Jonscher's power law, suggesting a small polaron hopping mechanism. Photodetection studies showed a strong photoresponse with significantly higher photocurrent under illumination,

demonstrating high photosensitivity and stable switching behavior. Overall, the combined results confirm that $CsPbI_3$ is a promising material for semiconductor and photodetector applications.

Funding
No funding received for this work.

Acknowledgment
The authors express their gratitude to the Department of Chemistry Sheth M. N. Science College, Patan, and Department of Chemistry Amity University, Gwalior for their assistance with experimental work and analysis support.

References

1. Abney, M. K. (2022). Photoluminescence and stability of perovskite-phase $CsPbI_3$ nanocrystals and development of nickel metal-organic decomposition inks (Doctoral dissertation).
2. Thomas, C. J. (2018). Surface functionalization of $CuInSe_2$ and $CsPbI_3$ nanocrystals: conversion yields, exciton kinetics, and thermal stability (Doctoral dissertation).
3. Limpamanoch, P., Rujisamphan, N., Kumnorkaew, P., Amornkitbamrung, V., Tang, I. M., Zhang, Q., & Supasai, T. (2019). Understanding Effects of Cesium in CH (NH_2) $_2PbI_3$ for Stabilizing CH (NH_2) $_2PbI_3/CsPbI_3$ Interface under UV Illumination.
4. Zhang, Q., Song, Y. H., Hao, J. M., Lan, Y. F., Feng, L. Z., Ru, X. C., ... & Yao, H. B. (2022). α-BaF_2 Nanoparticle Substrate-Enabled γ-$CsPbI_3$ Heteroepitaxial Growth for Efficient and Bright Deep-Red Light-Emitting Diodes.
5. Yao, Z., Zhao, W., & Liu, S. F. (2021). Stability of the CsPbI 3 perovskite: from fundamentals to improvements. Journal of Materials Chemistry A, 9(18), 11124-11144.
6. Wang, Y., Liu, X., Zhang, T., Wang, X., Kan, M., Shi, J., & Zhao, Y. (2019). The role of dimethylammonium iodide in CsPbI3 perovskite fabrication: additive or dopant?. Angewandte Chemie, 131(46), 16844-16849.
7. Ahmad, W., Khan, J., Niu, G., & Tang, J. (2017). Inorganic CsPbI3 perovskite-based solar cells: A choice for a tandem device. Solar Rrl, 1(7), 1700048.
8. Swarnkar, A., Marshall, A. R., Sanehira, E. M., Chernomordik, B. D., Moore, D. T., Christians, J. A., ... & Luther, J. M. (2016). Quantum dot–induced phase stabilization of α-CsPbI3 perovskite for high-efficiency photovoltaics. Science, 354(6308), 92-95.
9. Chang, X., Fang, J., Fan, Y., Luo, T., Su, H., Zhang, Y., ... & Zhao, K. (2020). Printable CsPbI3 perovskite solar cells with PCE of 19% via an additive strategy. Advanced Materials, 32(40), 2001243.
10. Haque, F., Wright, M., Mahmud, M. A., Yi, H., Wang, D., Duan, L., ... & Uddin, A. (2018). Effects of hydroiodic acid concentration on the properties of CsPbI3 perovskite solar cells. ACS omega, 3(9), 11937-11944.
11. Zhang, T., Dar, M. I., Li, G., Xu, F., Guo, N., Grätzel, M., & Zhao, Y. (2017). Bication lead iodide 2D perovskite component to stabilize inorganic α-CsPbI3 perovskite phase for high-efficiency solar cells. Science advances, 3(9), e1700841.
12. Wang, Y. K., Yuan, F., Dong, Y., Li, J. Y., Johnston, A., Chen, B., ... & Sargent, E. H. (2021). All-inorganic quantum-dot LEDs based on a phase-stabilized α-CsPbI3 perovskite. Angewandte chemie international edition, 60(29), 16164-16170.