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Examination of the Optical and Thermal Characteristics of Solid Materials

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Abstract:
For a variety of technological applications, the research of solid materials' thermal and optical properties is essential. A material's reaction to heat is determined by its thermal properties, which include thermal conductivity, specific heat capacity, thermal expansion, and thermal diffusivity. Its interaction with light is controlled by optical characteristics, including transmittance, absorbance, reflectance, refractive index, and optical bandgap. To precisely assess these attributes, experimental procedures like as ellipsometry, spectroscopy, and thermal analysis are used. Electronics, energy storage, and optoelectronics can all benefit from the design of materials with enhanced heat transfer, energy efficiency, and optical capabilities made possible by an understanding of the ability to manipulate these qualities. We hope that this paper will be useful and a reference for researchers in the field.
Keywords: Technological Applications, Solid Materials, Optical, Thermal, Energy Storage.

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اختبار الخصائص البصرية والحرارية للمواد الصلبة

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الملخص
لتطبيقات تقنية متنوعة، يعتبر بحث خصائص المواد الصلبة الحرارية والبصرية أمرا أساسيا. تتم تحديد استجابة المادة للحرارة بواسطة خصائصها الحرارية، التي تشمل توصيل الحرارة الحراري، السعة الحرارية النوعية، التمدد الحراري، والانتشار الحراري. بينما يتحكم تفاعل المادة مع الضوء بالخصائص البصرية، بما في ذلك نقاء النقل، الامتصاص، الانعكاس، معامل الانكسار، وفجوة الطاقة البصرية. لتقييم هذه السمات بدقة، يتم استخدام إجراءات تجريبية مثل الإيليبسومتري، والطيفية، والتحليل الحراري. يمكن أن نستفيد منها في صناعة الإلكترونيات، وتخزين الطاقة، والأجهزة البصرية من تصميم المواد ذات التحسين في نقل الحرارة، وكفاءة الطاقة، والقدرات البصرية التي تصمم بتفاعل هذه الخصائص. آملا أن تكون هذه الورقة مفيدة ومرجع للبحاث في المجال.

الكلمات المفتاحية: التطبيقات التكنولوجية، المواد الصلبة، الضوئية، الحرارية، تخزين الطاقة.

Introduction

The study of thermal and optical properties of solid materials is an important field of research [1]. Understanding these properties helps in various applications, such as designing materials for specific purposes, optimizing energy transfer [2], and developing new technologies [3]. Thermal properties of materials are related to their ability to conduct heat, while optical properties deal with how materials interact with light [4].

The investigation of thermal and optical properties of solid materials is a crucial aspect of materials science and engineering [5]. Understanding these properties is essential for designing and optimizing various technological applications such as electronic devices, energy storage systems, optoelectronics, and thermal management systems [6]. This article provides an overview of the study of thermal and optical properties of solid materials, highlighting their significance and the techniques employed to analyze and manipulate these properties.

The rest of the article is organized as follows: Section 2 presents the significance of the study. Section 3 provides a general explanation about the Thermal Properties. The Optical Properties explanation is positioned in Section 4. Section 5 lists the common Applications and Significance of the thermal and optical properties of solid materials. Results and discussion have taken place in Section 6. Eventually, the Concludes summary of the article has closed the article followed by the list of recent references.

Significance of the study

In this research, the thermal and optical properties of solid materials have been studied due to their importance in practical applications such as optical fibers. At the end of the research, we studied glass fibers as an application to the importance of the thermal and optical properties of materials. Additionally, Thermal properties were studied in the second chapter, and this chapter was devoted to studying (quantity of heat, heat capacity of matter, specific heat capacity, heat transfer, Stefan’s law of radiation, thermal expansion, thermal stress, metal diode thermometers). The optical properties of solids were studied in the third chapter, and this chapter was devoted to studying (prism scattering of light, scattering, absorption and emission, absorption of visible light in solids, colors of crystals, color centers, and excitons).

Thermal Properties

Thermal properties of solid materials encompass a range of characteristics that govern their behavior in response to heat [7]. These properties include thermal conductivity, specific heat capacity, thermal expansion, and thermal diffusivity [8]. Thermal conductivity refers to a material's ability to conduct heat, while specific heat capacity measures the amount of heat energy required to raise the temperature of a unit mass of material by a certain amount [9]. Thermal expansion relates to a material's tendency to expand or contract with temperature changes, while thermal diffusivity describes how quickly heat spreads within a material [10].

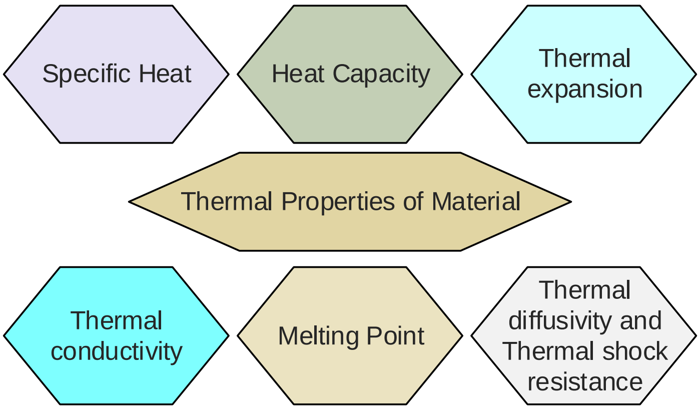

Figure 1: Thermal properties of materials

The study of thermal properties involves experimental techniques such as the transient hot-wire method, laser flash method, and Differential Scanning Calorimetry (DSC) [11]. These methods enable researchers to measure thermal conductivity, specific heat capacity, and thermal diffusivity accurately [12]. By characterizing these properties, scientists can optimize materials for efficient heat transfer, insulation, and temperature regulation in various applications [13].

Table 1: Specific heat of some solids.

Material	Chemical sample	Value (C(J/Kgc°)
Lead	Pb	$0.13x10^3$
Silver	Ag	$0.23x10^3$
Copper	Cu	$0.38x10^3$
Iron	Fe	$0.46x10^3$
Aluminum	Al	$0.92x10^3$
Ice	H_2O (s)	$2.10x10^3$

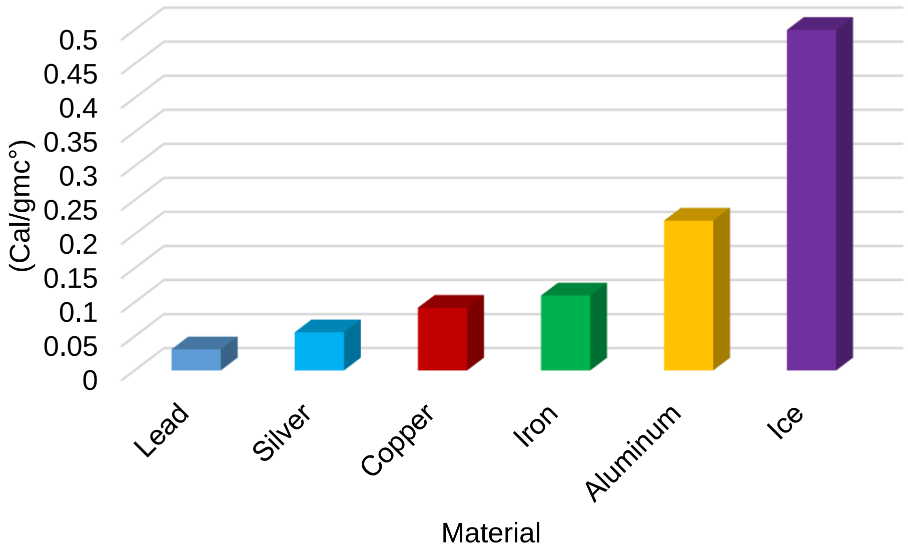

Figure 2: Specific heat of some solids.

Optical Properties

The classification of optical properties of solid materials is presented in Figure 3 which deals with their interaction with light across the electromagnetic spectrum as shown in Figure 4 [14]. These properties encompass parameters such as reflectance, transmittance, absorbance, refractive index, and optical bandgap as shown in Figure 5 and further explained tabulated in Table 2 [15]. Reflectance refers to the proportion of incident light that is reflected by a material, while transmittance measures the amount of light that passes through it [16]. Absorbance quantifies the amount of light that is absorbed by the material. The refractive index describes the material's ability to bend light, while the optical bandgap represents the minimum energy required for a material to absorb light and undergo electronic transitions [17].

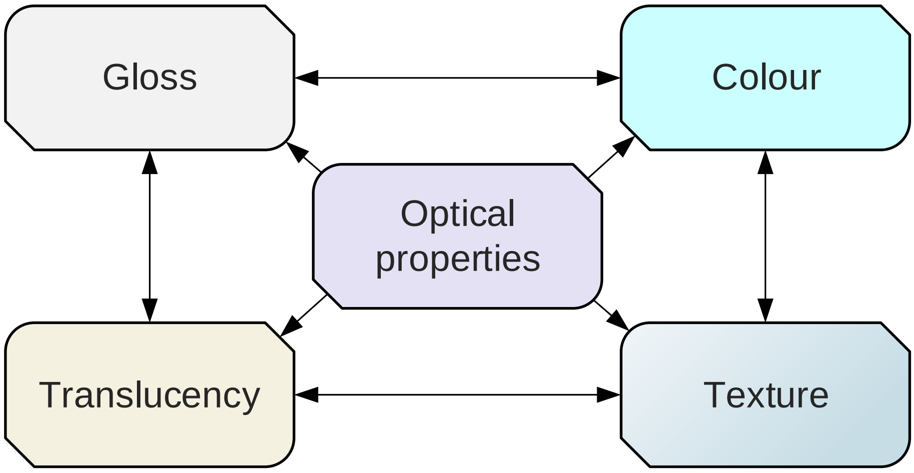

Figure 3: Classification of Optical properties.

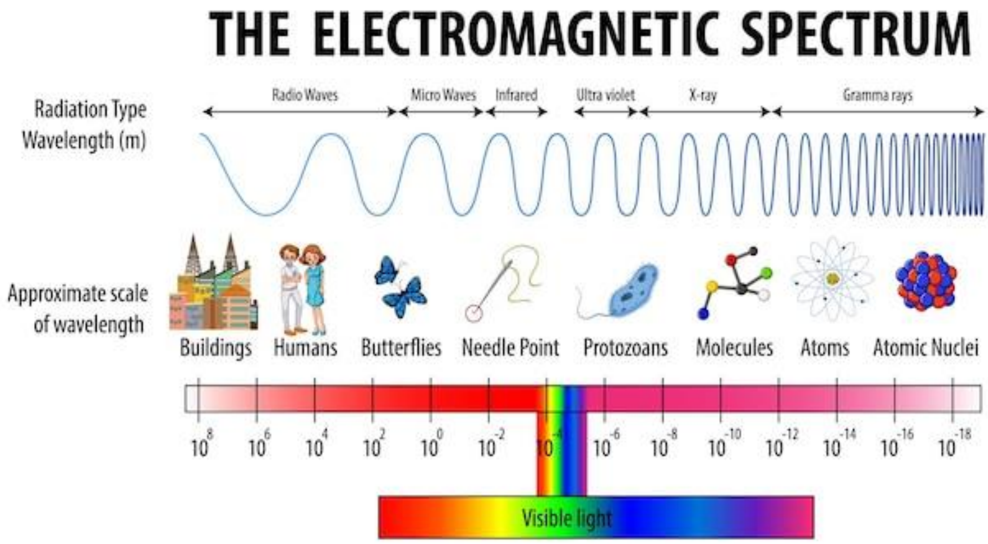

Figure 4: The electric spectrum.

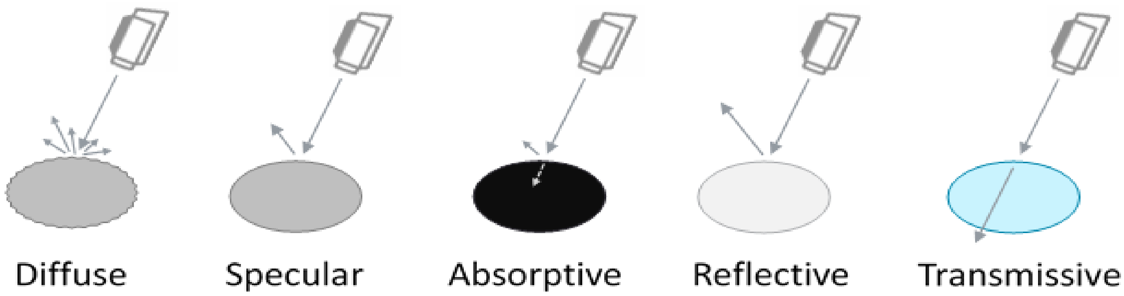

Figure 5: Forms of Optical Properties

Table 2: Optical properties parameters.

Parameters	Explanation
Reflectance	• Reflectance refers to the ratio of the reflected light intensity to the incident light intensity on a surface. It quantifies how much light is reflected by a material or surface. • Reflectance is usually expressed as a percentage or a decimal value between 0 and 1, where 0 represents no reflection (all light is absorbed) and 1 represents total reflection (no light is absorbed).
Transmittance	• Transmittance is the opposite of reflectance. It refers to the ratio of the transmitted light intensity to the incident light intensity when light passes through a material. • Transmittance indicates how much light is able to pass through a material without being absorbed or reflected. • Like reflectance, transmittance is often expressed as a percentage or a decimal value between 0 and 1.
Absorbance	• Absorbance is a measure of the amount of light absorbed by a material as it passes through it. • It is related to the concentration of the absorbing species in the material. • Absorbance is calculated using the Beer-Lambert Law, which states that absorbance is proportional to the product of the concentration of the absorbing species, the path length of light through the material, and a constant called the molar absorptivity. • Absorbance is dimensionless and is calculated using logarithms.
Refractive index	• The refractive index is a property that describes how light propagates through a medium. It is the ratio of the speed of light in a vacuum to the speed of light in the medium. • The refractive index determines how much light is bent or refracted when it passes from one medium to another.

	• Different materials have different refractive indices, and it plays a crucial role in various optical phenomena such as reflection, refraction, and dispersion.
Optical bandgap	• The optical bandgap refers to the energy difference between the highest occupied energy level (valence band) and the lowest unoccupied energy level (conduction band) in a material. • It represents the minimum energy required to excite an electron from the valence band to the conduction band, thus allowing the material to conduct electricity. • The size of the bandgap determines whether a material is an insulator, semiconductor, or conductor. • Materials with a large bandgap are insulators, while those with smaller bandgaps are semiconductors or conductors.

These concepts are important in the field of optics and materials science, and they have applications in various areas, including physics, chemistry, engineering, and optoelectronics [18]. Several techniques are employed to investigate the optical properties of solid materials, including spectroscopy, ellipsometry, and photoluminescence [19]. Spectroscopy techniques such as UV-Vis absorption spectroscopy, infrared spectroscopy, and Raman spectroscopy enable the analysis of a material's interaction with light at different wavelengths [20]. Ellipsometry measures changes in the polarization of light upon reflection or transmission, providing information about the refractive index and thickness of thin films [21]. Photoluminescence involves the emission of light by a material following the absorption of photons, providing insights into electronic transitions and bandgap properties [22].

Applications and Significance

The study of thermal and optical properties of solid materials has significant implications in various fields. In the electronics industry, understanding and manipulating these properties helps in designing efficient heat sinks, thermal interface materials, and thermoelectric devices for improved heat dissipation and energy conversion [23]. In the field of energy storage, materials with high thermal conductivity and specific heat capacity are desirable for better thermal management of batteries and supercapacitors [24]. Similarly, optical properties play a crucial role in the development of photovoltaic devices [25], light-emitting diodes, and optical sensors.

Moreover, researchers explore the relationship between thermal and optical properties to develop advanced materials with tailored functionalities. For instance, thermochromic materials exhibit reversible color changes with temperature, making them useful in smart windows and temperature sensors [26]. Optothermal materials can convert light into heat, enabling applications in solar thermal energy conversion and photothermal therapy.

Results and discussion

All substances exist in three states: solid, liquid, and gas. Solid bodies have a fixed shape and are incompressible. Particles in solid bodies are close to each other and oscillate around their fixed positions. The forces of attraction between these particles are strong. Liquid materials have a specific size and do not have a specific shape and are compressible. Slightly, the particles in liquid bodies are held together. Gases have a fixed shape or size and are compressible. Gas particles move randomly in all directions, and the forces of attraction between them are weak. Gases spread easily in the space available to them. The melting point is the constant temperature at which a pure solid body turns into a liquid. Boiling is the constant temperature at which all the liquid turns into a gas. The highest density is in solids and the lowest density is in gases. Electrical conduction: There are three materials: conductors, insulators, and medium materials. They are between gases and conductors in their ability to allow charges to move through them. Examples include silicon and germanium. Some impurities such as boron or phosphorus can be added to semiconductors to increase their conductivity.

The ratio of this force resulting from the change in length resulting from the change in temperature to the cross-sectional area is called thermal stress, and it is, as we note, a very large force if the amount of this change in length is not taken into account when building iron structures such as bridges or railways The resulting force has the potential to collapse such structures.

Conclusion

The study of thermal and optical properties of solid materials provides valuable insights into their behavior and performance in various applications. By understanding and manipulating these properties, scientists and engineers can design materials with enhanced thermal conductivity, specific heat capacity, and optical characteristics to meet the demands of diverse technological fields. Continued research in this area holds the potential for the development of innovative materials with improved energy efficiency, thermal management, and optical functionalities.

Through our study of the optical and thermal properties of some solid materials, we conclude that:

1- Aluminum has the largest specific heat value ($0.92 \times 10^3 J/Kg.C°$), and its value is equal to the specific heat, while lead, which has the smallest specific heat value, is equal to ($0.13 \times 10^3 J/Kg.C°$).

2- The silver material has the highest value of the heat conduction coefficient, which is equal ($406\ W/m.C°$), and the glass material has the smallest value of the heat conduction coefficient, which is equal to (0.8 W/Wm.℃).

3- The plutonium material has the highest coefficient of thermal longitudinal expansion, which is equal to ($5.4 \times 10^{-5} (C°)^{-1}$), and the silicon material has the smallest value of the coefficient of thermal expansion, which is equal to ($0.30 \times 10^{-5} (C°)^{-1}$).

4- The value of the refractive index increases when the wavelength decreases. We note that borosilicate glass with lead oxide has the highest refractive index, equal to 1.698 in violet color. Diamond has a refractive index of 2.458 compared to violet.

5- The optical properties of matter change due to the effect of temperature on it.

References

[1] Y. A. Marei, M. Emam, M. E. A. E. Ahmed, A. A. A. Attia, and M. A. Abdelrahman, "Thermal and optical investigations of various transparent wall configurations and building integrated photovoltaic for energy savings in buildings," *Energy Convers Manag*, vol. 299, p. 117817, Jan. 2024, doi: 10.1016/j.enconman.2023.117817.

[2] A. Alsharif *et al.*, "Ant Lion Optimization of On-Grid Supported by PV/Wind Considering Libyan Energy," *Science Proceedings Series*, vol. 3, no. 1, pp. 9–15, Jun. 2021, doi: 10.31580/sps.v3i1.1886.

[3] S. B. Aziz *et al.*, "A Comprehensive Review on Optical Properties of Polymer Electrolytes and Composites," *Materials*, vol. 13, no. 17, p. 3675, Aug. 2020, doi: 10.3390/ma13173675.

[4] M. Ali *et al.*, "An accurate prediction of electronic structure, mechanical stability and optical response of BaCuF3 fluoroperovskite for solar cell application," *Solar Energy*, vol. 267, p. 112199, Jan. 2024, doi: 10.1016/j.solener.2023.112199.

[5] N. R. Abdullah, G. A. Mohammed, H. O. Rashid, and V. Gudmundsson, "Electronic, thermal, and optical properties of graphene like SiC structures: Significant effects of Si atom configurations," *Phys Lett A*, vol. 384, no. 24, p. 126578, Aug. 2020, doi: 10.1016/j.physleta.2020.126578.

[6] A. A. Alhazime, "Effect of Nano CuO Doping on Structural, Thermal and Optical Properties of PVA/PEG Blend," *J Inorg Organomet Polym Mater*, vol. 30, no. 11, pp. 4459–4467, Nov. 2020, doi: 10.1007/s10904-020-01577-8.

[7] L. Qiu *et al.*, "A review of recent advances in thermophysical properties at the nanoscale: From solid state to colloids," *Phys Rep*, vol. 843, pp. 1–81, Feb. 2020, doi: 10.1016/j.physrep.2019.12.001.

[8] M. Abdunnabi, B. Belgasim, and A. Ramadan, "Review on Solar Thermal Desalination in Libya," *Solar Energy and Sustainable Development Journal*, vol. 7, no. SI, pp. 28–47, Sep. 2018, doi: 10.51646/jsesd.v7iSI.73.

[9] S. Ahmed Abdaljlil, O. Boiprav, A. R. Zerek, and A. Saleh, "Impact of Thermal Noise on Communication System Performance," in *2022 IEEE 2nd International Maghreb Meeting of the Conference on Sciences and Techniques of Automatic Control and Computer Engineering, MI-STA 2022 - Proceeding*, 2022, pp. 569–573. doi: 10.1109/MI-STA54861.2022.9837480.

[10] Mc. Guerrero Delgado, J. Sánchez Ramos, S. Álvarez Domínguez, J. A. Tenorio Ríos, and L. F. Cabeza, "Building thermal storage technology: Compensating renewable energy fluctuations," *J Energy Storage*, vol. 27, no. June 2019, p. 101147, Feb. 2020, doi: 10.1016/j.est.2019.101147.

[11] S. Attia, "Spatial and behavioral thermal adaptation in net zero energy buildings: An exploratory investigation," *Sustainability (Switzerland)*, vol. 12, no. 19, 2020, doi: 10.3390/SU12197961.

[12] H. Flity *et al.*, "Thermal conductivity parallel and perpendicular to fibers direction and heat capacity measurements of eight wood species up to 160 °C," *International Journal of Thermal Sciences*, vol. 195, p. 108661, Jan. 2024, doi: 10.1016/j.ijthermalsci.2023.108661.

[13] M. Kiani, S. Omiddezyani, E. Houshfar, S. R. Miremadi, M. Ashjaee, and A. Mahdavi Nejad, "Lithium-ion battery thermal management system with Al2O3/AgO/CuO nanofluids and phase change material," *Appl Therm Eng*, vol. 180, p. 115840, Nov. 2020, doi: 10.1016/j.applthermaleng.2020.115840.

[14] A. A. A. et al. , Abdussalam Ali Ahmed et al., "An Investigation of the Effect of the Hub Motor Weight on Vehicle Suspension and Passenger Comfort," *International Journal of Mechanical and Production Engineering Research and Development*, vol. 11, no. 5, pp. 51–64, 2021, doi: 10.24247/ijmperdoct20214.

[15] B. A. Al-Asbahi, "Studying the optoelectronic properties and emission quenching dynamics of poly-<scp>TPD</scp> by incorporating <scp>ZnO</scp> nanoparticles and multiwalled carbon nanotubes," *J Appl Polym Sci*, vol. 141, no. 5, Feb. 2024, doi: 10.1002/app.54882.

[16] L. V. Keldysh, "The effect of a strong electric field on the optical properties of insulating crystals," in *Selected Papers of Leonid V Keldysh*, WORLD SCIENTIFIC, 2023, pp. 20–22. doi: 10.1142/9789811279461_0003.

[17] C. Yu and G. Li, "Electrical energy harvesting by connected form stable phase change material composites," *Energy Convers Manag*, vol. 299, p. 117851, Jan. 2024, doi: 10.1016/j.enconman.2023.117851.

[18] S. M. H. Qaid, Q. ul Ain, H. M. Ghaithan, I. Mursaleen, A. Ahmed Ali Ahmed, and J. Munir, “First-principles investigations on the structural, optoelectronic, mechanical and transport properties of new stable lead-free double perovskites Cs2BB′I6 (B = Ag/Rb, B′ = Bi/Ga) halides,” *Materials Science and Engineering: B*, vol. 301, p. 117176, Mar. 2024, doi: 10.1016/j.mseb.2024.117176.

[19] B. Padha, S. Verma, Prerna, A. Ahmed, S. P. Patole, and S. Arya, “Plastic turned into MXene–based pyro-piezoelectric hybrid nanogenerator-driven self-powered wearable symmetric supercapacitor,” *Appl Energy*, vol. 356, p. 122402, Feb. 2024, doi: 10.1016/j.apenergy.2023.122402.

[20] C. Erkmen and I. Celik, “Interaction mechanism of a pesticide, Azoxystrobin with bovine serum albumin: Assessments through fluorescence, UV–Vis absorption, electrochemical and molecular docking simulation techniques,” *Spectrochim Acta A Mol Biomol Spectrosc*, vol. 308, p. 123719, Mar. 2024, doi: 10.1016/j.saa.2023.123719.

[21] J. Yang and S. Tao, “Automatic transformation of polarization state of light in void medium,” *Phys Scr*, vol. 99, no. 3, p. 035508, Mar. 2024, doi: 10.1088/1402-4896/ad2253.

[22] X. Li *et al.*, “Thermal-Triggered Phase Separation and Ion Exchange Enables Photoluminescence Tuning of Stable Mixed-Halide Perovskite Nanocrystals for Dynamic Display,” *Laser Photon Rev*, Jan. 2024, doi: 10.1002/lpor.202301244.

[23] W. Le, W. Yang, W. Sheng, and J. Shuai, “Research Progress of Interfacial Design between Thermoelectric Materials and Electrode Materials,” *ACS Appl Mater Interfaces*, vol. 15, no. 10, pp. 12611–12621, Mar. 2023, doi: 10.1021/acsami.2c21035.

[24] Z. Yi, P. Wei, H. Zhang, H. Sun, S. Zeng, and H. Yu, “Wide range temperature thermal performance of power battery module with double-sided thermoelectric device system with high energy efficiency,” *Appl Therm Eng*, vol. 227, p. 120375, Jun. 2023, doi: 10.1016/j.applthermaleng.2023.120375.

[25] A. Alsharif, A. Salem, D. Alarga, and A. A. Ahmed, “Stochastic Method and Sensitivity Analysis Assessments for Vehicle-to-Home Integration based on Renewable Energy Sources”.

[26] Y. Zhao *et al.*, “Thermochromic Smart Windows Assisted by Photothermal Nanomaterials,” *Nanomaterials*, vol. 12, no. 21, p. 3865, Nov. 2022, doi: 10.3390/nano12213865.