Role of Quantum Dots and Nanostructures in Photovoltaic Energy Conversion

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Abstract. Nanostructures and quantum dots have substantial effects on enhancing photovoltaic energy conversion efficiency, as evidenced in this comprehensive study. Materials that are nanostructured and nanosized particles are commonly used to address the urgent issues related to energy conversion. The use of nanostructured substances to address issues with energy and natural resources has garnered a lot of interest lately. Directional nanostructures in particular show promise for the conversion, collection, and storage of energy. Due to their unique properties, such as electrical conductivity, mechanical energy, and photoluminescence, quantum dots made from carbon (CQDs) and graphene quantum dots (GQDs) have been integrated into hybrid photovoltaic-thermoelectric systems (PV-TE). It evaluates the effects of nanostructures on solar energy technologies, in particular how they can improve power conversion and light absorption in solar cells. Optical light detectors, which transform photonic energy into signals that are electrical, are among the many optoelectronic uses of CQDs that have drawn attention because they are essential components of contemporary imaging and communication systems, such as visible light cameras, machine vision, medical X-ray and near-infrared image processing, and visible light detection devices. Besides supercapacitors, the study investigates how nanostructures could play a crucial role in contributing to addressing the global energy crisis sustainably, by working as photocatalysts for hydrogen synthesis and supercapacitors.

Keyword-: Quantum dots, nanostructures, PV, energy conversion technologies

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1 Introduction

Development of renewable energy sources such as solar, wind, wave, geothermal, and tidal energy is required due to the increasing need for energy. The photovoltaic effect allows solar energy—which includes heat and light—to be transformed into electrical power. Solar cells are the primary component in this process; they can produce electricity both individually and in sequence. The sunlight-powered generating gadget creates new hole-electron pairs by use of semiconductor p-n junctions. Solar energy conversion with a high yield, zero pollution, and potential is provided by photovoltaic (PV) panels. Surface temperature, however, can shorten cell life and efficiency. PV and thermoelectric (TE) are combined in hybrid PV-TE systems to increase conversion efficiency. Space sensing systems and car powertrains both use these systems [1]. Research advancements, optimization strategies, and the principles of thermal electricity and photovoltaics are some methods to boost efficiency. Because of its capacity to conduct electricity, strength in mechanics, chemical resistance, thermal endurance, photo-luminescence, affordability, and simplicity of surface functionalization, carbon nanotechnology is becoming more and more popular. Spacecraft power, water distillation, and generation of electricity are all possible using renewable energy sources.

It can also be used into construction materials, as demonstrated by the transparent solar energy windows made by Sharp. Technological developments like quantum physics and nanoparticles may boost solar panel efficiency and supply two or three times as much electricity.

These characteristics include carbon quantum dots (CQDs) and graphene quantum dots (GQDs). There are a number of industries that use this type of material, such as semiconductors, photovoltaic energy storage, biomedical, pharmaceutical, the environment, super capacitors, electro catalysis, and energy conversion. As new ways of addressing energy concerns emerge, these materials can reduce costs and have a small environmental impact [2]. Solar photovoltaics (PVs) and photo thermal systems are not able to generate enough solar power due to spectral mismatch, restricted absorption, and low thermal conductivity. It is possible to convert light into dark matter by using phosphors as spectral beam splitters (SBSs) in liquid or solid layers. Luminescent solar concentrators (LSCs) and recent advancements in the effort to improve their efficiency. Numerous mathematical and experimental investigations have been conducted recently to enhance LSC performance in various ways. LSCs and PVTs use luminous polymer layers that contain luminophores as the source of energy. To generate heat and electricity, SBS applications integrate several optical components in one structure, utilizing the advantages of hybridization, spectral regulators, and LSCs [3].

2 Impact of Quantum Dots and Nanostructures on Solar Energy Technologies

Owing to their special properties, semiconducting quantum dots, or QDs, are drawing interest for energy conversion and storage. But there isn't a thorough grasp of their particular uses. These materials, which include metal oxide, metal dichalcogenide, metallic halides, multinary oxides, and nonmetal substances QDs, are thoroughly introduced in this article. It talks about their sensible construction and uses in energy-related domains, such as super capacitors, lowering carbon dioxide (CO2), and photo catalytic H2 synthesis [4].

Quantum dots (QDs) have special optical and electrical characteristics that make them appealing for use in biomedical, sensors, and energy sources applications of devices. Their photoluminescence, numerous exaction production, and variable band gap make them perfect for effective conversion of electricity and absorbing as shown in Fig. 1. QDs are now being used by researchers to sensitize semiconductors in order to capture solar energy. However, the creation of green QDs has been facilitated by their poisonous character. The utilization of conventional and green QDs, namely carbon-based QDs like carbon and graphene, to enhance the absorption of solar electricity in photovoltaic and photo-electrochemical cells is covered in [5].

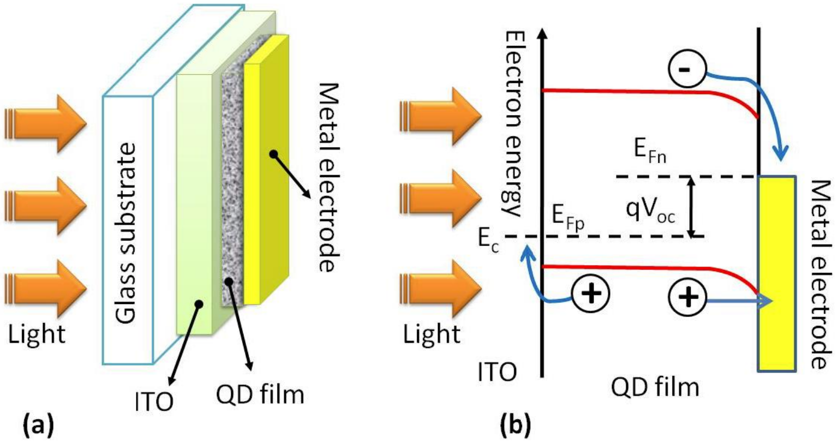

Fig. 1: Quantum Dots Solar cell

There has been conjecture on the potential efficacy of carbon quantum dots (CQDs) as electro catalysts for the splitting of water due to the latest developments in nanomaterial's. Because of their favorable morphologies, stable stability over time, and quick electron transfer rates, CQDs have demonstrated promise[5]. To assess materials for the use of CQDs, look into ecologically friendly synthesis processes, and assess if the application may be considered for commercial purposes, a great deal of research and writing has been done. Study also examined current applications for metal alloy nanoparticles. The low Tafel slopes of CQDs, their stability, and the fast electron transfer rates they possess make them promising as electrocatalysts. Water splitting might be improved by conjugating CQD and metal alloy nanoparticles, particularly when producing hydrogen [6].

There is nothing special about quantum dots other than the fact that they are just tiny, circular semiconductor crystals that are very efficient at absorbing and emitting light. Changing their size allows them to interact with different colors of light, which makes them useful for display and sensor technology.

Scientists are actively investigating quantum dot (QD) photo catalysts due to their high efficiency in converting chemical energy and solar energy. Photogenerated electron-hole pairs in CuInS2 QDs have a long lifetime, exhibit extremely high absorption coefficients, and are environment-friendly. There are several aspects of CuInS2 QDs that are investigated in this review, including their structural and electrical characteristics, production techniques, and their potential for use in photocatalysis. It covers the state of the art research on QD materials, modification techniques, and upcoming obstacles and prospects for photo catalysis advancement [7].

In order to efficiently produce energy from biomass substrates, recent research has investigated the use of sophisticated nano-module catalysts, including carbon nanotubes, nanosheets, nanoparticles, conductivity polymers, integrated nano polymers, nanoenzymes, and zero-dimensional nanomaterial's/carbon dots (CDs). Catalysts such as these constructed using nanotechnology are essential for transforming applications connected to energy. CDs have remarkable properties such high water dispersibility, photoluminescence, outstanding electro catalytic activity, biocompatibility, and non-toxicity. They are appealing for energy conversion and storage because of these qualities. It is anticipated that these cutting-edge tactics would be essential in encouraging sustainability in the energy sector [8].

Energy conversion and storage are becoming more and more necessary due to climate change and the depletion of fossil resources. It is anticipated that renewable energy sources like hydrogen, solar, and wind will be essential to addressing the current energy problem. Solar cells (SCs) that combine quantum dots (QDs) and polymers or nan composites have demonstrated improved performance efficiency. QDs have found application in rechargeable batteries, devices to store electricity, and synthesis; literature has concentrated on the utilization of QD-based electrode materials and their resulting composites for flexible devices and storage [9].

3 Quantum Dots: Properties and Synthesis

Zero-dimensional fluorescent carbon-based nanomaterials known as quantum dots (CQDs) have minimal toxicity, eco-friendliness, water solubility, good optical qualities, and straightforward manufacturing processes. They are widely used in solar cells, medication delivery, chemical sensing, biosensing, bioimaging, and light-emitting diodes as shown in Fig. 2. The structure, physical and chemical characteristics, synthesis method, and use as a catalyst in a number of processes are covered in this review paper. These processes include the ring opening of epoxides, levofloxacin degradation, azide-alkyne cycloadditions, multisubstituted 4H pyran synthesis, and selective alcohol oxidation. Future directions for this field of study are also mentioned [10].

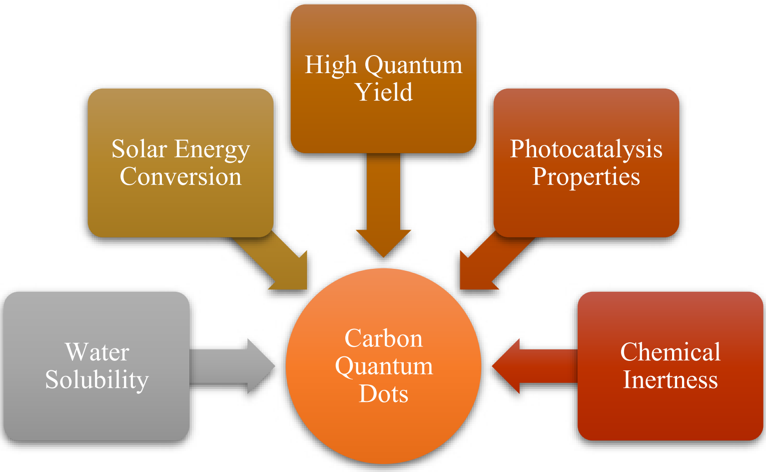

Fig. 2: Applications of carbon QD

Promising carbonaceous nanoparticles known as carbon quantum dots (CQDs) were identified in 2004 and have potential uses in optoelectronics, sensing, imaging, medicine, and catalysis. Carbon nanolights, or CQDs, are highly soluble and luminescent. Green synthetic techniques have been prioritized in the development of sustainable chemical methods for CQDs. The study in [11] gives an introduction of green source synthesis techniques and their applications, covers research on sustainable methods for photoluminescent CQDs, and emphasizes current developments in the photoluminescence applications of CQDs in chemical and biological areas. The circular economy promotes the transformation of trash into products with additional value, such as carbon quantum dots and luminous nanotechnology, which have potential uses in photocatalysis, storing electricity, sensing, and imaging. These nanomaterials are made from biomass and have uses in medication delivery, pollutant detection, energy storage, renewable energy, biosensing, and bioimaging [12]. Because of their special electrical, optical, and structural characteristics, quantum dots (QDs) have attracted a lot of attention. They may now be synthesized and used in a variety of sectors because to developments in synthesis techniques including hydrothermal and colloidal synthesis. Quantum dots (QDs) find use in spintronics, biomedicine, light-emitting diode (LED) color conversion, and cryptography. As well as the current difficulties facing QD research, in the present as well as the future, there is also an in-depth discussion of some of the challenges facing the field in the future. MXenes are layered structural materials with numerous uses. Additionally, their biocompatibility and production methods make these products popular due to their special qualities. Photoluminescence (PL) can be observed in MXene-based quantum dots (MQDs), which are created by breaking down MXenes into nanoscale fragments. This suggests that bandgap-less MXenes may have light-emitting uses. However, despite the diverse possible formations of MXene components, only carbide MXene-based MQDs have been reported to emit light. MXene QDs have a wide range of applications due to their cutting-edge synthesis methods. Since carbon quantum dots (CQDs) differ from conventional semiconductor quantum dots in their ability to reflect light, chemical inertness, biocompatibility, lack of toxicity, and affordability, they are attracting much attention.

The photoluminescence of QDs makes them an attractive material for biosensors. Because of the quantum confinement effect, subtle quantum dots emit at lower wavelengths, while bigger quantum dots emit at higher wavelengths. Biological applications benefit from zero-dimensional nanostructures, because of their greater solubility, reduced toxicity, and simplicity of manufacture. CQD biosensors are the subject of the study in [15], which explores their characteristics, difficulties, and prospective directions.

4 Considering solar cells when classifying nanostructures

The components of solar cells and nano-generators are one-dimensional nanostructures, such as nanorods, nanowires, and carbon nanotubes. These nanostructures have been the subject of numerous studies because of their special properties, such as their stability, excellent electron mobility, and high conductivity. The high conductivity, stability, and electron affinity of zinc oxide make it particularly desirable. Recent studies have focused on the synthesis of 1D ZnO nanostructures and their use in photovoltaics, particularly inorganic solar cells. These structures can serve as active components, capping layers, buffer layers, window layers, electron transfer layers, antireflection and passivation layers, and more. The difficulties and prospects for future research on solar cells based on 1D ZnO nanostructures are also covered [16]. The ubiquitous, environmentally friendly, and clean character of solar cells is drawing attention. However, only 20% of radiation is converted into electrical energy by publicly accessible solar cells. In silicon-based solar cells in particular, nan structuring can enhance light trapping and solar absorption. The frequency, size, and structure of nanostructures have a direct impact on the absorption of solar radiation. Nanomaterials and their characteristics have been investigated in more recent studies on quantum dot, dye-sensitized, polymer and nan composite perovskite, graphene, and carbon-based solar cells. The study in [17] examines the current status of nanomaterials for solar cells, including their benefits, synthesis processes, application strategies, and potential future obstacles and prospects. Third-generation solar cells known as dye-sensitized solar cells (DSSCs) have been the subject of much research because of their low cost, ease of production, and low toxicity. However, their lackluster long-term stability and low effectiveness in converting make them unsuitable for commercial or industrial application. Ru(II) dyes yielded the greatest efficiency of 12% for DSSC material that has been measured. An overview of light harvesting and trapping technologies, operational concepts, and current developments in DSSCs are given in this article. It revisits challenges of poor stability, scalability, and efficiency while highlighting the need for more study, better light collecting and trapping technologies, and future possibilities [18].

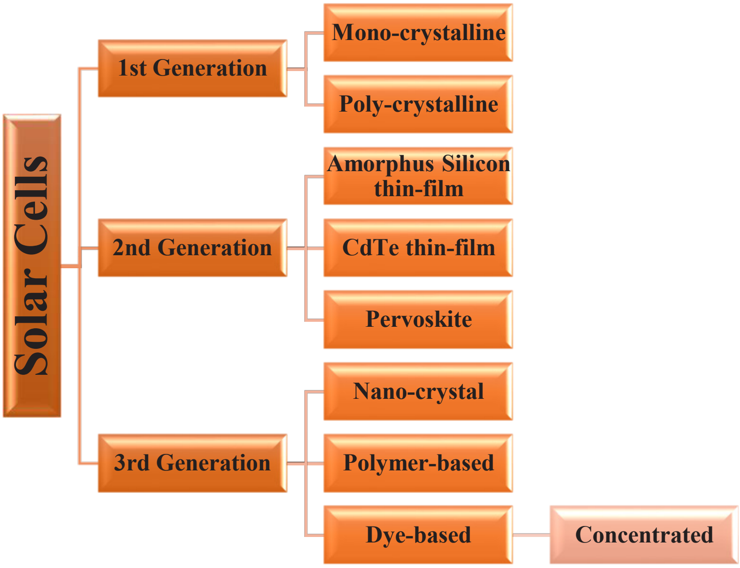

Fig. 3: Types of solar cell technologies

The goal of heterogeneous researchers internationally is to develop next generation photovoltaic solar cells in Table 3 (PVScs) with unique technical features that may be purchased commercially. Materials that can be used to create PVScs include organic and inorganic semiconductors as well as nanomaterials. It is anticipated that these cells will be non-toxic, non-degradable, extremely efficient, and reasonably priced. Displays, greenhouses, rooftops, underwater interpersonal interaction, smart eyewear, residences, industries, and more are just a few examples of the many domains in which applications find usage. Artificial intelligence and nanotechnology are anticipated to be key components of PVScs, with quantum dots and nanomaterials-based Scs showing promise for next-generation commercial cells [19]. There are countless uses in the future for solar energy, the Internet of Things, and other areas. The energy sector has shown a great deal of interest in 1D semiconductor nanowires (SN) because of their high surface area, distinct surface chemistry, and adjustable transport capabilities. Their large bandgap tuning makes them appropriate for optoelectronic applications. SNs are designed for high carrier-mobility electrical devices. Their rapid electron transport dynamics and effective production techniques make them perfect for solid-state transformation of energy, harvesting, and storage. Lithium-air batteries, supercapacitors, nanogenerators, and photovoltaic cells are examples of 1D-SN energy nano-systems in use today. The goal of [20] is to comprehend 1D-SN for the fabrication of innovative nano-systems for next-generation high-performance energy devices. Third-generation photovoltaic panels with a high efficiency in converting power (PCE) is dye-sensitized solar cells (DSSCs). The viability and performance improvement of ZnO/graphene nanocomposite material and its variants as photoelectrodes for DSSCs are covered in [21]. The review takes into account dye interaction, electron transport, optical characteristics, and structural factors. The ZnO/graphene-based cells have an efficiency of up to 11.5% in a variety of dyes and electrolytes. Due to their larger surface area and adjustable characteristics, the properties of nanoscale ZnO-based materials are critical for sensing applications. ZnO nanoparticles that have been metal doped can find more use in photocatalysis, solar cells, chemical and biosensors, light-emitting diodes, laser diodes, and medications. These characteristics may be adjusted to provide materials with several uses in different nanostructures [22-24]. In order to improve solar energy collection, scientists have spent the last several decades developing solar selective absorber coatings with great thermal stability and performance. The addition of nanomaterials to the inside, outside, or rear of laminated absorber coatings is essential for enhancing thermal performance. The innovative architectures of solar selective absorber coatings with layers based on nanoparticles. These coatings can increase the thermal stability and efficiency of solar cells. According to [23], the most promising combinations of nanomaterials for different substrates include ZnO, SiO2, CuO, Al2O3, and carbon derivatives. In the photovoltaic (PV) sector, crystalline silicon (c-Si) solar cells are essential; nevertheless, their power efficiency during conversion is lower and they have sensitivity to angle of incidence. Due to their quasi-omnidirectional antireflection capability, quasi-omnidirectional c-Si solar cells are a cost-effective way to boost daily/yearly power production [25-28]. In c-Si solar cells, Si nanostructures can achieve quasi-omnidirectional antireflection; however, because of strong carrier Recombination, they frequently have lower η. The progress made in reducing electrical loss in quasi-omnidirectional c-Si solar cells is reviewed in this article along with countermeasures [29]. For next-generation devices, the photovoltaic industry is investigating materials for hybrid solar cells made of organic and inorganic components. With a power conversion efficiency increase from 3.8 to 24.2%, perovskites provide excellent efficiency at a reasonable cost. The creation of a suitable electron transport layer is still difficult, though. This review looks at current trends, problems with performance, and suggestions for more study [30,31].

5 Conclusion

The study conclusively highlights the transformative capability of quantum dots and nanostructures in photovoltaic electricity conversion. Key findings and contributions of this research consist of:

- Improved photovoltaic performance through the combination of quantum dots and nanostructures, especially CQDS and GQDS, which give advanced electrical and optical residences conducive to solar energy conversion.
- The success utility of QDS in overcoming conventional solar mobile limitations, such as spectral mismatch and thermal conductivity, thereby improving the absorption efficiency and usual performance of sun energy systems.
- Improvement of sustainable synthesis strategies for quantum dots, contributing to the reduction of environmental effect and facilitating green energy solutions.
- Identity of the considerable potential of nanostructures in various power conversion and garage applications, underscoring their importance inside the development of renewable energy technologies.

The findings underscore the essential position of superior materials together with quantum dots and nanostructures within the ongoing improvement of efficient, sustainable, and cost-effective solar energy solutions. Future research must attention on optimizing the synthesis and integration of these substances into sun energy systems to similarly enhance their overall performance and commercial viability.

References

1. Tang, Jian, Hao Ni, Run-Ling Peng, Ning Wang, and Lei Zuo. "A review on energy conversion using hybrid photovoltaic and thermoelectric systems." Journal of Power Sources 562 (2023): 232785.https://doi.org/10.1016/j.jpowsour.2023.232785

2. Sikiru, Surajudeen, Temidayo Lekan Oladosu, Sanusi Yekinni Kolawole, Lawal Adeyemi Mubarak, Hassan Soleimani, Lukmon Owolabi Afolabi, and Afolabi-Owolabi Oluwafunke Toyin. "Advance and prospect of carbon quantum dots synthesis for energy conversion and storage application: A comprehensive review." Journal of Energy Storage 60 (2023): 106556.https://doi.org/10.1016/j.est.2022.106556
3. Coldrick K, Walshe J, McCormack SJ, Doran J, Amarandei G. “The Role of Solar Spectral Beam Splitters in Enhancing the Solar-Energy Conversion of Existing PV and PVT Technologies”. Energies. 16(19), (2023):6841.
4. Yu, Yutang, Tianyi Ma, and Hongwei Huang. "Semiconducting quantum dots for energy conversion and storage." Advanced Functional Materials 33, 16 (2023): 2213770.
5. Sahai, Sonal, Ashu Jangra, Lisy M. Thomas, and Vibha R. Satsangi. "Quantum Dots as Efficient Solar Energy Absorber: Review on Photovoltaics and Photoelectrochemical Systems." Journal of The Institution of Engineers (India): Series D (2023): 1-14.
6. Sher, Farooq, Imane Ziani, Megan Smith, Galina Chugreeva, Seyid Zeynab Hashimzada, Liziê Daniela Tentler Prola, Jasmina Sulejmanović, and Emina K. Sher. "Carbon quantum dots conjugated with metal hybrid nanoparticles as advanced electrocatalyst for energy applications–A review." Coordination Chemistry Reviews 500 (2024): 215499.https://doi.org/10.1016/j.ccr.2023.215499
7. Zhang, Jingjing, Aurelio Bifulco, Paola Amato, Claudio Imparato, and Kezhen Qi. "Copper indium sulfide quantum dots in photocatalysis." Journal of Colloid and Interface Science 638 (2023): 193-219. https://doi.org/10.1016/j.jcis.2023.01.107
8. Deshmukh V.V., Tejashwini D.M., Nagaswarupa H.P., Naik R., Al-Kahtani A.A., Kumar Y.A." Sr and Fe substituted LaCoO3 nano perovskites: Electrochemical energy storage and sensing applications" Journal of Energy Storage (2024): 89- 111724.
9. Kumar A., Gaur N., Nanthaamornphong A." Improving the latency for 5G/B5G based smart healthcare connectivity in rural area" Scientific Reports, (2024): 14 (1) 6976.
10. Singh A, Kafle SR, Sharma M, Kim BS. “Comprehensive Review on Multifaceted Carbon Dot Nanocatalysts: Sources and Energy Applications”. Catalysts. 13(11), (2023):1446. https://doi.org/10.3390/catal13111446
11. Kumar, Yedluri Anil, Ganesh Koyyada, Tholkappiyan Ramachandran, Jae Hong Kim, H. H. Hegazy, Sangeeta Singh, and Md Moniruzzaman. "Recent advancement in quantum dot-based materials for energy storage applications: a review." Dalton Transactions (2023).
12. Jisha, P. K., Prashantha, S. C., & Nagabhushana, H. (2017). Luminescent properties of Tb doped gadolinium aluminate nanophosphors for display and forensic applications. Journal of Science: Advanced Materials and Devices, 2(4), 437-444.
13. Alrobei, H., Prashanth, M. K., Manjunatha, C. R., Kumar, C. P., Chitrabanu, C. P., Shivaramu, P. D., ... & Raghu, M. S. (2021). Adsorption of anionic dye on eco-friendly synthesised reduced graphene oxide anchored with lanthanum aluminate: Isotherms, kinetics and statistical error analysis. Ceramics International, 47(7), 10322-10331.
14. Kulandaivel, D., Rahamathullah, I. G., Sathiyagnanam, A. P., Gopal, K., & Damodharan, D. (2020). Effect of retarded injection timing and EGR on performance, combustion and emission characteristics of a CRDi diesel engine fueled with WHDPE oil/diesel blends. Fuel, 278, 118304.
15. Hora, S. K., Poongodan, R., De Prado, R. P., Wozniak, M., & Divakarachari, P. B. (2021). Long short-term memory network-based metaheuristic for effective electric energy consumption prediction. Applied Sciences, 11(23), 11263.
16. Raj, T. V., Hoskeri, P. A., Muralidhara, H. B., Manjunatha, C. R., Kumar, K. Y., & Raghu, M. S. (2020). Facile synthesis of perovskite lanthanum aluminate and its green reduced graphene oxide composite for high performance supercapacitors. Journal of Electroanalytical Chemistry, 858, 113830.

17. Sariga, Ann Mariella Babu, Shashi Kumar, Rijo Rajeev, Ditto Abraham Thadathil, and Anitha Varghese. "New horizons in the synthesis, properties, and applications of MXene quantum dots." Advanced Materials Interfaces 10,5 (2023): 2202139.
18. Dhivyasri G., Manikandan M., Ajayan J., Sreejith S., Remya R., Nirmal D." A comparative study of AlGaN and BAlGaN based ultraviolet quantum well-based light emitting diodes" Optical and Quantum Electronics, (2024):56 (4) 649
19. Pourmadadi, Mehrab, Erfan Rahmani, Maryam Rajabzadeh-Khosroshahi, Amirmasoud Samadi, Razieh Behzadmehr, Abbas Rahdar, and Luiz Fernando Romanholo Ferreira. "Properties and application of carbon quantum dots (CQDs) in biosensors for disease detection: A comprehensive review." Journal of Drug Delivery Science and Technology 80 (2023): 104156.https://doi.org/10.1016/j.jddst.2023.104156
20. Karaagac, Hakan, Elif Peksu, and Asya Coskun. "Recent progress in solar cells based on one dimensional ZnO nanostructures." Nanotechnology (2023).DOI 10.1088/1361-6528/acda34
21. Ahmed R., Vandana C.P., Vijendar Reddy G., Sobti R., Chauhan S., Srivastava A.P." Analysis of efficient building for energy conversion and storage using phase change material." E3S Web of Conferences (2024): 507 1076.
22. Khan, Ashfaq, Mushtaq Khan, Nasir Ahmed, Zuhaib Ali Khan, and Muhammad Zeeshan Zahir. "Nanomaterials for Solar Cells." Nanomaterials for Energy Applications (2024): 5-31.
23. Indira, D. N. V. S. L. S., Ganiya, R. K., Babu, P. A., Xavier, A. J., Kavisankar, L., Hemalatha, S., ... & Yeshitla, A. (2022). Improved artificial neural network with state order dataset estimation for brain cancer cell diagnosis. BioMed Research International, 2022.
24. Jaidass, N., Moorthi, C. K., Babu, A. M., & Babu, M. R. (2018). Luminescence properties of Dy3+ doped lithium zinc borosilicate glasses for photonic applications. Heliyon, 4(3).
25. Lakshmi, L., Reddy, M. P., Santhaiah, C., & Reddy, U. J. (2021). Smart phishing detection in web pages using supervised deep learning classification and optimization technique ADAM. Wireless Personal Communications, 118(4), 3549-3564.
26. Spandana, K., & Rao, V. S. (2018). Internet of Things (Iot) Based smart water quality monitoring system. International Journal of Engineering and Technology (UAE), 7(3), 259-262.
27. Kumar, K. U., Babu, P., Basavapoornima, C., Praveena, R., Rani, D. S., & Jayasankar, C. K. (2022). Spectroscopic properties of Nd3+-doped boro-bismuth glasses for laser applications. Physica B: Condensed Matter, 646, 414327.
28. Vinitha, V., Preeyanghaa, M., Vinesh, V. et al. : Two is better than one: catalytic, sensing and optical applications of doped zinc oxide nanostructures:. Emergent mater. 4, (2021):1093–1124. https://doi.org/10.1007/s42247-021-00262-x'
29. Liu, Bo, Chunyu Wang, Shahab Bazri, Irfan Anjum Badruddin, Yasin Orooji, Samrand Saeidi, Somchai Wongwises, and Omid Mahian. "Optical properties and thermal stability evaluation of solar absorbers enhanced by nanostructured selective coating films." Powder technology 377 (2021): 939-957.
30. Zhong, Sihua, and Wenzhong Shen. "Quasi-omnidirectional crystalline silicon solar cells." Journal of Physics D: Applied Physics 53, no. 48 (2020): 483001.
31. Yusuf, A. S., Ramalan, A. M., Abubakar, A. A. and Mohammed, I. K. "Progress on Electron Transport Layers for Perovskite Solar Cells". Nigerian Journal of Physics (NJP), 32 (4), (2023):3027-0936. DOI: https://doi.org/10.62292/njp.v32i4.2023.156