iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 11 Issue: VI Month of publication: June 2023

DOI: https://doi.org/10.22214/ijraset.2023.54404

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue VI Jun 2023- Available at www.ijraset.com

Investigation of Materials for Photovoltaic Devices and Solar Energy Harvesting

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Abstract: The purpose of this study article is to look at various materials utilised in PV devices and investigate their qualities and potential for efficient solar energy collecting. The research includes a thorough examination of many material types, including standard silicon-based solar cells and developing alternatives such as perovskites, organic polymers, and quantum dots. The study focuses on the materials' performance, efficiency, stability, and cost-effectiveness, providing insights into the advancements and issues related with materials for PV devices.
Keywords: Photovoltaic devices, Solar energy harvesting, Material Investigation, Efficiency, Perovskite solar cells.

I. INTRODUCTION

Because of the growing demand for renewable energy sources and the urgency of mitigating climate change, solar energy harvesting has arisen as a crucial topic of study and development. Solar energy provides a sustainable and environmentally friendly alternative to existing fossil fuels, which are rapidly diminishing and contribute to greenhouse gas emissions. Solar energy, which is abundant and free, has enormous promise for satisfying global energy demands while reducing environmental effect. PV devices, commonly known as solar cells, are critical in converting sunlight directly into electricity. These devices are at the cutting edge of solar energy conversion technologies, with substantial developments throughout the years.

The importance of photovoltaic systems stems from its capacity to efficiently harness solar energy and generate power without emitting greenhouse gases or depleting natural resources. As the global demand for clean and sustainable energy intensifies, the deployment of solar systems has increased dramatically. Solar photovoltaic installations are already visible on rooftops, solar farms, and even in consumer gadgets, indicating a shift towards a more sustainable energy landscape.

The goal of this study is to evaluate the materials utilised in photovoltaic systems, as well as their capabilities and potential for efficient solar energy harvesting.

II. SILICON-BASED SOLAR CELLS

Silicon-based solar cells have replaced the photovoltaic (PV) field as the dominant technology. Silicon is used as a semiconductor material that efficiently converts solar energy into electricity. These solar cells have undergone many stages of development to improve their efficiency, manufacturing techniques and cost effectiveness.

First-generation silicon solar cells, also called crystalline silicon (c-Si) solar cells, consist of monocrystalline or polycrystalline silicon structures. It offers high conversion rates and long-term stability. Monocrystalline silicon solar cells are widely used in residential and commercial applications due to their uniform appearance and excellent performance. Solar cells made from polycrystalline silicon are also commonly used, which are cheaper to manufacture, but are slightly less efficient. Second-generation silicon solar cells, so-called thin-film solar cells, use thinner silicon layers than c-Si solar cells. This reduces material consumption and reduces manufacturing costs. There are several types of thin-film solar cells, including amorphous silicon (a-Si), cadmium telluride and copper indium gallium selenide (CIGS) solar cells. These technologies have advantages in terms of cost and flexibility, but their efficiencies are generally lower compared to c-Si solar cells.

Third-generation silicon solar cells aim to improve efficiency and reduce costs through advanced concepts and materials. Examples include multijunction solar cells composed of multiple semiconductor layers to capture a wider range of solar wavelengths, PERC (passivated emitter and rear cell) solar cells, and heterojunction intrinsic thin film (HIT) solar cells. . These designs improve light absorption, minimize recombination losses, and improve overall cell efficiency.

Challenges associated with silicon-based solar cells include relatively high manufacturing costs, the environmental impact of silicon extraction and processing, and the limited efficiency improvements observed in recent years. Researchers and manufacturers are actively exploring innovative approaches such as nanomaterials and new cell architectures to address these challenges and maximize the performance and cost effectiveness of silicon-based solar cells. I'm here.

III. PEROVSKITE SOLAR CELLS

Perovskite solar cells have attracted much attention in recent years due to their excellent properties and potential for high-performance photovoltaics. These cells use perovskite materials, usually metal halide compounds, as light absorbing layers. Perovskite solar cells have several advantages, such as unable bandgap, high light absorption, inexpensive processing, and ability to be fabricated using solution-based techniques. The unique properties of perovskite materials enable efficient charge separation and charge transport, contributing to high energy conversion efficiency. In just a few years of development, perovskite solar cells have achieved significant efficiency improvements comparable to conventional silicon-based solar cells. Perovskite solar cells have record efficiencies of over 25% and are rapidly approaching theoretical limits. However, perovskite solar cells also face challenges in terms of stability and long-term performance. Perovskite materials can degrade in the presence of moisture, heat, and light, limiting their durability and reliability. Researchers are actively working to address these stability issues through encapsulation techniques, interface engineering, and development of more stable perovskite compositions. Strategies to increase the efficiency of perovskite solar cells include optimizing the perovskite crystal structure, improving charge extraction and charge transport, and exploring tandem solar cell configurations. Tandem solar cells, which combine perovskite materials with other PV technologies such as silicon solar cells and thin-film solar cells, have the potential to achieve even higher efficiencies by exploiting complementary absorption properties to maximize light utilization. is showing.

IV. ORGANIC PHOTOVOLTAIC CELLS

Organic photovoltaic cells (OPV), also called organic solar cells, use organic polymers or small molecules as the active material in the light-absorbing layer. OPV cells have advantages such as light weight, flexibility, and the potential for low-cost, high-volume production using solution-based processing techniques. The efficiency of OPV cells has improved significantly in recent years, reaching values of 15% or more. Organic materials can be tuned to absorb a broad spectrum of solar wavelengths, allowing for the design of tailored absorption spectra and more effective utilization of the solar spectrum. However, OPV cells are generally less efficient compared to silicon or perovskite solar cells. One of the main challenges for OPV cells is achieving long-term stability and durability. Organic materials are sensitive to environmental factors such as moisture and oxygen, which can degrade their performance over time. Researchers are actively exploring strategies to improve OPV cell stability through the development of new materials, interface engineering, and encapsulation techniques. Techniques to improve OPV cell performance include optimizing the molecular structure of organic materials to improve light absorption and charge transport, improving interfaces between different layers, and implementing innovative device architectures. will be Furthermore, combining organic materials with other PV technologies, such as silicon and perovskite materials, in hybrid solar cells may provide synergies and improve overall performance.

V. QUANTUM DOT SOLAR CELL

Quantum dot solar cells, a promising new technology for the efficient conversion of solar energy, are nanoscale semiconductor particles that exhibit unique properties due to quantum confinement effects. Quantum dots are suitable for light harvesting in solar cells due to their properties such as tunable bandgap, high absorption coefficient, and generation of multiple excitons. Quantum-dot solar cells can be made from many different types of quantum dots, including inorganic materials such as lead sulfide (PbS) and cadmium selenide (CdSe), as well as new non-toxic alternatives. These materials offer advantages such as high absorption efficiency, the ability to tune the bandgap to specific regions of the solar spectrum, and compatibility with solution-based processing techniques. The efficiency improvement of quantum dot solar cells is significant, with efficiencies exceeding 13%. However, challenges regarding stability and long-term performance still remain. Quantum dots can degrade through oxidation, photodegradation, or surface defects, affecting the overall device performance. Researchers are investigating surface passivation techniques, encapsulation strategies, and new quantum dot compositions to improve stability.

Comparing quantum dot solar cells to other PV technologies, the potential for solution processability, tunable bandgap, and ability to collect multiple excitons per absorbed photon, resulting in improved efficiency. increase. However, current efficiencies still fall short of those of silicon and perovskite solar cells, and scalability and commercial feasibility need to be further developed.

VI. HYBRID AND TANDEM SOLAR CELL

Hybrid solar cells combine different materials and technologies to create a more efficient photovoltaic device. By integrating multiple materials with complementary absorption properties, hybrid solar cells can effectively utilize a wider range of sunlight and improve overall energy conversion efficiency.

One example of a hybrid solar cell is the combination of silicon and perovskite materials. Silicon offers stability and long-term performance, while perovskite offers the potential for high light absorption and high efficiency. These hybrid structures enable efficient charge generation, collection and transport, improving overall device performance. Tandem solar cells take a different approach by integrating multiple absorber layers with different bandgaps in a stacked configuration. Each absorbing layer captures a specific region of the solar spectrum, allowing for more efficient collection of light. Tandem solar cells can be constructed from a variety of materials such as perovskite/perovskite, perovskite/silicon, or perovskite/thin film combinations. The development of hybrid and tandem solar cells requires careful optimization of materials, interfaces and device architectures to ensure efficient charge transfer and minimal losses. These structures offer the opportunity to exceed the limits of individual materials to achieve higher efficiencies, making them promising avenues for future advances in solar energy conversion.

VII. CONCLUSION

This research report explores various aspects of photovoltaic device materials and their role in solar energy harvesting. A key technology in the photovoltaic industry, silicon-based solar cells have gone through several generations of development, advancing in efficiency and manufacturing processes. Perovskite solar cells not only offer unique properties and the potential for high efficiency, but also present challenges related to stability. Organic solar cells offer flexibility and cost advantages. Ongoing research is focused on improving efficiency and stability. Quantum dot solar cells offer exciting potential for efficient light harvesting, but their stability and commercial scalability are still areas under investigation. Hybrid and tandem solar cells combining different materials and configurations offer opportunities for improved efficiency and spectrum utilization.

This comprehensive survey of photovoltaic device materials highlights advances, challenges and opportunities in the field of solar energy harvesting. To contribute to our understanding of these materials, identify challenges, and explore future directions in the development of efficient and sustainable solar energy technologies by addressing key research goals and following the structure of the research papers outlined.

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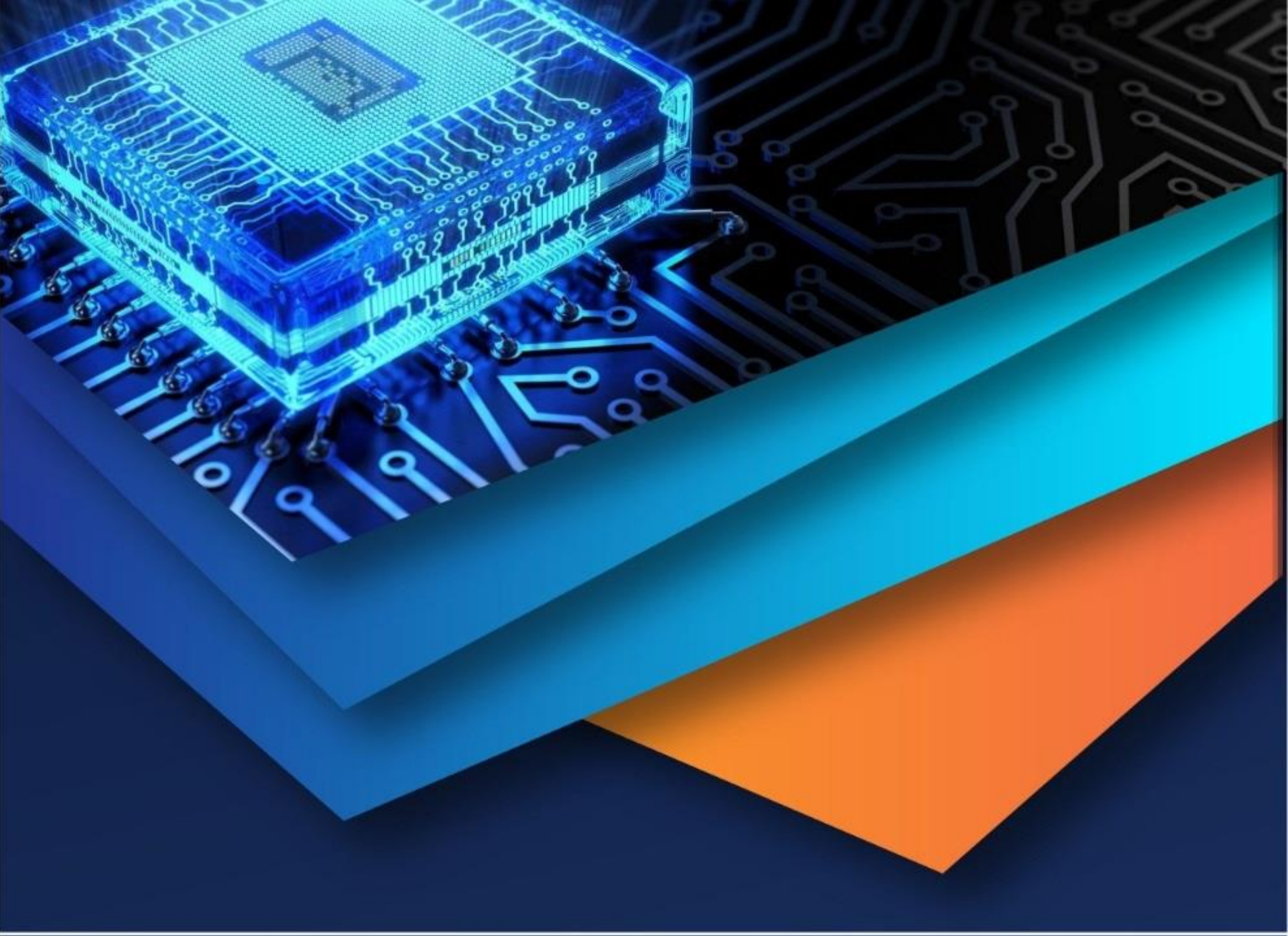

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