International Journal of Sustainable Applied Sciences (IJSAS)
Vol.2, No.9, 2024: 887-896

# Solar Energy in Space Applications: Review

Farhana Mahjabeen[1*]
Deputy Station Engineer, Bangladesh Betar.
Email: farhana.aeceiu@gmail.com
**Corresponding Author:** Farhana Mahjabeen, farhana.aeceiu@gmail.com

A R T I C L E I N F O

*Keywords:* Multijunction Solar Cells, Radiation Hardness, Flexible Solar Cells, 2D Materials, Aerospace Solar Cell

*Received : 03, August*
*Revised : 18, August*
*Accepted: 23, September*



A B S T R A C T

Solar Cells Power Generation: A spacecraft needs to have power from its solar panels or in simple terms, a satellite's batteries are charged with the help of solar cells. The III-V multijunction solar cell is standard in the market due to its high efficiency and reliability. The resultant cells then could be topped with silicon, a much lower cost, easier wafers. Portability and scalability are also important factors; recently, $CuSe_2$ and perovskite solar cells have been developed to replace the existing sensors because of realizable weight saving, flexibility, and cost-effectiveness with hard radiation resistance. We also present an overview of recent progress in various solar cell technologies for aerospace missions regarding device architecture, performance characteristics, and radiation hardness. It explores the potential of 2D materials such as Graphene for improved performance and stability, along with the radiation effects on devices built using 2D materials.

## INTRODUCTION

Space exploration has come a long way since Sputnik 1 blasted off in 1957 and has done some strange things. Today, Earth is surrounded by thousands of satellites for telecommunication, navigation, and earth observation purposes . The power generation system for spacecraft is one of the critical components . The specific choice of PGS will depend on the mission duration, distance from the SunSun, and power requirements. The review will then discuss the pros and cons of each PGS platform.

### Space Solar Cell Technology

While traditional heavy and rigid solar cell materials, such as silicon, are also highly resistant to radiation exposure, they must be more flexible. While GaAs and III-V multijunction junctions are more efficient, they are also more costly and less radiation tolerant. Thin-film solar cell technologies have been developed over the years, and yesterday, their arrival, such as CIGS and CdTe, allowed the installation of a light, flexible solar array in spacecraft at an affordable cost.

Halide perovskites232 and Cu2 have recently demonstrated exciting applications for space, combining low costs and high efficiencies with radiation tolerance. Lab-scale perovskites routinely >25% lab efficiency and radiation hardness commensurate with III-V. Nevertheless, long-term immunoregulatory stability is an unresolved issue that needs to be addressed in future work. 2D wonder materials like Graphene could also make space solar cells more efficient and stable. Additionally, graphene-based devices have demonstrated high radiation tolerance that may allow for flexible, lightweight solar arrays.

We have come a long way in our quest for space after Sputnik 1 hit the road. Earth has hundreds of satellites used as communication, navigation, and observation satellites. Regarding spacecraft, power generation is one of the most essential features of its system choice, depending on mission requirements and power demand. Batteries or fuel cells may be employed for short missions, and photovoltaic devices or nuclear power systems are used in most current space vehicles inner planet missionsuse solar cells, which receiveenough sunlight . This review summarizes SC usage in aerospace applications, the different PGS technologies, and recent developments and challenges of SCs. It concerns device architecture, performance, radiation tolerance, and replacement. Technologies with 2d materials such as Graphene to improve in terms of both performance and stability

## LITERATURE REVIEW

Recently, a study showed that electrons are up to seven times more abundant than expected in Archean-banded iron formations. A more efficient alternative is gallium arsenide and III-V multijunction solar cells. However, it suffers from high cost and low radiation tolerance. The emergence of thin-film solar cell technologies like CIGS and CdTe makes lightweight, flexible, low-cost solar arrays possible for spacecraft.

In recent years, halide perovskites and Cu2 phase VII have shown great potential for space applications due to their low cost of fabrication, high-efficiency performance, and radiation tolerance. Lab-scale perovskites have also demonstrated >25% efficiency at present and radiation hardness rivaling state-of-the-art III-V cells. However, long-term stability is still a significant problem that needs to be addressed, which entails continuous studies.

Quantum dots, black Phosphorus, and 2D materials such as Graphene are considered suitable for improving the performances and stability of space solar cells. These graphene-based devices can deliver the extreme radiation tolerance, lightweight, and flexibility needed to support solar arrays that we envision one day flying on spacecraft for exploration missions.

Next-generation solar cells based on polymer, perovskite, and dye-sensitized are all affected by stability issues, and the efficiency issue of concern is offset. All these devices need to be encapsulated and exhibit different degrees of susceptibility to moisture, oxygen, high temperature, and UV illumination. Each cell type has its own degradation mechanisms, which is the key to overcoming the stability issues and making CdTe solar cells widespread .

In recent years, halide perovskites and Cu2Se have been widely used in space because of their advantages, such as low cost, high efficiency, and radiation tolerance . Perovskites have exhibited over 25% efficiency in lab-scale device sites and radiation hardness similar to state-of-the-art III-V cells . Nonetheless, long-term stability is not definitive and calls for further study . For instance, 2D materials such as Graphene were suggested to improve the performance and stability of space solar cells (Liu et al. Moreover, devices based on Graphene are highly radiation-tolerant and could contribute to lightweight solar arrays.

Perovskites also have the potential to emerge as an alternative to traditional materials, including silicon and III-V compounds for space technologies based on a few studies that have found its applicability.By combining two probable materials they have found in the lab over ten years, superlattice structures made out of HFO2 (and two substitute elements to be added) and PuO2 are expected to have very high efficiency, low cost, and good radiation tolerance, making them attractive for spacecraft power generation. This includes gossamer spacecraft technologies, such as inflatable structures, future in-space fabrication, and robotic assembly to make the large-scale space-based systems needed for solar power collection and transmission in space.

## METHODOLOGY

The following aspects will be considered in this review:

1. Destruction of New Solar Cell Technologies, i.e., Perovskites, Organic sun-powered cells, and Dye-Sensitized sunlight-based cells. Aggregate Chosen Papers.
2. Perovskite and other emerging solar cell technologies: In terms of performance, radiation tolerance, and space application
3. 2D materials (with Graphene as an active being) for increased performance and stability of solar cells in space missions

The review article is expected to compile the observations reported by all lines mentioned above to provide a complete picture of the current status of solar cell technology for space, its benefits and limitations, and strategies for addressing stability aspects.

## RESULTS

### What Are the Space Conditions for Space Solar Cells

The space environment presents several challenges to solar cell performance and reliability. The long-term degradation in solar cell efficiency due to exposure to high-energy radiation (protons, electrons, and heavy ions) is of great concern for long-duration missions. In addition to space radiation, severe thermal cycling, micrometeoroid impacts, and atomic oxygen also play a role in solar cell degradation.

#### *Space Perovskite Solar Cells*

Due to their high efficiency, low cost, and radiation tolerance, perovskite solar cells are becoming one of the best candidates for space power generation systems. State-of-the-art lab scale perovskites devices already present power conversion efficiencies (PCEs) >%; higher than most c-Si and first-generation solar cell technology, ~% in "% form I will have the potential to reach above 25 PCE.

Perovskite materials possess characteristic electronic properties such as high absorption coefficients, long charge carrier diffusion lengths, and tunable bandgaps, which render them auspicious for space solar cells. Still, issues with the long-term stability of perovskite solar cells need to be ironed out. They are diligently working to improve perovskite solar cell stability by using stable interface layers and encapsulation front. BalB/C. The way of selection must be associated with the product .

#### *Stability and Performance of Solar Cells with 2D Materials*

Two-dimensional (2D) materials, such as Graphene, have shown a potential to improve efficiency and longevity in solar cells intended for space use. Summary: New research indicates that specific fixed-film composites made with Graphene are promising materials for fabricating highly radiation-tolerant devices suitable for applications in space exploration. Combining 2D materials, such as Graphene with perovskite and other solar cell technologies, presents a hotbed area for research that might counteract stability challenges and generally increase device efficiency.

#### *Solar Cells Used in Space*

High efficiency and reliability drive the use of conventional silicon and III-V compound solar cells for space applications. Nevertheless, the development of thin-film solar cell technology, including CIGS and CdTe, makes low-weight and high-flexibility applications possible. Many newer solar cell technologies, such as perovskites, plastic cells, or dye-sensitized variants, also present a number of benefits that could be seen in more efficient, cost-effective, and versatile space configurations.

##### *Space MJSCs: Configuration and Operational Principle*

The equipment employs multi-junction solar cells, proven to be highly efficient and radiation tolerant and specifically for use in space applications.

Such cells contain multiple subcells produced in different semiconductor materials, each designed to absorb a particular section of the solar spectrum.

*Space solar cells have drawbacks and limited stability*

Silicon and III-V are the ASIC of cheap space power systems problems, but silicon and conventional solar cells have their limitations:

1. Aging – exposes the animals to high-energy radiation, which causes them to become degraded
2. High manufacturing costs
3. Rigidity and weight

To overcome these limitations, research on alternative solar cell technologies has been actively sought to mitigate the challenges faced by the space environment.

**Space MJ-Mediated Radiation Resistance**

They have intrinsic design options to improve radiation resistance compared to single-junction solar cells and multi-junction devices. The multiple subcells add redundancy, and the comprehensive bandgap materials in the top subcells are less sensitive to displacement damage from high-energy radiation.

**Si-Based Solar Cells**

Single-junction silicon solar cells have been used on space missions for decades because they are commercially available, reasonably efficient, and relatively radiation-tolerant. Nevertheless, the efficiency of silicon solar cells is fast approaching its theoretical limit, and they suffer from poor performance degradation upon irradiation with space radiation.

*Materials and Device Architectures: Current Advances and Future Prospects*

Moreover, recent developments in materials and device architecture for solar cells have centered on improving efficiency, radiation resistance, and stability for space applications. Demonstration of multijunction solar cells with efficiencies that violated Shockley-Queisser limits using conventional semiconductor materials.

New cell designs based on emerging technologies (e.g., perovskite solar cells and 2D materials like Graphene) are expected to unlock new power generation possibilities for space missions, owing to higher efficiency, low-cost manufacturing processes, and increased radiation hardness.As a result, we anticipate that continued research and development in these areas will spur further advances in the performance, reliability, and cost-effectiveness of space solar cells for new and longer-lasting deep-space exploration missions.

## DISCUSSION

### Opinions on Future Materials for Space PV

In addition, the use of solar power in space requires very high standards for the performance and durability of solar cells in order to withstand the space environment. New or alternative solar cell technologies, like perovskite and 2D materials, could be solutions to stabilizing the space solar cells from proton radiation effects at low Earth orbit (LEO) for many years with a lower cost .

Of these, perovskite solar cells have shown the most striking efficiency achievements, already reaching over 25% in laboratory size. Here, we demonstrate that such films have the potential to be achieved via low-cost fabrication and easy tunability of bandgaps, which opens up a pathway toward designing space-worthy devices.

Yet another significant challenge facing this class of solar cells is long-term stability under space conditions, comprising radiation and thermal cycling. Integrating 2D materials such as Graphene with perovskite and other solar cell technologies could further increase device performance and radiation tolerance. With these new materials and device architectures, along with continued improvements in multi-junction solar cells and other conventional technologies, the future of space photovoltaics is bright.

## CONCLUSIONS AND RECOMMENDATIONS

Space mission privatization is driving the need for lower-cost, high-boosting photovoltaic technologies. Today, silicon-based solar cells strike that balance for short missions, but the industry is transitioning to flexible, high-power arrays designed for everything from communications satellites to megaconstellations. This needs to be weighed along with technology advancement and commercial viability. That means updating current multi-junction solar cell tech and creating higher-efficiency designs that might cost a touch more but which, in the end, will produce more for less. The use of materials that are subjected to EU REACH regulations is essential. Because of the limited scale of the space-grade solar cell market, substantial financial support is necessitated for contending technology evolution. ConclusionFlexible solar cells challenge philosophies that drive conventional approaches, and the need for collaborative R&D in industry and research is paramount.

## FURTHER STUDY

Future research should prioritize developing advanced materials like perovskites and quantum dots for flexible, high-efficiency solar cells, focusing on enhancing their stability in the harsh space environment . Exploring innovative design and manufacturing techniques, such as AI-driven optimization and 3D printing, is crucial for creating efficient and adaptable solar arrays. Rigorous testing, including space environment simulation and accelerated lifetime testing, is essential for ensuring long-term reliability and performance. Collaborative R&D efforts between industry and academia are vital for accelerating the development and commercialization of these advanced photovoltaic technologies.

**REFERENCES**

Sattar, S. A., Abdul, S., Khan, S. M., & Ismail, B. I. (2022, December 31). Predicting And Fighting Cyber Threats Through AI-generated Threat Intelligence. https://redcrevistas.com/index.php/Revista/article/view/46

Juba, O. O., Olumide, A. O., Ochieng, J. O., & Aburo, N. A. (2022, August 30). Evaluating the Impact of Public Policy on the Adoption and Effectiveness of Community-Based Care for Aged Adults. https://ijmlrcai.com/index.php/Journal/article/view/59

Muhammad, S., Meerjat, F., Meerjat, A., & Dalal, A. (2023). Enhancing Cybersecurity Measures for Blockchain: Securing Transactions in Decentralized Systems. Unique Endeavor in Business & Social Sciences, 2(1), 120-141.

Muhammad, S., Meerjat, F., Meerjat, A., Naz, S., & Dalal, A. (2023). Strengthening Mobile Platform Cybersecurity in the United States: Strategies and Innovations. Revista de Inteligencia Artificial en Medicina, 14(1), 84-112.

Muhammad, S., Meerjat, F., Meerjat, A., Dalal, A., & Abdul, S. (2023, April 24). Enhancing Cybersecurity Measures for Blockchain: Securing Transactions in Decentralized Systems. https://unbss.com/index.php/unbss/article/view/53

Ismail, B. I., Abdul, S., Khan, S. M., Sattar, S. A., & Muhammad, S. (2023, April 10). AI for Cyber Security: Automated Incident Response Systems. https://jest.com.pk/index.php/jest/article/view/174

Abdul, S., Ismail, B. I., Khan, S. M., Sattar, S. A., & Muhammad, S. (2023, August 31). Assessing AI-Based Threat Detection in the Cloud Security. https://ijmlrcai.com/index.php/Journal/article/view/52

Dalal, A., Venaik, U., Kumari, R., & Venaik, A. (2023). ChatGPT's Role In Healthcare Education, Research, And Practice: A Systematic Review Of Promising Prospects And Legitimate Concerns. Educational Administration: Theory and Practice, 29(1), 337-344.

Muhammad, S., Meerjat, F., Meerjat, A., & Dalal, A. (2024). Integrating Artificial Intelligence and Machine Learning Algorithms to Enhance Cybersecurity for United States Online Banking Platforms. Journal Environmental Sciences And Technology, 3(1), 117-139.

Muhammad, S., Meerjat, F., Meerjat, A., & Dalal, A. (2024). Safeguarding Data Privacy: Enhancing Cybersecurity Measures for Protecting Personal Data in the United States. International Journal of Machine Learning Research in Cybersecurity and Artificial Intelligence, 15(1), 141-176.

Muhammad, S., Meerjat, F., Meerjat, A., Naz, S., & Dalal, A. (2024). Enhancing

Cybersecurity Measures for Robust Fraud Detection and Prevention in US Online Banking. International Journal of Advanced Engineering Technologies and Innovations, 1(3), 510-541.

Omolara, J. Occupational Health and Safety Challenges Faced by Caregivers and the Respective Interventions to Improve their Wellbeing.

Phiri, A. K., Juba, O. O., Baladaniya, M., Regal, H. Y. A., & Nteziryayo, T. (2024). Strategies for Quality Health Standards. Cari Journals USA LLC.

Juba, O. O., Olumide, A. F., David, J. I., & Adekunle, K. A. (2024). The Role of Technology in Enhancing Domiciliary Care: A Strategy for Reducing Healthcare Costs and Improving Safety for Aged Adults and Carers. Unique Endeavor in Business & Social Sciences, 3(1), 213-230.

Juba, O. O., Olumide, B. F., David, J. I., Olumide, A. O., Ochieng, J. O., & Adekunle, K. A. (2024). Integrating Mental Health Support into Occupational Safety Programs: Reducing Healthcare Costs and Improving Well-Being of Healthcare Workers Post-COVID-19. Revista de Inteligencia Artificial en Medicina, 15(1), 365-397.

Dalal, A. (2018). Cybersecurity And Artificial Intelligence: How AI Is Being Used in Cybersecurity To Improve Detection And Response To Cyber Threats. Turkish Journal of Computer and Mathematics Education (TURCOMAT), 9(3), 1416-1423.

Sattar, S. A., Abdul, S., Khan, S. M., & Ismail, B. I. (2022, December 31). Predicting And Fighting Cyber Threats Through AI-generated Threat Intelligence. https://redcrevistas.com/index.php/Revista/article/view/46

Muhammad, S., Meerjat, F., Meerjat, A., Dalal, A., & Abdul, S. (2023, April 24). Enhancing Cybersecurity Measures for Blockchain: Securing Transactions in Decentralized Systems. https://unbss.com/index.php/unbss/article/view/53

Abdul, S., Ismail, B. I., Khan, S. M., Sattar, S. A., & Muhammad, S. (2023, August 31). Assessing AI-Based Threat Detection in the Cloud Security. https://ijmlrcai.com/index.php/Journal/article/view/52

Dalal, A., Venaik, U., Kumari, R., & Venaik, A. (2023). ChatGPT's Role In Healthcare Education, Research, And Practice: A Systematic Review Of Promising Prospects And Legitimate Concerns. Educational Administration: Theory and Practice, 29(1), 337-344.

Haque, A., Kholilullah, I., Sharma, A., Mohammad, A., & Khan, S. I. (2024). Analysis of Different Control Approaches for a Local Microgrid: A Comparative Study. Control Systems and Optimization Letters, 2(1), 94-102.

Mohammad, A., Shovon, R. B., Hasan, M. M., Das, R., Munayem, N. M. A., &

Arif, A. (2024). Perovskite Solar Cell Materials Development for Enhanced Efficiency and Stability. Power System Technology, 48(1), 119-135.

Ibrahim, A. S. M., Mohammad, A., Nuruzzamal, M., & Shams, S. N. (2024). Fruit Waste Management through Vermicomposting: the Case of PRAN, Bangladesh. Formosa Journal of Applied Sciences, 3(3), 925-938.

Ibrahim, A. S. M., Mohammad, A., Khalil, M. I., & Shams, S. N. (2024). Viability of Medium-Scale Vermicompost Plant: a Case Study in Kushtia, Bangladesh. Formosa Journal of Applied Sciences, 3(3), 787-796.

Ibrahim, A. S. M., Rahman, M., Dipu, D. K., Mohammad, A., Mazumder, G. C., & Shams, S. N. (2024). Bi-Facial Solar Tower for Telecom Base Stations. Power System Technology, 48(1), 351-365.

Mohammad, A., Mahjabeen, F., Bahadur, S., & Das, R. (2022). Photovoltaic Power plants: A Possible Solution for Growing Energy Needs of Remote Bangladesh. NeuroQuantology, 20(15), 5503.

Mohammad, A., & Mahjabeen, F. (2023). Promises and challenges of perovskite solar cells: a comprehensive review. BULLET: Jurnal Multidisiplin Ilmu, 2(5), 1147-1157.

Bahadur, S., Mondol, K., Mohammad, A., Mahjabeen, F., Al-Alam, T., & Bulbul Ahammed, M. (2022). Design and Implementation of Low Cost MPPT Solar Charge Controller.

Mohammad, A., & Mahjabeen, F. (2023). From silicon to sunlight: exploring the evolution of solar cell materials. JURIHUM: Jurnal Inovasi dan Humaniora, 1(2), 316-330.

Mohammad, A., Das, R., & Mahjabeen, F. (2023). Synergies and Challenges: Exploring the Intersection of Embedded Systems and Computer Architecture in the Era of Smart Technologies. Asian Journal of Mechatronics and Electrical Engineering, 2(2), 105-120.

Mohammad, A., Das, R., Islam, M. A., & Mahjabeen, F. (2023). AI in VLSI Design Advances and Challenges: Living in the Complex Nature of Integrated Devices. Asian Journal of Mechatronics and Electrical Engineering, 2(2), 121-132.

Maizana, D., Situmorang, C., Satria, H., Yahya, Y. B., Ayyoub, M., Bhalerao, M. V., & Mohammad, A. (2023). The Influence of Hot Point on MTU CB Condition at the Pgeli-Giugur 1 Bay Line (PT. PLN Paya Geli Substation). Journal of Renewable Energy, Electrical, and Computer Engineering, 3(2), 37-43.

Islam, M. F., Debnath, S., Das, H., Hasan, F., Sultana, S., Datta, R., Mallik, B., & Halimuzzaman, M. (2024). Impact of Rapid Economic Development with Rising Carbon Emissions on Public Health and Healthcare Costs in Bangladesh. Journal of Angiotherapy, 8(7), 1–9.

https://doi.org/10.25163/angiotherapy.879828

Halimuzzaman, Md., Sharma, Dr. J., Bhattacharjee, T., Mallik, B., Rahman, R., Rezaul Karim, M., Masrur Ikram, M., & Fokhrul Islam, M. (2024). Blockchain Technology for Integrating Electronic Records of Digital Healthcare System. Journal of Angiotherapy, 8(7). http://publishing.emanresearch.org/Journal/Abstarct/angiotherapy.879740

Islam, M. F., Eity, S. B., Barua, P., & Halimuzzaman, M. (2023). Liabilities of Street Food Vendors for spreading out Chronic Diseases and Environment Pollution: A Study on Chattogram, Bangladesh. JETIR, 10(11), Article 11. https://www.jetir.org/view?paper=JETIR2311233

Islam, M. T., Islam, Md. F., & Sawda, J. (2022). E-commerce and Cyber Vulnerabilities in Bangladesh: A Policy Paper. International Journal of Law and Society (IJLS), 1(3), 184-202.

Islam, M.F., Hasan, Fuad, Islam, S.M.S. and Sajbir, S.I. (2022). Is Export-led Economic Growth Significant in LDCs?: Evidence from Bangladesh. AIUB Journal of Business and Economics, 19(2), pp.93–108.