

Recent Advances in Solar Cells for Aerospace Applications: Materials and Technologies

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This editorial provides a comprehensive overview of the latest advances in solar cell material research and the potential applications of these materials in space. The overview highlights the need for a multidisciplinary approach that considers materials, manufacturing and integration to further promote the use of solar energy in space and support the growth of programs like mega-constellations of satellites.

Solar cells play a critical role in the shift towards a future with cleaner and more sustainable energy. As the demand for renewable energy sources grows, solar cells are being increasingly utilized in various industries, including aerospace and terrestrial solar power plants, as well as in portable electronic devices (Safyanu *et al.* 2019). However, operating solar cells in space poses significant challenges, particularly for aerospace applications. These challenges include exposure to intense radiation, which can reduce solar cell performance and its lifespan, as well as sudden and extreme temperature changes in space, which can cause damage to the cells or malfunctions. Furthermore, space debris, such as micrometeoroids, can cause physical damage to the cells and affect their ability to produce energy. To ensure the reliability and longevity of solar cells in space, it is essential to overcome these challenges via the continued advancement of their technology.

Solar cells are widely used to supply electrical power to space missions that can last for several years. Some examples of applications are illustrated in Fig. 1. As the space exploration industry grows and more satellites are deployed for various purposes, including telecommunications and earth observation, the need for high-performance and more durable solar cells has become increasingly urgent. To meet this demand, the field of solar cell technology has invested in continuous research and development (R&D), focusing on improving photovoltaic materials and the processes used to synthesize them.

Nowadays, the most widely used photovoltaic materials in solar cells include silicon-based materials, such as monocrystalline and polycrystalline silicon, and thin-film materials, such as copper indium gallium selenide (CIGS) and gallium arsenide (GaAs) (Safyanu *et al.* 2019; Verduci *et al.* 2022). Despite their widespread use, these traditional photovoltaic materials have limitations, such as high production costs, low light-to-electricity conversion efficiency, and low durability. To overcome these challenges, researchers are exploring using new materials with the potential to revolutionize the solar cell industry through their low cost and high efficiency (Fig. 2).

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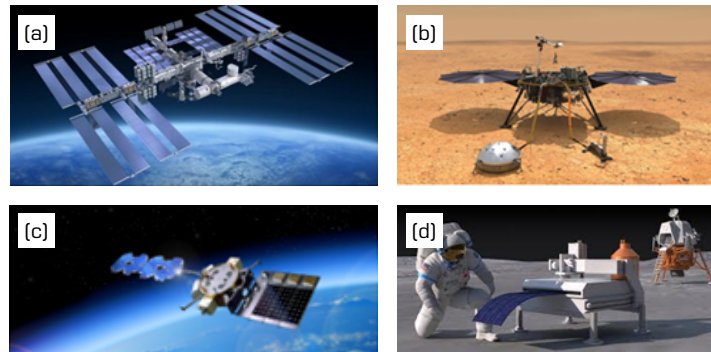


Figure 1. Illustrations of potential solar cell applications: (a) International Space Station powered by solar panels (Solar Cell, 2022), (b) NASA's InSight Lander robot, powered by solar energy, and holder of the off-world record of power generation (Bernardes *et al.* 2021), (c) Air Force Research Laboratory's Arachne flight experiment in orbit (Space News, 2022) and (d) a lunar lander vehicle with sequential in-space printing of a perovskite solar module (McMillon-Brown *et al.* 2022).

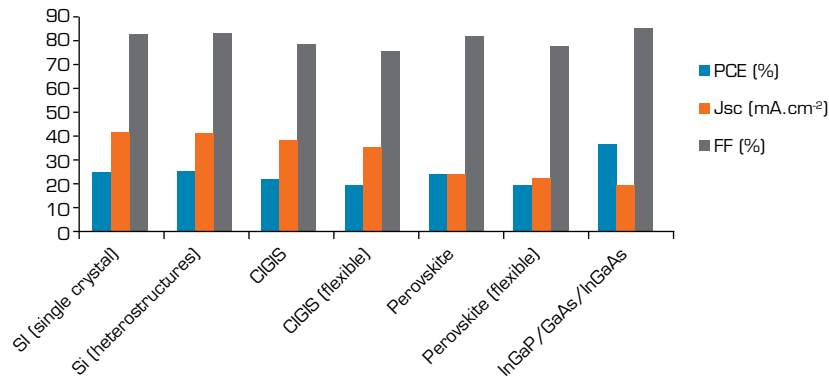


Figure 2. Comparison among photovoltaic material technologies. PCE = Power Conversion Efficiency, Jsc = Solar cell short-circuit density, and FF = Fill Factor.

One such material that has garnered much attention in recent years is perovskite (Verduci *et al.* 2022). These crystals are synthesized from low-cost and abundant elements, such as lead and tin, and have shown exceptional promise in solar cell research and development. Perovskites boast a high absorption coefficient, can absorb a wide range of light and have a high light-to-electricity conversion efficiency of around 25.5%. Additionally, perovskite-based solar cells have emerged as promising candidates for aerospace power systems due to their appealing properties, such as flexibility, cost-effective manufacturing, lightweight and exceptional radiation resistance (McMillon-Brown *et al.* 2022).

In recent years, using 2D materials, such as graphene and MXenes (e.g., Ti₃C₂T_x), in solar cell electrodes has garnered significant attention. They have been tested under space-relevant conditions as components of electronic devices such as transistors and sensors. Despite their thin structure, they have shown remarkable resistance to high-energy particles, including electrons, protons, and gamma rays. This resistance, combined with their potential for high-efficiency photovoltaic conversion, makes 2D material-based solar cells a promising technology for future space applications (Solar Cell, 2022).

The technology used in solar cell fabrication is of paramount importance in producing solar cells for the aerospace industry. Two of the most widely used techniques are screen printing for silicon-based cells and deposition for thin-film cells. Screen printing involves the transfer of a layer of conductive material onto a substrate using a stencil or mesh screen. This method is particularly suitable for creating large, intricate designs with consistent accuracy and precision. On the other hand, deposition utilizes physical or chemical processes to deposit thin layers of materials, such as silicon, oxides and metals, onto a substrate, which are essential components of solar cell fabrication. Recently, new and innovative fabrication techniques, such as roll-to-roll processing and solution processing, have emerged through advances in technology. These state-of-the-art methods offer improved efficiency, cost-effectiveness, and the ability to produce large-area solar cells, thus making them ideal for aerospace applications where

weight and cost are critical factors. Incorporating advanced fabrication techniques has opened new avenues for integrating solar cells into aerospace systems, a crucial step towards the growth of market segments such as mega-constellation programs and telecommunications satellites.

The design and integration of solar cells are critical factors in maximizing their efficiency in aerospace applications. State-of-the-art III-V multijunction solar cells are widely considered the most advanced photovoltaic technology for space use due to their high power conversion efficiency (PCE) and radiation resistance (Verduci *et al.* 2022). Integrating these solar cells with other essential components, such as energy storage systems, can enhance the reliability and autonomy of satellite and propulsion systems, thus leading to seamless and efficient performance. The combination of materials, fabrication techniques, and integrated design is crucial in ensuring the optimal performance of solar cells in the demanding environment of aerospace applications.

In conclusion, the role of solar cells in the shift towards a greener future for energy production cannot be overstated. These cells are vital in various industries, especially aerospace, where they power satellites and other space missions. The unique conditions in space, such as intense radiation, extreme temperature changes, and space debris, pose significant challenges to solar cell performance and durability. To tackle these challenges, the field of solar cell technology is constantly evolving, with researchers exploring new materials like perovskites and 2D materials that offer improved efficiency and cost-effectiveness. The development of advanced fabrication techniques, such as roll-to-roll processing and solution processing, has paved the way for integrating solar cells into aerospace systems, making them a critical component of the space industry. The interplay of materials, fabrication techniques and integrated design is crucial for ensuring the optimal performance of solar cells in the harsh environment of aerospace applications. As we continue to move towards a more sustainable energy future, solar cells will play a vital role in powering our world and beyond.

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