From Lab to Field: Overcoming Challenges in Perovskite Photovoltaics Commercialization through 2D Interface Engineering

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Perovskite photovoltaics (PePV) have emerged as a highly promising alternative energy solution over the past decade. Their potential for high efficiency makes them suitable for both large-scale solar farms and low-power applications, such as Internet of Things (IoT) devices. The power conversion efficiency (PCE) of PePVs has now surpassed 26%, approaching the performance of the most efficient crystalline silicon solar cells. Despite these impressive PCE, translating this performance to large-area photovoltaic (PV) panels in real-world outdoor settings remains a significant challenge. One of the critical hurdles is interface engineering, which is essential for the effective commercialization of PePVs technology. This involves the use of solution-processable two-dimensional (2D) materials, such as graphene and transition metal dichalcogenides, to enhance the interfaces within the solar cells. These 2D materials play a crucial role in protecting the perovskite layer from environmental factors like oxygen, moisture, and metal ion migration. Additionally, they improve charge dynamics at the interfaces, which is vital for maintaining high efficiency and stability.

The potential and challenges of PePVs have been demonstrated through extensive field testing. For instance, at a solar farm on the HMU campus in Crete, five square meters of perovskite PV panels were installed, and their energy output was continuously monitored using custom-built maximum power point trackers. Over eight months (T80 of 5,832 hours), the energy output experienced a 20% decline, despite initially surpassing 260 W at its peak. The primary causes of this degradation were identified as high temperatures, solar irradiance, moisture, and oxygen infiltration due to lamination failure. Distinctive light-soaking behaviors were also observed, which affected the power output and revealed the progression of optical defects over time. These behaviors are crucial to understand as they impact the long-term performance and stability of PSCs.To enhance the performance, durability, and stability of PSCs in real-world environments, advanced characterization techniques are being deployed alongside conventional methods. Continuous I-V tracing, for example, enables real-time monitoring of current-voltage characteristics over extended periods. This provides valuable insights into the operational stability and dynamic behavior of PSCs, especially under fluctuating environmental conditions. Therefore, optimizing the optical configuration, including the orientation and inclination of modules during installation, is essential to maximize energy output. This is particularly important in climates with substantial temperature fluctuations. Understanding phenomena such as light-soaking and analyzing temperature dependence coefficients are crucial for predicting the long-term stability of PSCs. In conclusion, while PSCs hold great promise for the future of solar energy, significant challenges remain in translating their high efficiency to large-scale applications. Through continued research and field testing, particularly in interface engineering and advanced characterization techniques, we can better understand and overcome these challenges, paving the way for the effective commercialization of PePVs technology.