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Novel selective templating method could enable stable perovskite solar cells

Researchers at Nanyang Technological University have addressed the stability issue that impedes the commercialization of perovskite solar cells (PSCs) by developing a way to achieve stable, efficient PSCs through the engineering of chemically inert low-dimensional (CI LD) interfaces.

The method relies on overcoming a fundamental trade-off that has been frustrating scientists: balancing the superior power conversion efficiencies of PSCs with their operational longevity. Traditionally, the implementation of low-dimensional halogenometallate interfaces has enhanced stability but at the expense of electronic performance due to the reactive nature of the bulky organic cations involved. These cations, while serving as essential structural components that protect the perovskite lattice from environmental degradation, exhibit chemical reactivity that undermines the long-term integrity and function of the interface.

The new method, however, takes a pioneering approach to synthesizing chemically inert interfaces that integrate bulky organic cations with low reactivity, thereby preserving the perovskite's delicate architecture without compromising its optoelectronic properties. This has proven to be no trivial task: the bulky cations required are generally poorly soluble in solvents that are compatible with the underlying perovskite layers, and their low chemical reactivity inherently impedes direct crystallization processes necessary for interface formation. These challenges have restricted the practical adoption of CI LD interfaces despite their theoretical appeal.

To circumvent these obstacles, the researchers devised a novel selective templating growth strategy. This technique leverages pre-existing metastable low-dimensional (LD) interfaces formed with conventional cations as structural templates. By facilitating an organic cation exchange process, the more stable chemically inert bulky cations gradually replace the original reactive species, effectively transforming the interface into a robust, long-lasting, and electronically favorable region. This templated conversion maintains the precise layering and crystallinity required for high-efficiency charge transport, all while drastically enhancing interfacial stability.

A major benefit of this method is in its ability to disengage the formation of chemically inert interfaces from the otherwise limiting solubility and reactivity constraints. The starting template offers a scaffold where the growth and cation exchange can occur under mild, perovskite-compatible conditions. This process ensures that the underlying

perovskite material is not exposed to aggressive chemical environments or solvents that would otherwise degrade its functional properties. Such delicate chemistry control is paramount for scaling the manufacturing of PSCs without sacrificing quality or reproducibility.

Performance benchmarks from prototype devices fabricated using the selective templating growth method have been impressive. Devices demonstrated power conversion efficiencies reaching 25.1% over an active area of 1.235 square centimeters, positioning these solar cells among the highest performing in their size class globally. This is a significant milestone, as maintaining high efficiency at increasing device scales has traditionally posed an engineering challenge, often due to exacerbated defects and interfacial losses at larger dimensions.

But perhaps even more impressive is the operational stability exhibited by these PSCs, which retain over 93% of their initial efficiency after 1,000 hours of continuous operation under simulated solar illumination. Furthermore, aging tests at elevated temperatures revealed an even higher stability, with over 98% efficiency retention after 1,100 hours at 85°C.

The implications of this advance could extend beyond merely stabilizing PSCs; the selective templating growth framework offers a versatile platform for engineering interfaces tailored to diverse perovskite compositions and device architectures. By unlocking access to chemically inert low-dimensional halogenometallate interfaces, researchers now have a powerful tool to mitigate interface-induced degradation pathways, which have been a persistent bottleneck limiting PSC longevity. This could catalyze a new generation of highly reliable devices, accelerating the integration of perovskite-based photovoltaics into mainstream energy systems.

Moreover, the work draws attention to the broader utility of organic cation exchange as a synthetic strategy in thin-film optoelectronics. The ability to program interfacial chemistry post-deposition opens avenues for fine-tuning electronic band alignment, defect passivation, and interlayer adhesion, all essential for maximizing device performance. This could find applications beyond photovoltaics, in fields such as light-emitting diodes, photodetectors, and other semiconductor heterostructures where interface control dictates function.

The researchers' approach illustrates the critical role of metastable phases as dynamic templates, challenging traditional views that metastability is purely an obstacle to be avoided. Instead, metastable LD phases function as crucial intermediates that facilitate the formation of more stable and functional material configurations. This reframing enriches the fundamental science underpinning perovskite materials and inspires innovative synthetic routes grounded in kinetic control.

Importantly, the compatibility of this templating strategy with existing perovskite compositions and fabrication protocols suggests its rapid translatability to industrial processes. The technique does not demand exotic materials or prohibitively complex handling, which bodes well for its adoption in large-area manufacturing. Industry stakeholders focused on improving photovoltaic module durability and performance stand to benefit immensely from integrating these findings into production lines.

This research also underscores the continuing evolution of PSC technologies as they approach commercialization readiness. While initial excitement around perovskites often centered on their record efficiencies obtained in small-area laboratory cells, it is the conquering of stability issues that will ultimately determine their market impact. By delivering near-commercial scale active areas with demonstrated long-term operational stability, the study by Rao et al. alleviates critical concerns about device reliability, a prerequisite for consumer trust and regulatory approval.

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