Integrated Engineering for High-Performance Perovskite Solar Cells

Sang Il Seok

Department of Energy and Chemical Engineering, Ulsan National Institute of Science and Technology (UNIST), Ulsan, Korea, E-mail: seoksi@unist.ac.kr

Perovskite solar cells (PSCs) have progressed from laboratory curiosities to record-breaking photovoltaic devices, with certified power-conversion efficiencies skyrocketing from 3.8 % in 2009 to beyond 26 % in just over a decade. This extraordinary rise is rooted in a nuanced interplay of crystal chemistry, defect physics, and interfacial energetics. Our group has pioneered solvent-engineering protocols—coupling anti-solvent droplet deposition with tailored alkyl-ammonium chloride additives—to produce dense, pinhole-free formamidinium lead tri-iodide ($FAPbI_3$) films while stabilizing the optically active α-phase. We further developed SnO_2-based electron-transporting layers and low-temperature hybrid TiO_2/SnO_2 colloids that simultaneously suppress electronic defects, accelerate electron extraction, and preserve substrate flexibility. Precise energy-level alignment at the buried junction quenches nonradiative recombination, extends photovoltage, and yields long-term operational lifetimes under continuous one-sun illumination. Most recently, we revealed how side-reaction by-products such as methylformamidinium (MFA^+) modulate phase stability and defect distributions, offering an additional lever for fine-tuning device performance. This presentation will highlight these advances and provide an integrated perspective on how materials synthesis, interface engineering, and device design continue to push the efficiency and stability frontiers of PSCs.