Interfacial material engineering for high performance perovskite solar cells

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Metal halide perovskite-based photovoltaic (PV) cells have attracted attention as the next generation PV cell in terms of high standard of power conversion efficiency (PCE) over 25% and low-cost printing-based production processes.[1] A recent major trend in the perovskite photovoltaics is to modify the quality of hetero-junction interfaces by passivating the defect for enhancing PCE and device durability. Interfacial engineering is also essential to passivating defects at grain boundaries of polycrystalline perovskite films. It suppresses charge recombination and leads to increase open-circuit voltage (Voc) of PV devices by minimizing the energy deficit of a perovskite semiconductor between its bandgap and Voc. We have been investigating the method for such passivation by using organic and inorganic materials on solution-based coating processes. For fabrication of high PCE devices using multi-cation hybrid perovskite ($FA_{0.83}MA_{0.17}GexPb_{1-x}(I_{0.9}Br_{0.1})_3$), Ge cation was doped to Pd cation to modify the interface between perovskite crystal and SnO_2 electron transport layer (ETL). The device gave PCE over 22% and Voc of 1.19V with Voc deficit of 1.33V.[2] At the same junction interface, thin films (<10 nm) of amorphous metal oxides such as SnOx are effective in creating a void-less compact interlayer to connect ETL and perovskite. In cell fabrication using all-inorganic perovskite, $CsPbI_2Br$ (bandgap, 1.9eV), we modified the surface of SnO_2 ETL with an amorphous SnOx (<5 nm) as an interlayer for junction with $CsPbI_2Br$ layer. Using a dopant-free polymer hole-transport layer (HTL), the $CsPbI_2Br$ device yielded a PCE of 17% with a high Voc reaching 1.42V.[3] A reference device without the SnOx interlayer gave a poor current-voltage performance with a large hysteresis and a low Voc (<1.2V). Another example of inorganic nanosheet is MXene, a 2D layered material comprising Ti_3C_2. We treated a colloidal solution of MXene by oxidation to from nanosheets of HO-$Ti_3C_2T_x$, which show semiconductivity suitable for ETL. Thin layer (<20 nm) of the oxidized MXene works as a good ETL in a planar device with PCE over 18%.[4] PCE increases to more than 20% when HO-$Ti_3C_2T_x$ is hybridized with SnO_2, which chemically interacts HO-$Ti_3C_2T_x$ via oxygen bonding. Organic small molecules also serve as modulators to passivate the defects at the junction interface. Among various molecular modulators, we found an organic peroxide, artemisinin (anti-malarial drug), works as a passivator at the interface of SnO_2 ETL and multi-cation perovskite ($Rb_{0.05}Cs_{0.05}(FA_{0.83}MA_{0.17})_{0.9}Pb(I_{0.95}Br_{0.05})_3$).[5] A thin plastic film-based mechanically flexible solar cell (total thickness <130 μm) was fabricated which works with a high PCE of 21%. Such lightweight flexible devices have a superior value in power per weight (W/g) performance.

Applications of perovskite PV devices are also spread to consumer electronics related to IoT devices. The latter is requested to have high performance under weak indoor light of LED illumination. The above $CsPbI_2Br$ device is one of the best for such indoor applications and work with efficiency over 30% and high Voc over 1.1V even under 200 lux luminance. Among extensive applications, robust stability of perovskite solar cells in space environments has been demonstrated by several research groups. In our collaboration with JAXA, we have examined the stability of perovskite cells against exposure to high energy particle irradiations (proton and electron beams) and demonstrated high tolerance of the cell against the irradiations.[6,7] The radiation tolerance is due to use of very thin PV films and the intrinsic defect tolerant nature of halide perovskites.

References:

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