Electrocatalytic Counter Electrodes for Low-cost Solution Processed Liquid Junction Solar Cells

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Liquid junction solar cells (LJSCs) represent a cost-effective, easy-to-fabricate approach in photovoltaic technology, harnessing the unique properties of photoactive materials (quantum dots (QDs), dyes, silicon nanowires (SiNWs) or textured Si) to convert sunlight into electricity with enhanced power conversion efficiency (PCE) and flexibility. These are typically solution-processed solar cells and have garnered considerable scientific attention due to their potential to overcome limitations associated with traditional crystalline Si or thin film-based solar cell technologies and pave the way forward for novel applications in renewable energy. At the heart of the LJSC is the "electrocatalytic counter electrode" (CE) or cathode, which plays a pivotal role in controlling the PCE and stability of LJSCs.

A LJSC has a configuration like that of a battery; it has a photoanode, an electrolyte based on a redox couple (e.g., I-/I3-, Br-/Br3-, Sn2-/nS2-, [FeIII(CN)6]3-/ FeII(CN)6]4-, Co(II)/Co(I) etc) and an electrocatalytic CE. The function of the electrocatalytic CE in a LJSC is to facilitate the transfer of electrons from the current collector to the oxidized species present in the electrolyte and maximize this reduction process at the CE/electrolyte interface. Minimizing the overpotential linked with the reduction process is equally crucial for efficient cell operation. The choice of electrocatalytic materials greatly influences the efficiency and stability of LJSCs. Commonly used materials include metals or their alloys like platinum (Pt), gold (Au) etc., conducting polymers (e.g., poly(3,4-ethylenedioxythiophene), polypyrrole etc.), carbon-based nanomaterials (e.g., carbon nanotubes, reduced graphene oxide etc) and transition metal oxides or chalcogenides (TMOs or TMCs, e.g., Cu2S, NiS, WO3 etc) and their composites. These have been extensively investigated for their electrocatalytic properties. A schematic illustrating the role of the electrocatalytic CE in an LJSC is displayed in Figure-1.

In our lab at IITH, a wide range of low-cost electrocatalytic CEs for high-efficiency solution-processed LJSCs have been developed. Our efforts have been directed towards developing novel electrocatalytic materials that offer high catalytic activity, stability, and compatibility with electrolytes in the LJSC architecture.

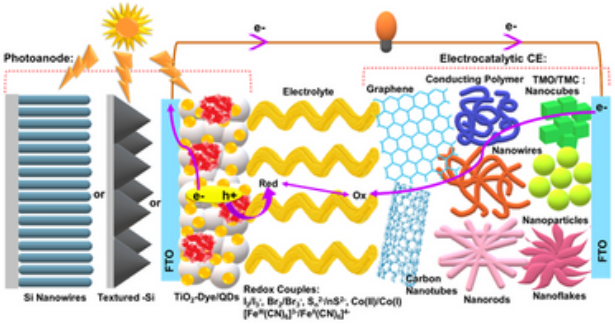

Figure-1: Schematic illustrating the role of electrocatalytic CE in a LJSC

For instance, a quasi-solid state solar cell with antimony nanorods anchored to SiNWs photoanode, I3-/I- redox couple-based gel containing dispersed Cu2O nanocubes and an electrocatalytic NiO CE delivered a PCE of 4.7% (under 1 sun). Noticeably, the cell endured 500 hours of continuous 1 sun illumination accompanied by a ~24% drop in its PCE. Another architecture of ionic liquid functionalized graphene nanoparticles anchored to SiNWs with a WO3 film as an electrocatalytic CE delivered a best PCE of 7.93%, with an average value of 7.26%. LJSC with vertically aligned SiNWs, co-sensitized with fluorescent and narrow gap CdTe nanoparticles, and cuboidal shapes of zinc tetraphenyl porphyrin (ZnTPP) dye offered broad and strong visible light absorption that resulted in a maximum PCE of 9.1% when combined with a polymeric gel electrolyte of an I2/I3- redox couple as the hole transport material and a CE of PEDOT film doped with imide ions. A crack-free smooth and homogeneous polymer surface, a shallow work function, and a high electrical conductance of the electro-catalytic imide-doped PEDOT polymer contributed significantly to the observed high PCE of the LJSC.

A Si-free tandem solar cell was developed with a photocathode or CE of p-type NiO sensitized with AgBiS2 QDs, which was combined with a photoanode based on trigonal-selenium sub-microtubes (t-Se s-mT) and CdS anchored to titania (TiO2). The cell delivered a PCE of 7%, wherein the AgBiS2/NiO served as an excellent electrocatalyst for the reduction of Sn2– electrolyte species and the nano-structured morphology enhanced the electrochemical surface area, yielding high photocurrents. These examples demonstrate the ability of CEs to control the performance of LJSCs.

In summary, solution-processed LJSCs represent a promising frontier in photovoltaic technology, offering the potential to alter the landscape of renewable energy conversion, thus contributing towards a sustainable future. Advancing research and innovation in this area necessitates the development of environmentally benign, earth-abundant and electrocatalytic CEs for highly efficient solar cells for diverse applications.

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