High Open-Circuit Voltage Cells Based on Inorganic, and Organic – Inorganic Hybrids

Saar Kirmayer, Eran Edri, David Cahen and Gary Hodes

High open circuit voltage solar cells are an important tool in the efforts for sunlight energy harvesting, either to drive electrochemical reactions or as the top cell in a multi-junction stack. High open circuit voltage requires a combination of a suitable energy band structure together with good charge transfer kinetics. In this talk we will review some of our efforts to achieve such high voltage solar cells.

In the first approach, Extremely Thin Absorber (ETA) solar cells were studied using both electrodeposited and Sequential Ion Layer Adsorption and Reaction (SILAR)-deposited CdSe as absorber, mesoporous TiO_2 as electron conductor and CuSCN (CTC) or suitable conjugated polymers as hole conductors. Both deposition methods form CdSe nanoparticles of about 4 nm. However, while electrodeposited CdSe nanoparticles aggregate into ca. 100 nm clusters, the SILAR CdSe is more evenly distributed throughout the mesoporous film, as small particles. When annealed, the electrodeposited nanocrystals merge and grow in size as a function of temperature and time, while the SILAR ones remain small and well-distributed. Annealing also forms oxide species at the surface of the absorber. I will show that by adjusting the annealing temperature and environment, the concentration of these oxides can be controlled. We found that the oxide species act as hole traps. The trapped positive charges cause a strong upward shift in the titania conduction band, forming an energy band alignment that otherwise would be incapable of delivering high voltages ($V_{oc}/E_g \approx 0.5$). Therefore, ETA cells that are made, using these sensitized mesoporous films, deliver unusually high open circuit voltages (V_{OC}) for CdSe, up to 0.84 V under one sun. Unfortunately, we suspect that the same trapping mechanism also reduces the maximum possible photocurrent that can be drawn from the cell.

In the second approach, solution-processed organic-inorganic lead halide perovskite absorbers were used in conjunction with organic hole conductors to form high voltage solar cells. These perovskite materials, although spin-coated from solution, form highly crystalline materials, which exhibit high charge carrier mobillities. Their simple synthesis, along with high chemical versatility, allows tuning the charge carrier mobility, as well as their electronic, and optical properties. They therefore offer a completely new field to explore for photovoltaic materials.

In these cells, the absorber, which also serves as the electron conductor, is deposited from solution and is self-assembled on a porous, high surface area scaffold, either conductive titania or insulating alumina. The remaining pore volume is filled, again by solution methods, with an organic semiconductor having suitable energy band alignment, to allow hole extraction. Two types of operation principles are demonstrated for these cells: one resembles the ETA cell and the other that of a bulk heterojunction, both showing high V_{OC} values of up to 1 V and 1.3V, respectively. By judicious selection of the perovskite lead halide-based absorber, matching organic hole conductor and contacts, a high open circuit voltage solar cell can be achieved, and although further study is needed, a general guideline for additional improvement of cell performance is set.