Controlled porosity for enhanced properties in wet-coated photovoltaic thin films

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Wet-coating methodologies based on spin or dip-coating can be used to prepare films for optoelectronic devices, such as dye-sensitized solar cells (DSSCs) and perovskite solar cells (PSCs). It is well recognized that the film morphology impacts the efficiency of the final device. In particular, porosity strongly influences the interpenetration, and therefore the charge transfer interface, between the photoactive material and the electron/hole transporting layers. A long-range organization of the porous network can also impact the light harvesting properties.

Soft- or hard-templating, using polymer surfactants or solid nanospheres as sacrificial structuring agents, allow for the nanostructuration and porosity design of materials to achieve improved light management and photocurrent generation. The heat treatment applied to the structures after deposition has to be finely controlled in order to create crystallized layers with accessible porosity while avoiding the collapse of the structured porous network.

I will illustrate the impact of these film structuration strategies through different examples taken from the work of our group on TiO_2, $CH_3NH_3PbI_3$ perovskite and hybrid TiO_2/perovskite systems. (i) In DSSCs, the use of surfactant-assisted templated mesoporous TiO_2 films led to more than 2 times higher photovoltaic efficiencies compared to solar cells assembled with random TiO_2 nanoparticles films, due to their increased accessible surface area and subsequent higher photoactive dye loading. (ii) In PSCs, we have developed inverse-opal TiO_2 layers as porous electron transporting material, leading to hybrid TiO_2–perovskite architectures with highly tunable photonic modes. The influence of the diameter of the perovskite-filled TiO_2 spherical pores on the conversion efficiency has been studied both in terms of light harvesting and charge transfer properties. (iii) An alternative strategy based on the photonic structuration of the perovskite itself as a 3D inverse opal photoanode has been investigated. Although the individual 3D inverse opal perovskite layers displayed a photonic absorption enhancement of more than 15 % compared to an unstructured dense film, only ~3 % photonic absorption enhancement was retained in full solar cell devices due to a combination of electronic-related counter-effects and local light absorption in the hole transporting material, confirming the interest of the TiO_2 scaffold in the hybrid configuration.

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