Graphene Below the Percolation Threshold to Increase Photoconversion Efficiency in Dye-Sensitized Solar Cells

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In the scenario of renewable energy sources, dye sensitized solar cells (DSSCs) have rapidly gathered a high interest as viable and low cost alternatives to commercially available silicon-based solar cells. Presently, the photoconversion efficiency (PCE) in traditional DSSC photoanodes is limited by charge transfer to the counter electrode and by charge recombination at dye or electrolyte interfaces. Recent work on the design of oxide photoanode towards improvement of PCE proposed the exploitation of highly conducting one-dimensional (1D) and two-dimensional (2D) oxide nanostructures like nanotubes, nanowires, composite systems or hierarchically assembled photoanodes to address this issue. A potentially appealing alternative to 2D oxide nanostructures is represented by the incorporation of graphene sheets in TiO_2 traditional photoanodes.

Here, we demonstrate a fast and large area scalable methodology for the fabrication of efficient DSSCs by simple addition of graphene platelets (graphene concentration in the range 0 to 1.5% wt.) into a TiO_2 mesoporous film.

Two dimensional (2D) Raman spectroscopy, scanning electron microscopy (SEM) and atomic force microscopy (AFM) confirm the presence of graphene after 500 °C annealing for 30 minutes. Graphene addition increases photocurrent density from 12.4 mA cm^{-2} in bare TiO_2 to 17.1 mA cm^{-2} in optimized photoanode, boosting photoconversion efficiency (PCE) from 6.3 up to 8.8%.

The investigation of the 2D graphene distribution showed that an optimized concentration is far below the percolation threshold, indicating that the increased PCE does not rely on the formation of an interconnected network, as inferred by prior investigations, but rather, to increased charge injection from TiO_2 to the front electrode.

The key advance with respect to the state of the art lies in the investigated range of graphene concentrations. We demonstrate that a very limited amount of graphene (as high as 0.01% in weight) is sufficient to maximize cell performance. Further graphene addition detrimentally affects PCE, while typical concentrations in the literature are well above the ones investigated in our work.

We will also discuss the comparison with DSSCs obtained by addition multiwalled carbon nanotubes instead of graphene.

Our experimental findings suggest a very cheap, fast, simple and highly reproducible method to significantly enhance the photoconversion efficiency in DSSCs.