Photocurrent Generation in PbSe Quantum Dot-TiO_2 Nanorod Devices Fabricated by a Laser Assisted Spray Process

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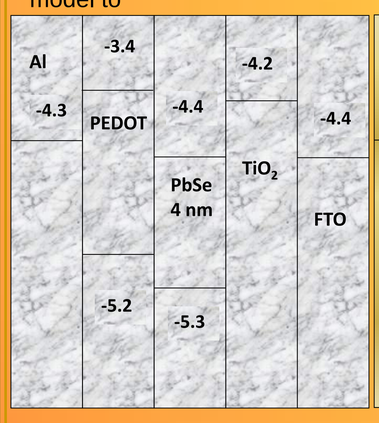
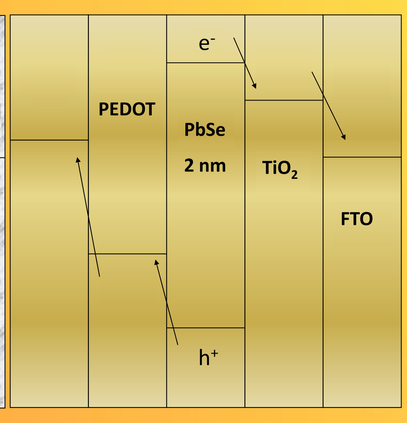
Abstract

PbSe quantum dots are assembled onto TiO_2 films of nanotubular morphology. Upon band gap excitation across the 0.35 eV bad gap off set between PbSe with an average diameter of 2 nm and TiO_2 with the given topology, photocurrent is generated through the injection of electrons from the PbSe quantum dots to the TiO_2 nanorods. The results in this study indicated the successful fabrication of a PbSe/ TiO_2 device, with improved photoelectrochemical performance using 2 nm dots and PEDOT: PSS. The I-V characteristics of the solar cell indicate potential multiple exciton generation for this device architecture.

Introduction

From our band gap model and from experimental data it was found that PbSe with an average diameter of 2 nm are required for sufficient band gap expansion, hence permitting electron injection into TiO_2. The effective mass of the electrons and holes allows the model to





The following process will occur upon exciton generation by a photon with energy $E = hv$:

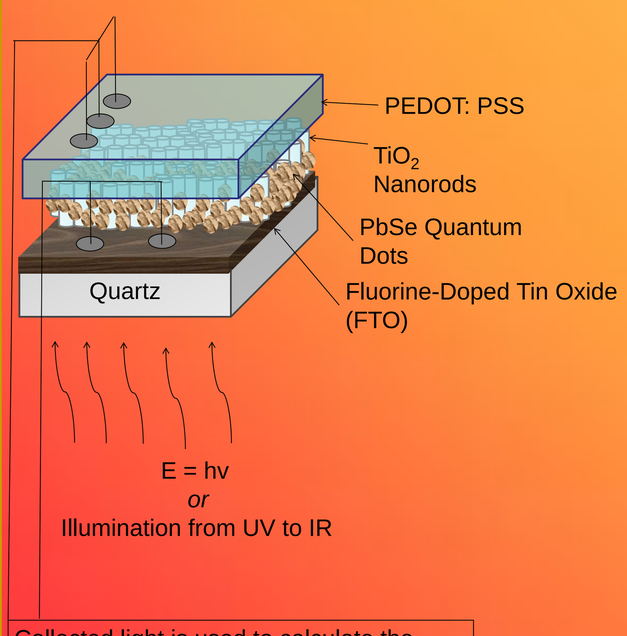
PbSe + h → PbSe (e + h) → PbSe + h '

PbSe (e) + TiO_2 → PbSe + TiO_2 (e)

PbSe (h) + Red → PbSe + Ox

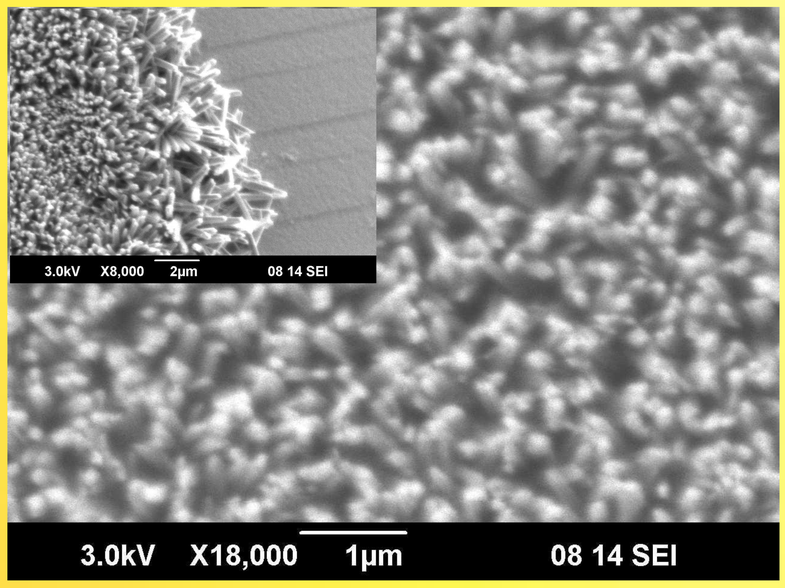
There are several components which compete with the recombination rate of the exciton pairs; namely dissociation via band bending, the electron affinity of the TiO_2, and the high hole mobility provided by the polymeric complex PEDOT: PSS.

Solar Cell Architecture

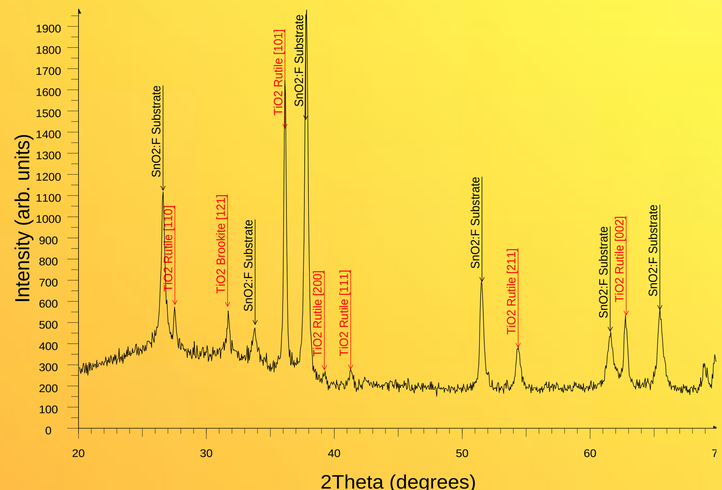


Collected light is used to calculate the external quantum efficiency; *I-V* characteristics are studied.

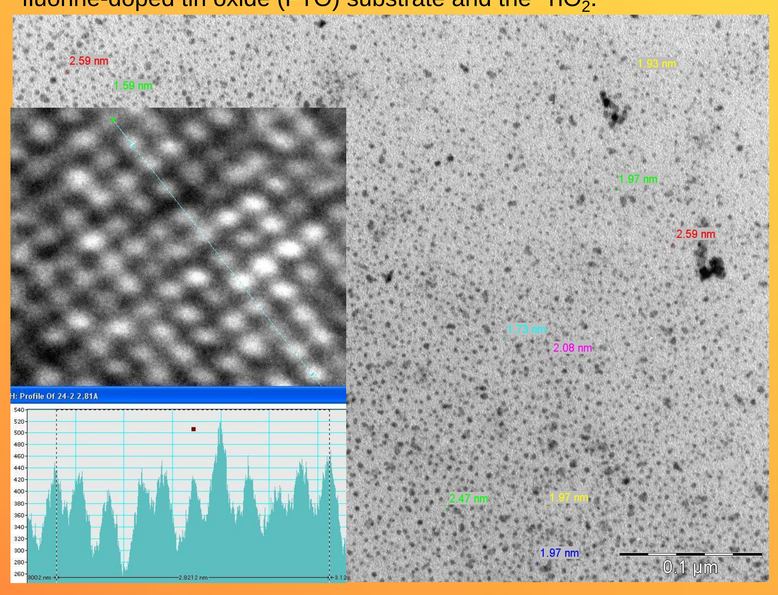
Depiction of the PbSe quantum dot/PEDOT:PSS solar cell. The capabilities of the device rely on the architecture of the PbSe QD/TiO_2 structure and the efficient hole transport of the PEDOT:PSS. The PbSe is deposited via a Laser Assisted Spray process through a novel dual nozzle design.



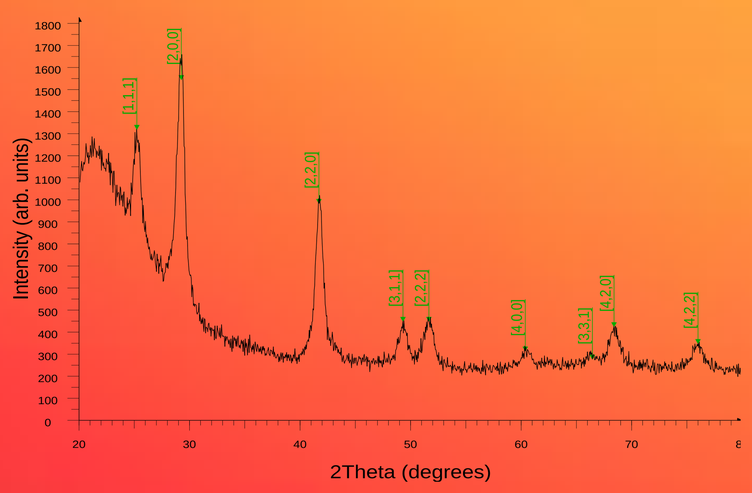
Titanium Dioxide nanorod (TiO_2) image taken with a scanning electron microscope. The TiO_2 nanorods are a good choice for the construction of solar cells due to the very large surface area they present relative to typical *pn* junction cells. Inset elucidates the average TiO_2 nanorod length of 2 µm, with 180 nm diameters. The density of the nanorods is controlled in order to yield the maximum monolayer coverage with the PbSe quantum dots.



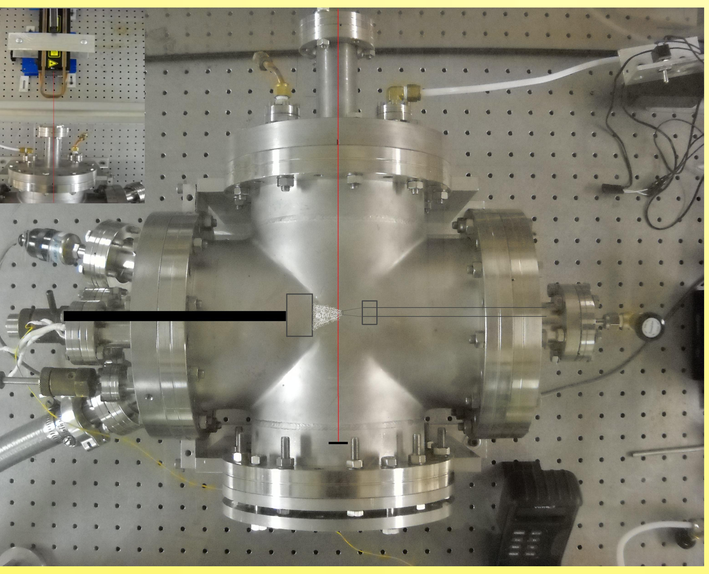
X-Ray Diffraction Pattern for the hydothermally grown TiO_2 nanorods with average length 2 µm and a well controlled density. The site density is dependant upon the lattice mismatch between the fluorine-doped tin oxide (FTO) substrate and the TiO_2.



Scanning Electron Microscope Image of the PbSe quantum dots grown to an average diameter of 2 nm, which corresponds to a conduction band off-set of 0.35 eV, a value which will facilitate the electron injection into and ballistic transport through the TiO_2 nanorods.



X-Ray Diffraction Pattern for the PbSe quantum dots showing the crystalline result of the novel growth process.



Laser Assisted Spray process top-view with diagram depicting the internal action of the process. The beam entering from the top of the picture, intercepts the aerosol in order to remove the surfactant coating of the PbSe.

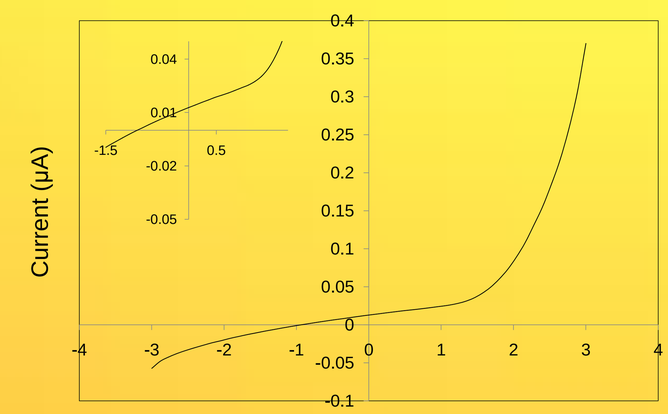
Solar Cell Characteristics

The solar cell output current I_{out} as a function of an external voltage source was characterized in order to establish two important features of the device:

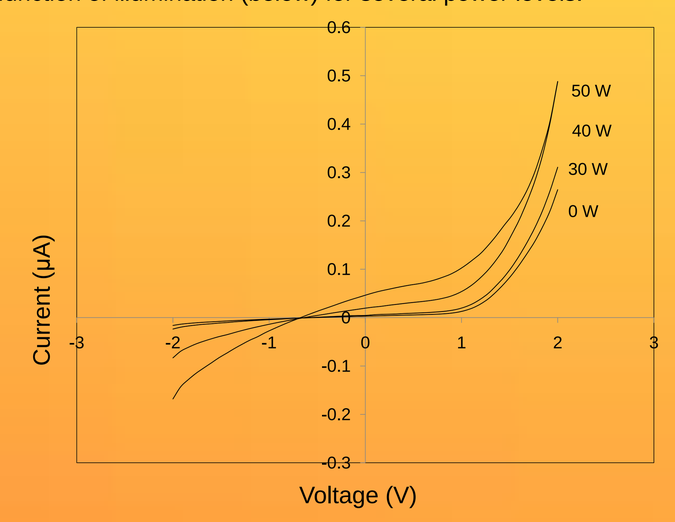
(1) The PbSe QDs form a layer with wave functions which overlap such that quantum confinement is still realized.

(2) Engineering the band gap offset between the PbSe QDs and the rutile TiO_2 allows for efficient electron transfer into and quasi-ballistic transport through the nanorods.

(3) The rate of dissociation exceeds the *combined* rates of carrier cooling, recombination, and radiative decay.



The I-V curve (above) of a solar cell placed under illumination from a tungsten source supplied with 35 W of power. The change in I-V as a function of illumination (below) for several power levels.



CONCLUSIONS:

We have demonstrated the production of 2 nm average diameter PbSe quantum dots with the proper band alignment . Also, hydrothermally grown TiO_2 nanorods designed have been optimized. A Laser Assisted Spray process is used to deposit a monolayer of PbSe quantum dots, as well as the polymer PEDOT: PSS which promotes hole mobility. The criterion for multiple exciton generation are met [2] with this device architecture.

References:

[1] Y. Hamakawa, *Thin-Film Solar Cells*, Springer, Ch's1,2, pages 2-21

[2] A. Nozik, *Chemical Physics Letters*, **457**, 3-11 (2008)

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