Coupling of Resonant Modes of Embedded Dielectric Microspheres in Solution-Processed Solar Cells

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Either from a cost saving or improved carrier collection perspective, thin absorber layers are increasingly becoming part of novel photovoltaic technologies. To maintain or boost the efficiency, light trapping strategies are being developed to capture photons in the widest spectral range and with the smallest quantity of absorbing material. From textured surfaces to complex plasmonic nanostructures, many approaches are being investigated to increase the optical path within solar cells [1]. Particularly interesting is the use of optical resonators to boost light absorption in the active material [2]. Resonances from these architectures have successfully been employed in sensors and lasers, exploiting the large amount of energy stored within the optical cavities due to total internal reflection. Grandidier et al. theoretically studied the benefits of coupling whispering gallery modes of submicrometric dielectric spheres into an amorphous silicon solar cell. By choosing wisely the sphere diameter, diffractively excited resonant modes of the spheres couple into the high dielectric constant substrate, increasing the photogenerated current [3]. Several groups have studied the use of dielectric microspheres to enhance the optical absorption, but the incorporation of these resonators in actual solar cells has been elusive so far [4,5].

In this work, we combine inexpensive optical resonators such as dielectric colloidal spheres with solution processed PbS-TiO_2 solar cells. These heterojunctions are currently leading the race towards high performance colloidal quantum dot solar cells and [6], we have chosen them to study the ideal configuration of the sphere monolayer within the solar cell, leading to the largest number of resonant modes coupled into the absorbing layer. The PbS quantum dots (QDs) layer is built by alternatively spin casting solutions of the p-type semiconductor and an organic ligand onto a nanocrystalline titania (nc-TiO_2) substrate. This deposition method allows the infiltration of the QDs into the voids between spheres, completely embedding them. The higher refractive index of the PbS (n=2.4) versus that of the silica spheres (n=1.425) favors the leakage of the resonant modes into the semiconductor film. The optimum configuration of the spheres within a colloidal PbS-TiO_2 bulk heterojunction solar cell is investigated. A monolayer of hexagonally packed silica spheres is placed in three different locations within the PbS layer of the heterojunction (figure 1a,b). Enhancements in photocurrent are found in the cases where the spheres are partially or completely infiltrated with PbS and are explained in terms of the coupling of resonant modes of the silica spheres within the semiconductor layer according to FDTD simulations (figure 1c).

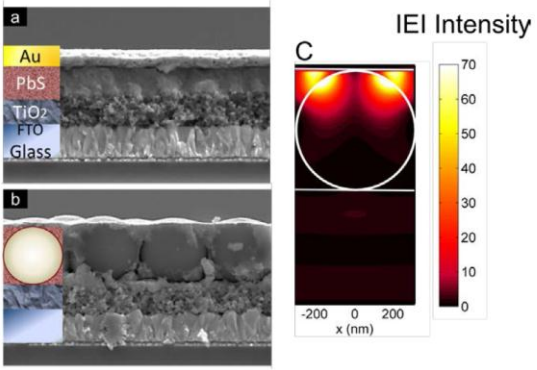

Figure 1: Crossectional SEM images from (a) a reference PbS-TiO_2 cell and (b) a similar heterojunction with a SiO_2 sphere monolayer embedded within the PbS film. (c) Calculated spatial distribution of the electric field intensity at λ=1037nm for the architecture depicted in (b).

References

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