HYBRID NP-QD PHOTOVOLTAIC LIGHT HARVESTING BY HYBRID SILICON NANOPILLAR (NP) - QUANTUM DOT(QD) CONJUGATE VIA NONRADIATIVE ENERGY TRANSFER

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Project context and objectives

The thermodynamic limit of 80 percent efficiency is well beyond the capabilities of current photovoltaic technology. An integrated, multidisciplinary effort is needed to drive transformational changes in the way solar cells are conceived, designed, and implemented. In this regard, hybrid Silicon Nanostructure-Colloidal QD conjugate photovoltaic device can take the advantage of higher light absorption with Rainbow-absorption capabilities and very high photon to electron conversion efficiency. Such a device could push the efficiency limit close to thermodynamic limit.

The spirit of the project is exploratory since the proposed hybrid material scheme for solar cells involves several key technological challenges before its advantages are distinguished. Appropriate design is necessary for efficient transfer of energy from QD to nanopillars. As the process of pillar formation by top-down approach there must be good process control for defect free pillar surface to avoid any surface recombination. Another challenge is to have large area coverage of nanopillars. Other issues related to conformal transparent top contact and surface planarization have to be addressed.

Brief description of the main results

For realization of the project objective we have utilized two different structures for the solar cell , namely axial and radial junction cells. Each of these two schemes has its own advantages and limitations. The main results are described below.

Following are the main steps for processing of Axial and Radial junction cell:

For axial junction we start with pn junction substrate supplied by University of Southampton, on the other hand, for radial junction we choose a moderately doped p-Si and fabricate the nanopillar and subsequently dope the nanopillar with solution based P dopant by rapid thermal annealing.

Nanosphere or colloidal lithography with SiO_2 particle for etch mask formation on silicon substrate.

Achievement: Up to one centimetre square of conformal (ML) particle coverage.

Size reduction of particle for etch opening and subsequent ICP-RIE etching of nanopillar in a top down approach

Achievement: Optimized processes established for full control on size and shape of the pillar.

Fabrication of radial junction nanopillar solar cell

Achievement: Doping of the nanopillar with spin-on dopant (phosphorous) to make a n-type outer layer for p-n junction developed using rapid thermal dopant diffusion at 1050ºC, and characterized by SIMS profiling. Doping was successfully implemented in the working devices.

Fabrication of axial junction nanopillar solar cell

Achievement: Planarization procedure of the as-etched nanopillar array structure for contacting and avoid junction shorting using spin coated PMMA and back etching was investigated. Although the planarization procedure works, in principle, further optimization is required for good electrical isolation.

Infiltration of Quantum Dot (QD): Colloidal CdSe QDs (red-emission) were infiltrated via spin coating between nanopillar.

Achievement: In solar cells with infiltrated QDs, photocurrent enhancement is observed.

Final results, potential impact and use:

A proof-of-principle demonstration of a hybrid QD-Nanopillar photovoltaic device was made, addressing the technological possibilities and challenges. We have fabricated functional hybrid solar cell with combination of silicon nano-pillar and CdSe QDs. The current-voltage (I-V) response under AM 1.5 solar irradiation source was tested. The short circuit current density (Isc) was higher in nanopillar solar cells compared to the planar cells. In addition, a relative increment in Isc for hybrid cell as compared to normal nano pillar cell is obtained. The overall improvement with the hybrid solar cells, compared to planar cells, is partly attributed to reduction in surface reflection due to nanostructuring, and to some extent due to exciton transfer from CdSe QD to Silicon. On the other hand, compared to planar cells the open circuit voltage was lower and the shape of I-V response curve was also degraded, indicating improvements in surface passivation and device design are necessary. This is primarily due to the surface damage resulting from nano-structuring of silicon, leading to increased surface recombination of photo-generated carriers. This issue can be solved by better surface passivation of the cell, and is one direction for continuation of the research activity. Other near future activity related to project are- efficient infiltration of the QD on the nano-pillar, better control on top contact to reduce resistive losses and leakage loss and better coverage (ML) of the colloidal particles.

This new method of light harvesting can be extended to thin film silicon p-n junction with very high efficiency but with significant reduction of cost. As the processes are simple and less time consuming it would be possible for mass production and commercialization with very good trade-off between efficiency and cost. The technology can be extended to fabricate flexible photovoltaic device with soft polymer materials with embedded nanowires freed from the substrate.