Optoelectronic properties of Silicon quantum dots

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The radiative efficiency of bulk silicon (Si) solar cells under the AM1.5G spectrum is limited theoretically to 29% due to the incomplete utilization of high energy photons and transmission of photons with less energy than the Si band gap [1]. One way to enhance the efficiency is to use a stack of solar cells, in which each cell has a band gap that is optimized for the absorption of a certain spectral region. The theoretical efficiency of tandem solar cells with a bulk Si bottom cell increases to 42.5 % when one additional solar cell with 1.8 eV band gap is used and to 47.5 % with two further solar cells with band gaps of 1.5 and 2 eV placed on top of the bulk Si cell [2]. III-V tandem cells are already being realized and show very high efficiencies [3], but their fabrication involves cost intensive technologies like metal organic vapour phase epitaxy and materials that are rare in the earth crust such as Indium or toxic such as Arsenic.
For a high band gap solar cell based on Si compounds, silicon quantum dots in dielectrics have shown promising characteristics. Because of the charge carrier confinement in Si quantum dots it is possible to adjust the band gap by a control of the Si quantum dot size. Size controlled nanocrystals in SiO_2 have been realized with a superlattice of evaporated $SiO_2/SiO_x/SiO_2$ layers [4] and the $SiO_x \rightarrow SiO_2$ + Si phase separation, solid state crystallization and photoluminescence properties are already well understood. However, it is a major challenge to achieve charge carrier transport through a network of Si nanocrystals embedded in a SiO_2 matrix.
The crucial question for arrays of silicon nanocrystals to be used in solar cells is whether effective charge carrier transport can be ensured through quantum dots with sufficiently confined electronic states.
In this paper, the optical absorption and photocurrent of a SiO_2 superlattice with 4 nm SiO_2 barrier layers and 4 nm Si NC layers is studied. DC IV measurements in dark and under illumination of a 4 nm Si NC / 4 nm SiO_2 superlattice with 30 bilayers are shown in Figure 3. The sample was not annealed after evaporation of the Al contacts. Spiking of Al through the 10 nm capping oxide can thus be neglected. Therefore, the current has to tunnel through two 10 nm thick SiO_2 layers. The

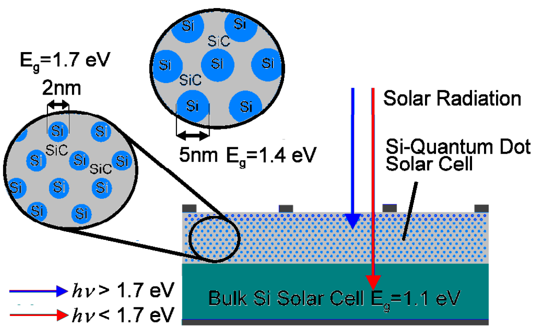

Figure 1: *Principle of an all-silicon tandem cell with a quantum dot top solar cell (left). The control of the band gap allows extending the concept to multi solar cells employing three or more cells. The band gap is tuned by a size control of the Si nanocrystals employing a multilayer approach [4].*

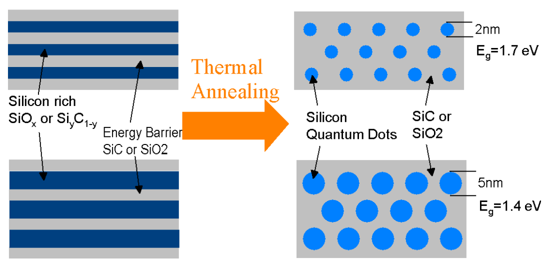

Figure 2: *Schematic of the procedure to achieve size control of Si NC in Si based dielectric matrices. Layers with silicon excess are deposited alternately between stoichiometric layers. The stoichiometric layers act as a diffusion barrier for the silicon atoms and therefore limit the growth of silicon nanocrystals during the annealing step.*

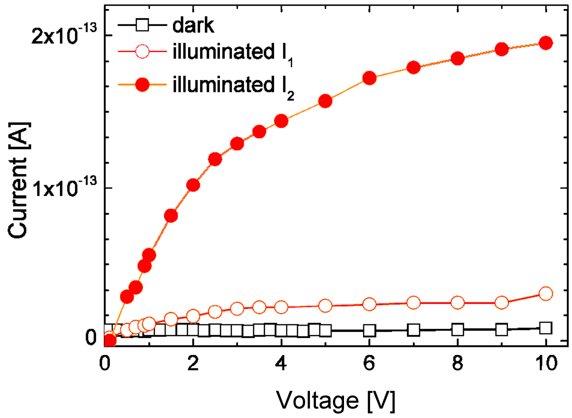

Figure 3: *Dark and illuminated IV-curves for a SiO_2 superlattice consisting of 30 bilayers with a 4 nm thick SiO_2 barrier layer and 4 nm Si-NC layer.*

measured currents are at the sensitivity limit of the picoammeter. However, we observe a pronounced increase of the current with illumination, which corresponds to a photoresponse $\sigma_{photo}/\sigma_{dark} \approx 10^2$. At voltages < 1V, the current rises steeply, and saturates as the voltage is increased above 2 V. The current saturation value is $2 \cdot 10^{-13}$ A. The measurement was done in a cryostat at $2 \cdot 10^{-5}$ mbar pressure to rule out a Fermi level shift due to surface adsorbates. Therefore, it was not possible to determine the photon flux without changing the light in-coupling optics. However, I_2 can be assumed to be roughly $2 \cdot I_1$. Even though we have demonstrated a photoresponse of a 4 nm Si NC / 4 nm SiO_2 superlattice the measured photocurrent is still very low. There are several key factors that have to be optimized for better electrical transport: The non-ideal contacts with large energy barriers and tunnel transport through two 10 nm thick capping oxide layers, the 4 nm SiO_2 tunnel barrier between two adjacent Si NC layers and the distance between the single Si NC, and finally doping of the embedding SiO_2 matrix has to be introduced.

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