量子ドット太陽電池における光吸収増強のためのナノウォールグレーティング構造の設計とシミュレーション

Design and Simulation of Grating-Shaped Nano-Wall Structures for Light Absorption Enhancement in Quantum Dot Solar Cells

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Quantum Dot Solar Cells (QDSCs) have been profusely researched as a way to extend the range of wavelengths of light absorbed by photovoltaic devices. However much progress is still to be made as most practical devices reported so far only show a mild increase of the short-circuit current (JSC) and a sharp drop of their open-circuit voltage (VOC) compared to reference bulk devices because of the strong thermal exchange of carriers between bulk states and QD-bound states. In this work, we theoretically discuss the potential benefits of embedding the QDs in non-planar p-i-n junctions. We propose an appropriate structure for such a non-planar QDSC and conduct both optical and electric simulations of its operation. We show that the strong enhancement in light absorption by QDs due to light trapping in the device allows for a remarkable increase of the External Quantum Efficiency (EQE) compared to its planar counterparts and helps decreasing the drop in VOC.

We discuss what the architecture of a non-planar InAs/GaAs QD-device should be. We propose to adopt a core-shell p-i-n structure, and show that in this case, where the diameter of the core is reduced due to the presence of the QDs, a Nano-Wall architecture (see Fig. 1) is electrostatically more appropriate than a Nano-Wire-based structure for a sound operation of the device and a complete drop of the built-in voltage.

We perform optical and electric simulations of our device, and compare the results with those obtained for a planar cell including ten QD layers. We assume the QDs properly grown to extend the range of absorbed wavelengths, with a Ground State peak absorption at 0.97eV. Light propagation and absorption is calculated by a *Rigorous Coupled Wave Analysis* method. For the electric simulation of both devices, we adopt the model proposed by Gioannini *et al.* [1] including bulk-QD thermal contact and assuming one-step absorption processes and we implement it using a finite difference method.

We find that a Nano-Wall width W of 180nm and a period P=550nm (see Fig. 1) for the grating give an optimal absorption of 85% of the AM1.5 light spectrum in the range 280nm-850nm and 12.67% of the light in the QD-absorbed range of wavelengths, while the planar device is limited to 70.28% of light in the 280nm-850nm range and 1.80% in the QD-absorbed range. We attribute this strong enhancement of light absorption to the light trapping in the grating. Our electric simulation shows that this enhanced light absorption not only leads to an increased EQE (see Fig.2), but also contributes to decrease the drop of VOC often visible in practical QDSC devices. As a future development of our research, we will also investigate the optical and electric properties of a more complex 2D-grating.

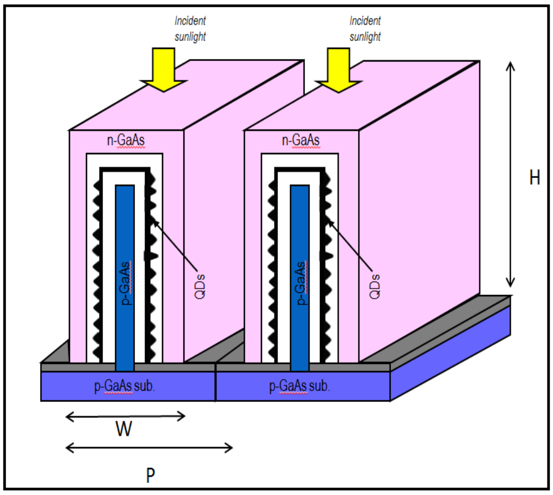

Figure 1- Schematic representation of the studied device. Simulation shows that for H=5microns, W=180nm and P=550nm are optimal parameters.

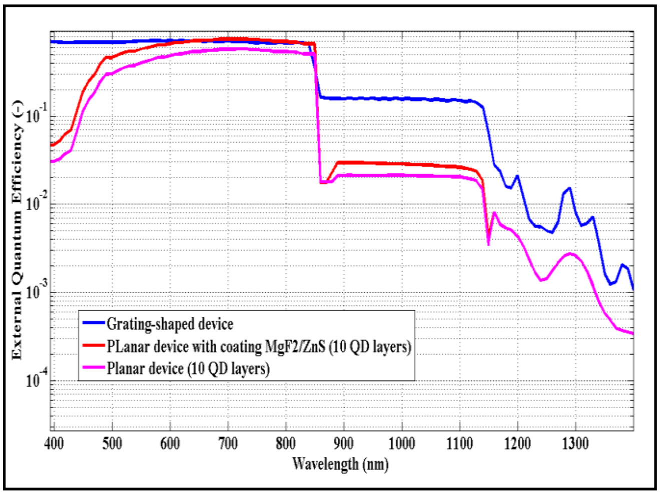

Figure 2 - Comparison of EQE between grating-shaped devices. A strong enhancement is visible for our device in the range 850nm-1400nm

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