Numerical Study of Quantum Dot Embedded Solar Cells

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***Abstract* — A quantum dot intermediate band solar cell with anti-reflection coating is proposed and studied numerically. We built our device model by using Matlab® coding. A proper inclusion of quantum-dot-related carrier absorption is adapted through modified extinction coefficient k, and effective band gap of the device. The transmission matrix method is applied to simulate the multiple reflection in the heterostructures. The final simulation shows about 9% enhancement of power conversion efficiency in quantum dot device against the non-quantum-dot device.**

***Index Terms* — quantum dot, simulation, transmission matrix method, photovoltaic cells.**

I. Introduction

To overcome the crisis of fossil fuel, alternative energy sources have brought much attention in these days. One of them is the photovoltaic technology. Traditionally a single band gap material can provide as high as 44% of power conversion efficiency (PCE) in the ideal case. A. Luque et al. proposed that intermediate band solar cell (IBSC) can realize triple band absorption with one junction, much easier and simpler than tandem multi-junction solar cell. It can be calculated theoretically that single junction with IB can reach more than 60% efficiency to convert solar energy into electricity [1].

How to implement such IBSC structure? One of the most promising methods is to incorporate quantum dot layers into the solar cells. Quantum dots (QDs) have been important for optoelectronic applications due to its nature of three-dimensional confinement and δ-like function of density of state that could produce a low-threshold and highly efficient laser. To put these quantum mechanical structures into a traditional device will need a proper simulation method to estimate its effect. Here, we propose a transmission matrix method to better address the optical field distribution in the multiple-layer solar cell and numerically study the design concept of embedding the QD structure within a single junction heterostructures p-i-n cell with anti-reflection coating at front. The intermediate band concept is realized by InAs quantum-dot (QD) structure grown within GaAs.

Based on an actual manufactured design, we use Matlab first fit measurement data with our model and then further explore the theoretical maximum conversion efficiency obtained by the modulation of the thickness of the p-type layer and the thickness of the intrinsic layer. From our model, the addition of QD layer within GaAs based solar cell can enhance the power conversion efficiency as high as 1.4%. The detailed analysis will be demonstrated in the following section.

II. Theory

In this section, we will introduce the theory we used in the simulation. In addition to the regular carrier transport equations, it includes the concept of effective band-gap dark-current [2], the transmission matrix method, the collection probability and AR coating effect to better consider both the optical and electrical side of the photovoltaic devices.

A. Effective band-gap dark-current

To simulate the intermediate band solar cell numerically, we first consider the following basic photovoltaic current-voltage relation:

$$J = J_{SC} - J_0\left[\exp\left(\frac{V + J \times R_S}{KT}\right) - 1\right] - \frac{V + J \times R_S}{R_{Sh}} \qquad (1)$$

, where J_{SC} is the short circuit current density derived in next section, J_0 is the saturation current density, R_S is the series resistance, R_{Sh} is the shunt resistance and KT is the Boltzman constant times temperature.