Design and Modelling of Photonic Power Converters with Light Management in Solcore

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***Abstract*—A vertically-stacked five-junction photonic power converter is modelled with and without a distributed back reflector using Solcore, an open-source set of computational tools for the modelling of photovoltaic devices in a Python framework. The thickness of the absorbing layer and the back reflector are optimized, demonstrating the possible reduction in device thickness and improvement in operating efficiency enabled via improved light management. Other capabilities and general use of Solcore will also be addressed.**

Keywords—Solcore, open source modelling, photovoltaics, photonic power converters, power over fiber

I. Introduction

Photonic power converters (PPC) are photovoltaic devices which directly convert optical energy into electricity. PPCs are typically used in power over fiber applications, where power and data are transmitted through a glass optical fiber rather than typical electrical wiring [1].

One of the current limitations of PPCs are relatively large power losses in comparison with conventional electrical wiring. To improve device performance, one can reduce the absorbing layer thicknesses for improved carrier collection and voltage. In order to overcome the decreased absorbance of thinner layers, a distributed Bragg reflector (DBR) can be used to induce a light-trapping effect. Consequentially, the thinning of absorbing layers can allow for reduced material costs.

In this work, Solcore is used to model and design a GaAs PPC with a DBR. Solcore is a new, open source set of computational tools that can be used for the design and simulation of solar cells, created by the Quantum Photovoltaics Group at Imperial College London [2]. This modular based package, written with Python, includes optical and electrical solvers that can be used to model solar cells with various designs, including multi-junction solar cells and quantum well devices.

II. Model Description

The simulation consists of two monolithic vertically-stacked multi-junction GaAs PPCs irradiated with a Gaussian beam centered at 835 nm, with and without a DBR. The thickness of the bottom junction in the DBR device was minimized and compared with the normal PPC. The basic capabilities of modelling a photovoltaic cell with a DBR structure is shown in a Solcore example file on their GitHub repository [3].

A. Photonic Power Converter Geometry

The PPC modules were constructed in Solcore by creating individual layers of uniform materials (*Layer* objects), forming the layers into p-n junctions (*Junction* objects), then arranging the junctions into the final photovoltaic structure (*SolarCell* object). Each p-n junction consists of a thin emitter layer of n-GaAs, and a thicker base layer of p-GaAs, and the DBR consisted of 20 alternating layers of AlAs and GaAs. The uniform plane wave light source with a Gaussian spectrum (*LightSource* object) was defined with a central wavelength (835 nm), linewidth (2 nm), and power (10.7 W/cm^2). The architecture of the devices are shown in Fig. 1.

B. Optical Model

The model uses the transfer matrix method (TMM) to calculate the reflection, absorbance, and transmission through the PPC using the open source "tmm" Python software package [4]. The *SolarCell* object with fully defined material systems, and *LightSource* object were used as inputs into the TMM solver.

C. Photovoltaic Model

The depletion approximation model was applied to solve the electrical characteristics of the cell, based on equations found in literature with two added capabilities: PIN junctions and the incorporation of TMM and rigorous coupled-wave analysis optical solvers [5]. This depletion approximation solver accepts the optical model, and *SolarCell* and *LightSource* objects as inputs.

D. Thickness Calculation

The thickness of the two DBR layers and the bottom junction absorber were solved iteratively, starting from the conventional PPC (PPC-A) and adding a DBR layer to the rear (PPC-B). The thicknesses of the DBR and absorber were varied separately to satisfy the following conditions:

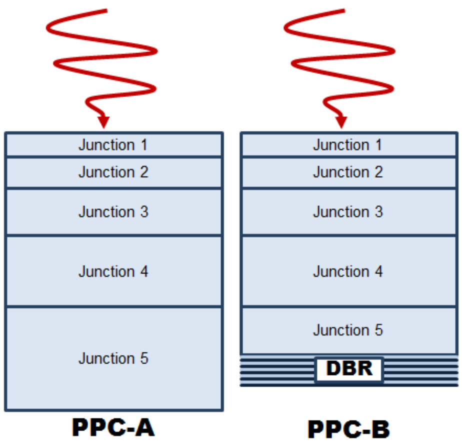

Fig. 1: PPC without (left) and with (right) a DBR layer, where PPC-A has a Junction 5 nominal thickness of 2217 nm

1) DBR: maximize quantum efficiency at 835 nm in the bottom junction;
2) Junction 5 Absorber: minimize thickness while retaining the same short circuit current density as PPC-A in junction 5.

III. Results & Discussion

To evaluate the simulation, a 5 junction GaAs PPC was modelled and compared with experimental results. The addition of the DBR causes a light trapping effect, and increases the effective optical thickness of the bottom junction. This allows PPC-B to have a thinner bottom junction than PPC-A, as seen in Fig. 2, and the results listed in Table 1. The external quantum efficiency of PPC-B in Junction 5 can be seen in Fig. 3, where the optimal DBR layer thicknesses are at the maximum efficiency. The thickness of PPC-A was chosen based off 98% absorption through the Beer-Lambert law, but the overall quantum efficiency of the device modelled with TMM is significantly lower.

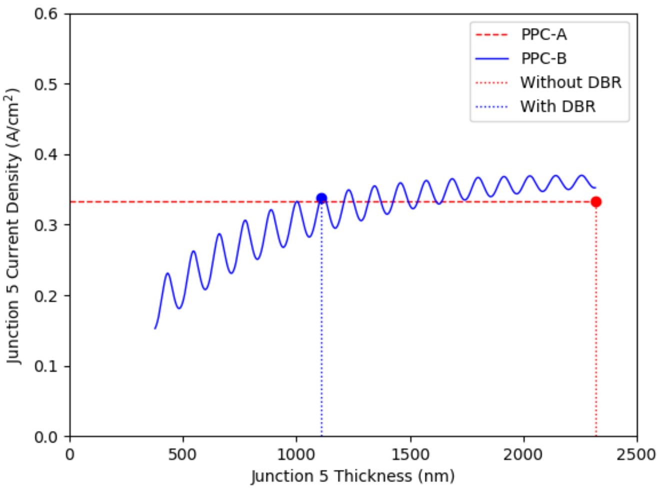

Fig. 2: Short circuit current density of PPC-A with fixed Junction 5 thickness (2217 nm) and PPC-B with varied Junction 5 thicknesses and a DBR of AlAs=52.8 nm and GaAs=67.2 nm.

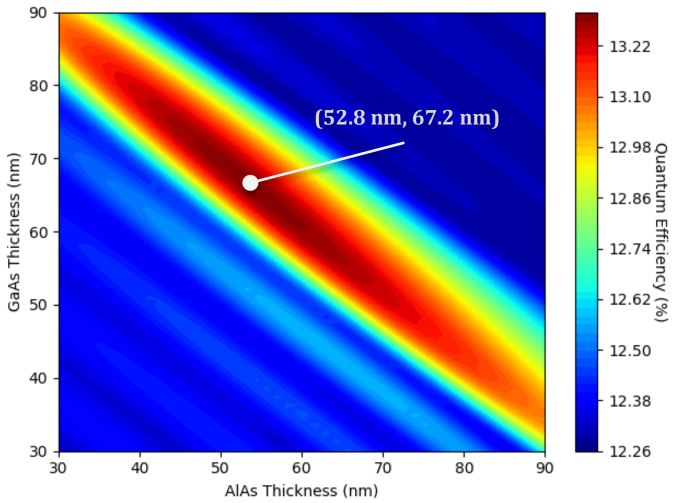

Fig. 3: External quantum efficiency of PPC-B junction 5 (thickness=1108 nm) at various DBR layer thicknesses

TABLE I. PPC Layer Thicknesses

Layer	PPC-A	PPC-B
Junction 5	2217 nm	1108 nm
DBR Layer 1 (AlAs)	/	52.8 nm
DBR Layer 2 (GaAs)	/	67.2 nm

Results show that the thickness of the bottom junction in PPC-B is roughly half of PPC-A. However, a large benefit of light trapping techniques is to thin all layers in a multi-junction cell in order to increase efficiency, lower material cost, and increase power output. Future work on this model will include optimizing each layer thickness for quantum efficiency and power output. Other future work will include the incorporation of luminescent coupling within the PPC [6].

Acknowledgment and References

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