Quasi-3D Optimization of Grid Architecture for Photovoltaic Converters Using Solcore

*Veikka Nikander, †Jianguo Wei, *Arto Aho, *Ville Polojärvi, *Antti Tukiainen, and *Mircea Guina

*Optoelectronics Research Centre, Physics Unit, Tampere University, Tampere

†Global Energy Interconnection Research Institute Europe GmbH, Berlin

Contact: *veikka.nikander@tuni.fi

Abstract: Numerical study of metal front contacts grid spacing for photovoltaic (PV) devices is presented with application to PV converter of relatively small size. The model is constructed based on the open source Solcore Python library. A three-step-process is developed to create a hybrid quasi-3D model. The optimal grid spacing was simulated at different temperatures to yield the highest conversion efficiency under various illumination conditions. The results show that the grid spacing needs to be reduced for higher temperatures to yield the highest efficiency. Moreover, the tolerance of the grid spacing is found to be more critical at higher temperature.

I. INTRODUCTION

Photovoltaic (PV) converters are devices based on semiconductor pn-junctions, operating on the similar principle as the solar cells, yet with the main difference in terms of illumination: PV converters being illuminated by a light beam with a narrow spectrum, typically delivered by a laser source [1][2]. Their main applications are for remote power delivery over optical fibre; here the electrical power is first converted into laser light which is then transferred through an optical fibre to the PV device, converting the light back to electricity. Power over fibre systems are advantageous over traditional electric power transfer for example in applications that require galvanic isolation or low electromagnetic interference [3].

The optimal PV converter design relies on one hand on the optimization of the its layer structure similarly to solar cells. However, the design of the front metal grid, which should generally ensure efficient charge collection with minimal voltage loss, is another important optimization aspect. Grid design becomes even more crucial for PV converters given the high light intensity, their relatively small areas, and geometry matching the beam shapes delivered by the fibre optics elements.

Here, a numerical study of front contact grid spacing used in PV converters employing a hybrid quasi-3D (HQ3D) model is presented. The model is based on Solcore [4] and a double diode model (DDM) fitting. Solcore is an open source Python-based library for PV modelling equipped with multiple simulation tools including, e.g., Transfer Matrix Method (TMM), Fortran-based Poisson-Drift-Diffusion (PDD) solver and SPICE-based Quasi3D solver. The HQ3D model calculates from given device structure, grid profile and illumination profile the current-voltage (*I*-*V*) characteristics for the cell and a detailed 2D voltage map over the surface of the device. An example of input parameters is given in Figure 1. From the simulation results, it is possible to detect the areas of higher losses and most importantly get the efficiency of the simulated device. Optimization is done for three different temperatures, as this is a parameter that typically varies unless an active control is employed.

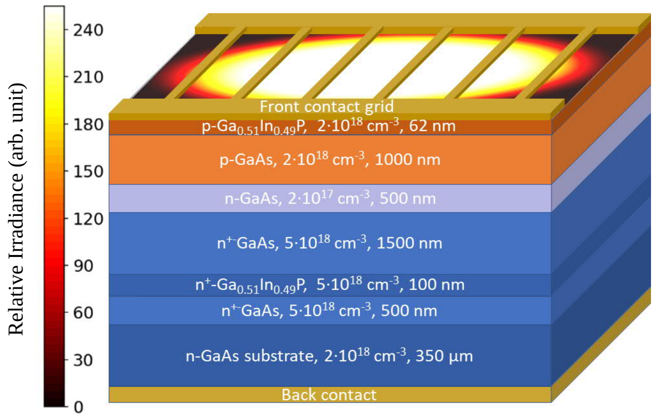

Fig1. Structure used in the simulations [5] and a sketch of the front contact metal grid and illumination irradiance profiles.

II. HYBRID QUASI-3D MODEL

The HQ3D modelling starts by determining the devices 1D behaviour using TMM and PDD solvers. TMM calculates the internal quantum efficiency of the structure, which is then passed to PDD solver for calculation of the *I*-*V* characteristics of the 1D structure. After the 1D behaviour is determined, a DDM is constructed by fitting the double-diode equation to the PDD-created *I*-*V* characteristics using a highly efficient method [6] utilizing Lambert *W*-function [7] and Nelder-Mead method [8].

After the DDM is calculated, a circuit equivalent quasi-3D structure is determined. This structure models the flow of current inside the device and takes also into account effects of front metal grid and illumination profile. The model discretizes the area to smaller sub-devices in the growth plane. The sub-devices are connected to each other by resistors that model the lateral current flow. Resistance values of the connecting resistors are determined with sheet resistance

$$R_{sh} = \frac{1}{qd\mu N}, \quad (1)$$

where q is charge, d is thickness, μ majority carrier mobility and N doping of given layer. Sheet resistance values for layers above junction are key parameters in the grid optimization.

Illumination and grid profile for each device is determined based on specific profile matrices. These matrices can be created mathematically or extracted from experimental data converted to greyscale images. The illumination matrix scales the light-generated current calculated with PDD to subparts. The grid profile matrix determines the place of contact fingers and the busbar. Parts of the device that are underneath the contact grid have no light generated current.

The final circuit equivalent model is then given to a SPICE solver, ngspice [9], which calculates the total *I-V* characteristics of the device and voltage map over the surface of the device and metal contacts.

The HQ3D model is a valuable tool for determination of the optimal grid profile, but its capabilities reach much wider spectrum of device parameters such as illumination profile and even device structure design. Here, the model is utilized for optimization of a PV-converter but can also be applied to other PV devices as well, most notably, concentrated PV solar cells.

III. RESULTS

The HQ3D-model was used for optimizing a case study representing the GaAs pn-junction based PV-converter architecture [5], with specific material structure seen in Fig. 1. Simulation was done considering 808 nm laser light illumination and a grid with fingers cross area of 4.5 μm. We considered three operation temperatures: ~300 K, ~325 K and ~350 K. First temperature is chosen for easy comparisons with standard test conditions, second is realistic target for achievable temperature for passively cooled device and third is more pessimistic operating temperature for converter. All these temperatures are possible operating temperatures for practical implementations depending on cooling and ambient temperature of operating environment. A polynomial fit is employed for the simulated data points to extract more accurately the optimal spacings. The relative output power and optimal grid finger spacing at each temperature are shown in Fig. 2, together with the optimal spacing and sensitivity of spacing shown in the inset.

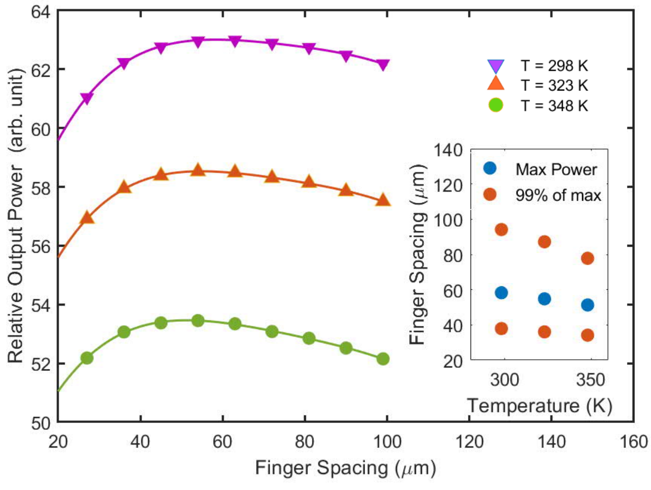

Fig 2. Output power as function of spacing. Inset: Optimal spacings as function of temperature.

As expected, the temperature variation has a significant effect on the conversion efficiency [10]. In general, the results are well aligned to experimental results of similar devices [11]. As a general trend, the optimal spacing decreases fairly linearly from 58 μm at 300 K to 51 μm at 350 K. The range for feasible spacings starts to narrow also as temperature increases such that spacing range which generate over 99 % of the optimum output narrows from 56 μm at 300 K to 44 μm at 350 K.

IV. CONCLUSIONS

A hybrid quasi-3D model for simulating the behavior of photovoltaic devices has been created based on the open source Python library Solcore. It has been successfully used to optimize the grid spacings of photovoltaic converters for different operation temperatures. The optimal grid design and variation with temperature appears to play an important role in order to achieve maximum efficiency of the PV-converters in specific operation environment. For example, if consistency of output power is required from the converter, decreasing its operating temperature and using the optimal spacing will result in more stable output. As the next development steps we are working on experimental validation of the model and expansion of its use to other photovoltaic architectures.

ACKNOWLEDGMENTS

This work is supported by the State Grid Corporation of China (Project no.840) and the ERC AdG project AMETIST (Grant Agreement No. ERC-2015-AdG 695116).

REFERENCES

[1] B. C. DeLoach, R. C. Miller, S. Kaufman, Sound alerter powered over an optical fiber. The Bell System Technical Journal, 57(9), pp. 3309–3316, 1978.

[2] E. Oliva, F. Dimroth, and A. W. Bett, “GaAs converters for high powerdensities of laser illumination,”Prog. Photovolt.: Res. Appl 16(4), pp. 289–295, 2008.

[3] F. V. B. de Nazare, M. M. Werneck, "Hybrid Optoelectronic Sensor for Current and Temperature Monitoring in Overhead Transmission Lines," IEEE Sensors Journal, 12(5), pp. 1193–1194, 2012.

[4] D. Alonso-Álvarez, T. Wilson, P. Pearce, “Solcore: a multi-scale, Python-based library for modelling solar cells and semiconductor materials,” J Comput Electron 17, pp. 1099–1123, 2018.

[5] K. Vänttinen, J. Lammasniemi, K. Rakennus “A Ga0.51In0.49P/GaAs-based photovoltaic converter for two-directional optical power and data transmission,” Prog. Photovolt: Res. Appl., 3, pp. 57–63, 1995.

[6] Y. C. Xiankun Gao. LambertW -function based exact representation for double dio-de model of solar cells: Comparison on fitness and parameter etraction. Energy Conversion and Management 127, 443–460, 2016.

[7] R. Corless, G. H. Gonnet. “On the Lambert W Function”,.Advances in Computational Mathematics 5, 329–359, 1996.

[8] J. Nelder, R. Mead, “A simplex method for function minimization”.Computer Journal 7, 308–313, 1965.

[9] ngspice [Online] http://ngspice.sourceforge.net/.

[10] A. Luque, S. Hegedus, “Handbook of Photovoltaic Science and Engineering Second Edition”, John Wiley & Sons, Ltd, pp. 122–123, 2011.

[11] A.Aho, R. Isoaho, “Temperature coefficients for GaInP/GaAs/ GaInNAsSb solar cells”, AIP Conference Proceedings 1679, 050001, 2015.