Numerical Modelling of Photon Recycling in Solar Cells and its Simulation

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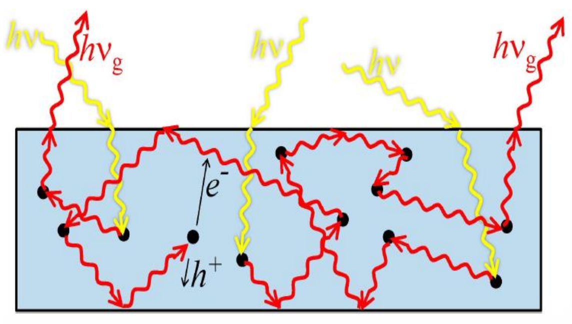
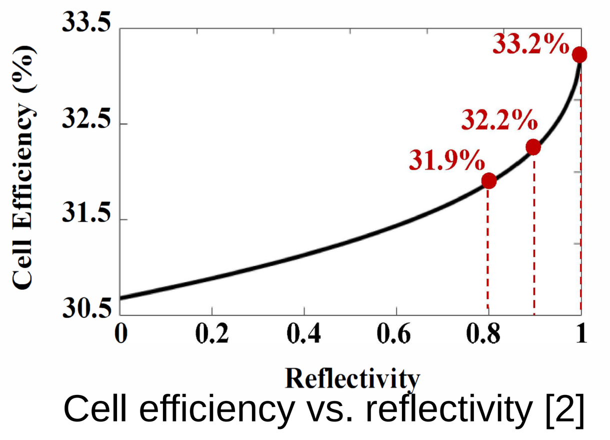
Introduction

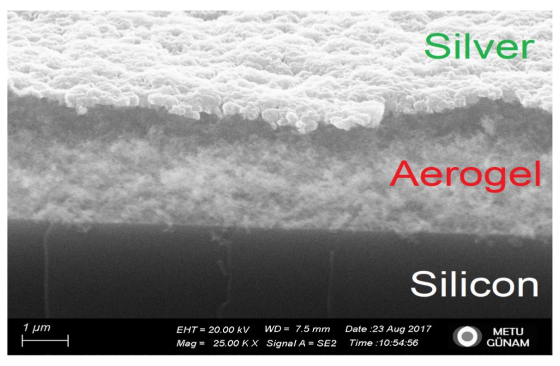
- The process of re-absorbing a photon emitted by the radiative recombination is called as photon recycling [1].
- In 2012, the solar cell efficiency record was renewed by a single-junction GaAs solar cell as 28.8% with the aid of effective photon recycling [3].
- There is no available simulation tool for PR due to high-level complexity of modelling. In this project, we have tried to numerically model and simulate photon recycling in solar cells with MATLAB and SCAPS [4].
- The aim of the project is that simulation of photon recycling will create a prognosis to aerogel applications in APP research group. Aerogel is a material which can be used as a back-reflector in order to enhance photon recycling.



Physical illustration of photon recycling process [2]



Cell efficiency vs. reflectivity [2]



SEM image of aerogel layer in a solar cell

Methodology

General Formulation of Photon Recycling

- An additional term corresponding to generation rate due to photon recycling has been added to the standard set of equations used in simulation programs.

$$\nabla^2\phi = -\frac{q}{\varepsilon}(p - n + N_D^+ - N_A^-) \quad [1]$$

$$\frac{\partial n}{\partial t} = +\frac{1}{q}\nabla\cdot J_n + (G_n - R_n) + G_E + \boxed{G_{PR}} \quad [2]$$

$$\frac{\partial p}{\partial t} = -\frac{1}{q}\nabla\cdot J_p + (G_p - R_p) + G_E + \boxed{G_{PR}} \quad [3]$$

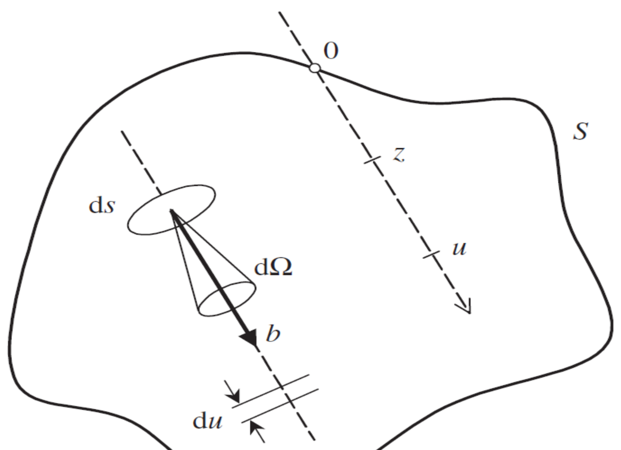
Additional Term

- So as to formulate the G_{PR} term in the above equation set, we introduce a new equation, which is photon continuity equation that is formulated in equation 4. [5]

$$\frac{db}{du} + \alpha b = \alpha b_n \quad [4]$$

- b_n is formulated with generalized Roosbroeck and Shockley equation in equation 5. [6]

$$b_n(E,\varphi) = \frac{2}{h^3c^2}\frac{n^2E^2}{\exp\left(\frac{E-q\varphi}{kT}\right)-1} \quad [5]$$



Parameters involved in photon continuity equation [5]

- At the end of formulization with proper boundary conditions, we end up with 5 equations to obtain the G_{PR} term, which are shown in equations 6-10.

$$b(E,x,\mu) = \begin{cases} +\frac{\alpha}{\mu}\exp\left(\frac{-\alpha x}{\mu}\right)\times\left[\frac{R_F}{\Phi}\Psi_{0F} + \int_0^x b_n \exp\left(\frac{\alpha x'}{\mu}\right)dx'\right] \; for \; 0<\mu\le 1 \\ -\frac{\alpha}{\mu}\exp\left(\frac{-\alpha x}{\mu}\right)\times\left[\frac{R_R}{\Phi}\Psi_{0R} + \int_x^w b_n \exp\left(\frac{\alpha x'}{\mu}\right)dx'\right] \; for \; -1\le\mu<0 \end{cases} \quad [6]$$

$$G_{PR}(x) = 2\pi\int_{E_G}^{\infty} dE \int_{-1}^{1}\alpha(E)b(E,x,\mu)d\mu \quad [7]$$

$$\Phi = \exp\left|\frac{2\alpha w}{\mu}\right| - R_F R_R \quad [8]$$

$$\Psi_{0F} = R_R\int_0^w b_n \exp\left(\frac{\alpha x'}{\mu}\right)dx' + \exp\left(\frac{2\alpha w}{\mu}\right)\int_0^w b_n \exp\left(\frac{-\alpha x'}{\mu}\right)dx' \quad [9]$$

$$\Psi_{0R} = R_F\int_0^w b_n \exp\left(\frac{\alpha x'}{\mu}\right)dx' + \int_0^w b_n \exp\left(\frac{-\alpha x'}{\mu}\right)dx' \quad [10]$$

The Algorithm to Simulate Photon Recycling

The solar cell structure is simulated with SCAPS without G_{PR} term and the quasi-Fermi level separation is given as input to MATLAB.

MATLAB code generates an initial photon recycling generation rate profile and gives the profile to SCAPS.

SCAPS simulates the structure with additional photon recycling generation profile and new quasi-Fermi level separation is given again to MATLAB.

This quasi-Fermi level separation and generation profile exchange continues until the quasi-Fermi level separation converges to some point.

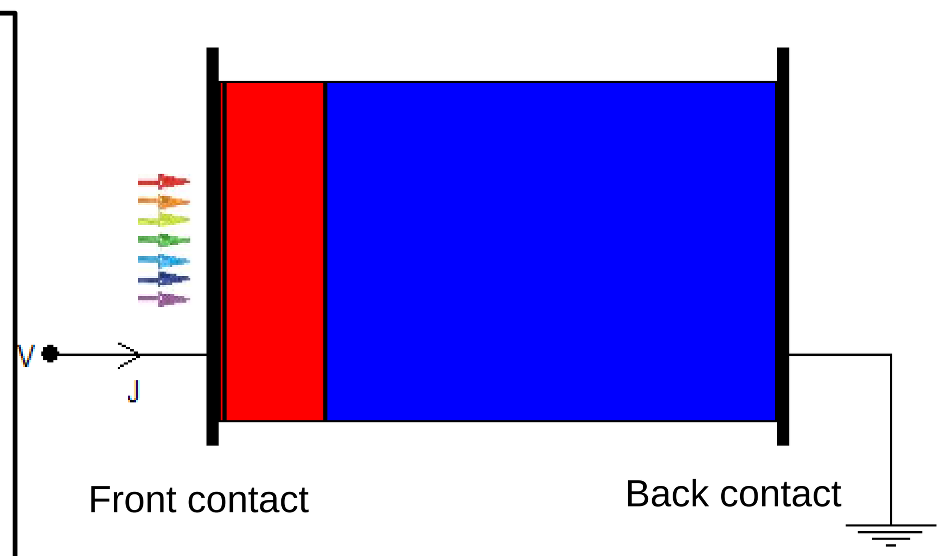
After the convergence, simulation results taken into consideration photon recycling is obtained.

- In this part of the project, we have got contact with Marc Burgelman, the programmer of SCAPS and he sent us to some useful codes which make SCAPS and MATLAB interact.

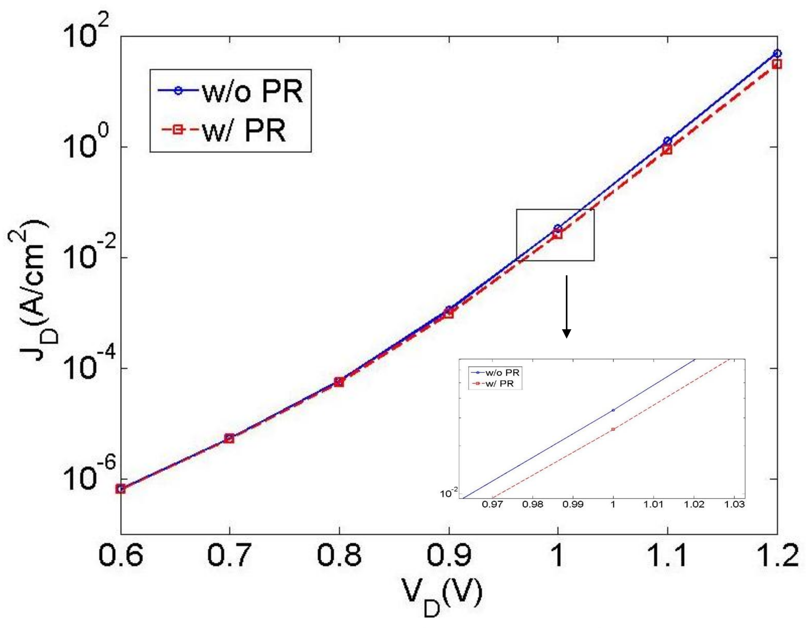
Results

Simulation parameters:

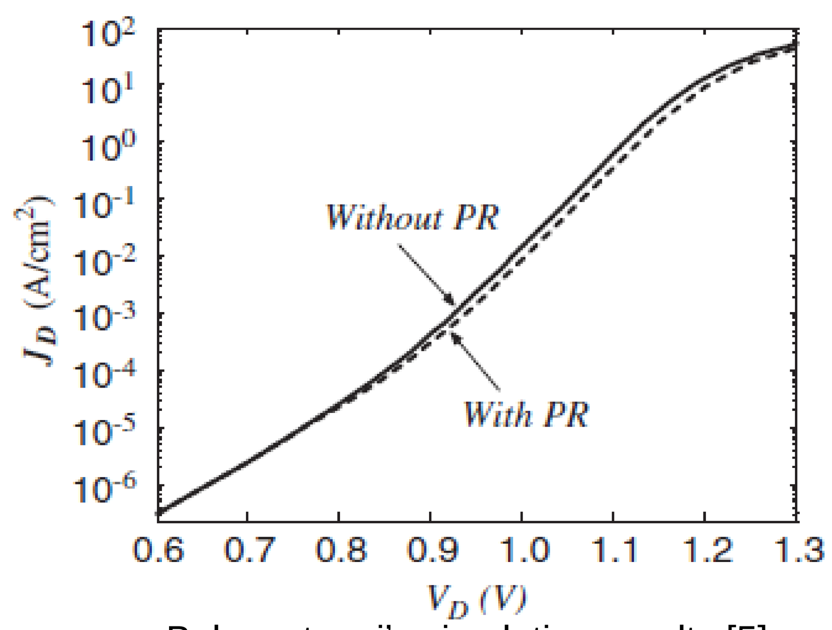
- p-GaAs emitter w=0.9 µm, $N_A = 2\cdot 10^{18}\ m^{-3}$
- n-GaAs base w=4.0 µm, $N_D = 2\cdot 10^{17}\ cm^{-3}$
- p- $Al_{0.8}Ga_{0.2}As$ window layer w=0.05 µm, $N_A = 1\cdot 10^{17}\ cm^{-3}$
- Surface recombination velocity S = $1\cdot 10^4\ cm/s$ (base, emitter) S= $1\cdot 10^4\ cm/s$ (window)



The simulated structure



Our simulation results



Balenzategui's simulation results [5]

Conclusions and future work

- A numerical model was implemented to simulate the effects of photon recycling. Due to some missing simulation parameters, the results are not same as in the literature. However, the decrease pattern in current density shows consistency.
- As future work, all simulation parameters will be obtained to get the exact results with the literature data.

References

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