New assessment of the efficiency limits in solar photovoltaics

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Context

Solar photovoltaics should play a major role to fulfil the goals set for the energy transition and Paris Agreement. In the sustainable development scenarios of the International Energy Agency (IEA), the share of photovoltaics in electricity generation is expected to increase from 6% in 2017 to 22% in 2030. Nowadays, most commercial photovoltaic modules are made of silicon (Si) wafers with thicknesses of more than 150 µm, an average conversion efficiency of about 20%, and record solar cells up to 26.7%. To accelerate the energy transition, it is necessary to further increase the conversion efficiency of solar cells, and to reduce their cost.

Ultrathin solar cells with thicknesses at least 10 times lower than conventional solar cells could have the unique potential to efficiently convert solar energy into electricity while enabling material savings, shorter deposition times and improved carrier collection. In 2019, we have achieved an important milestone by trapping sunlight efficiently in a GaAs solar cell as thin as 200 nm, using a nanostructured back mirror. This new architecture is based on multi-resonant absorption and led to a record efficiency of nearly 20% [1]. In a recent review published in Nature Energy [2], we have highlighted the very high potential of ultrathin solar cells, the challenges to overcome to get closer to the theoretical limits, and the most promising research directions.

Scientific project

In this internship, we propose to reassess the theoretical limits of silicon solar cells, and to show that the well-known Shockley-Queisser limit of single-junction solar cells should be revisited with an appropriate light-trapping model (the absorption upper bound). The starting point is the following: the well-known fundamental efficiency limit of silicon solar cells is 29.4% and requires a thickness of 100 µm [3]. However, it is based on an absorption model that assumes Lambertian scattering, which is not the optimal light-trapping scheme. Recently, we have developed a new absorption model based on multi-resonant absorption, and we have derived analytical formulas for the absorption upper bounds [4]. This work paves the way towards a reassessment of the fundamental efficiency limit of silicon solar cells, expected to be above 30% for much thinner cells (a few tens of µm). Since the vast majority of installed solar panels are made of silicon, the results of this study will have an important impact in the field.

This work will be focused on the development of theoretical models and the use of simulation tools. The short-term objective is to combine multi-resonant absorption models and transport equations of charge carriers in a silicon solar cell. The model will be first compared to previous publications, and then it will be used to derive the new fundamental efficiency limits of silicon solar cells based on the absorption upper bound. The mid-term objective is to design ultrathin solar cells that get close to the theoretical limits, and to explore the tradeoffs that constrain the efficiency of actual devices.

The team

This work will be done in close collaboration between the C2N (SUNLIT Team) and the IPVF both located on Paris-Saclay campus in Palaiseau (one block away). More information on the SUNLIT Team: https://sunlit-team.eu
Profile: Student in M2 with a solid knowledge in semiconductor physics and optics.
Possibility to continue with a PhD grant on ultrathin, high-efficiency solar cells in 2023.
Send CV and motivation letter to: stephane.collin@c2n.upsaclay.fr

References:

[1] H.-L. Chen et al., *A 19.9%-efficient ultrathin solar cell based on a 205-nm-thick GaAs absorber and a silver nanostructured back mirror*. Nature Energy 4, 761-767, 2019.
[2] I. Massiot, A. Cattoni, S. Collin. *Progress and prospects for ultrathin solar cells*. Nature Energy 5, 959-972, 2020.
[3] T. Niewelt et al., *Reassessment of the intrinsic bulk recombination in crystalline silicon*. Solar Energy Materials and Solar Cells 235, 111467 (2022).
[4] S. Collin and M. Giteau, in preparation (2022).