Two-temperature hot carrier solar cell.

Nathan Roubinowitz , Thomas Vezin* , Daniel Suchet* , Jean-François Guillemoles**

**Institut Photovoltaique d'Île de France, UMRIPVF9006, CNRS, Ecole Polytechnique IPP, ENSCP PSL, Palaiseau, France*

Hot carriers solar cells offer a perspective to increase the conversion efficiency. In traditional single-junction solar cells, the maximum theoretical efficiency is limited to around 30% (Schockley-Queisser limit), while the extraction of hot carriers before their relaxation to the band-edge would allow to reach the thermodynamic limit of 86% [1]. To date, no satisfying HCSC has been demonstrated. This calls for a better understanding of the constituents of such solar cells, for instance by the development of new characterization and modeling techniques. In the historical approach to hot carrier solar cells [2], electrons and holes are assumed to form quasi-thermal distributions with the same temperature larger than that of the lattice ($T_e = T_h > T_{amb}$). However, because different carrier types may have different effective masses and different coupling with the phonons, the possibility of having $T_e \neq T_h$ must be addressed [3].

We first propose a purely optical method that allows the direct and distinct estimation of electron and hole temperatures in steady state, published in [4]. This technique, based on continuous-wave photoluminescence, relies on the precise determination of the band-filling signature. We apply this technique to an InGaAsP single quantum well. Electron temperature surpasses 1000 K at the largest excitation intensity, while holes remain colder, close to lattice temperature. Nonetheless, the increase in hole temperature is too large to be explained purely by photon absorption, demonstrating an energy transfer from electrons to holes.

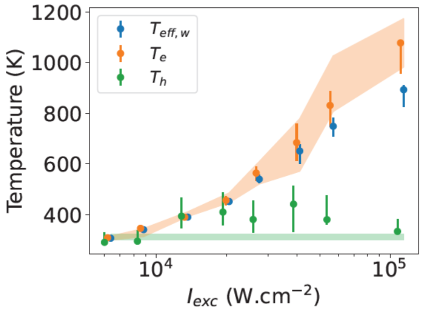

Figure 1: distinction of electrons and holes temperatures as a function of the excitation intensity

Second, we model the functioning of such a two-temperature HCSC [5]. We study its efficiency and sensitivity to the energy-selective contacts design. We show that the two-temperature HCSC is always more efficient than the one-temperature one, by around 2 percentage points at best. Then we show that the optimal design of 2T HCSC cell resembles that of the 1T HCSC.

References:

[1] R. T. Ross and A. J. Nozik. 'Efficiency of hot-carrier solar energy converters'. Journal of Applied Physics, vol. 53, no. 5, pp. 3813–3818 (1982)

[2] D. König, Y. Yao, B. Puthen-Veettil and S. C. Smith. 'Non-equilibrium dynamics, materials and structures for hot carrier solar cells : a detailed review', **vol. 35**, no. 7 (2020)

[3] F. Gibelli, L. Lombez and J.-F. Guillemoles. 'Two carrier temperatures non-equilibrium generalized Planck law for semiconductors'. Physica B: Condensed Matter, vol. 498, pp. 7–14 (2016)

[4] Thomas Vezin, Nathan Roubinowitz, Laurent Lombez, Jean-François Guillemoles, and Daniel Suchet, 'Direct determination of electron and hole temperatures from continuous-wave photoluminescence measurement', Physical Review B (2024)

[5] Thomas Vezin, PhD thesis, chap. 6 'Operation, design and resilience of a two-temperature hot carrier solar cell' (2024)