Multi-temperature hot carrier solar cell: an issue or an opportunity?

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A hot-carrier solar cell (HCSC) is a high-efficiency photovoltaic concept where electrons and holes are at a higher temperature than the lattice. If this temperature is converted into voltage through a thermoelectric conversion, these hot carriers can result in higher cell efficiency, possibly allowing to reach the thermodynamic limit of 86% [1]. This gives the two requirements for a HCSC: establishing a hot-carrier population and converting the temperature into extra voltage through energy-selective contacts.

On the first aspect, one should consider the generation of the hot carriers, and the design of absorbers that can make this generation easier. In most previous approaches to hot carrier solar cell, e.g. [2], carriers are assumed to form quasi thermal distributions with temperature larger than that of the lattice ($T_e = T_h > T_{amb}$). However, because different carriers 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 present here the how such a situation can be modelled, experimentally studied and we present then a characterization of a such two-temperatures absorber [4] and the impact on the operation of HCSC [5].

We propose a purely optical method which allows the direct and distinct estimation of electron and hole temperatures in steady state, published in [4]. This technique, based on 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 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 (fig 1).

On the second aspect, we address the question of the operation of a HCSC in the regime where electrons are hotter than holes [5]. For that purpose, we develop a two-temperature HCSC model and study its efficiency and sensitivity to the energy-selective contact design. We show that the two-temperature HCSC is always more efficient than the one-temperature one (fig 2). We also present how the theory can be extended to include these cases and discuss what are the relevant key parameters to be considered in such a situation.

Actual hot carrier devices would deviate from ideal assumptions of the initial idea of Ross and Nozik [1]. We will finally explore how resilient is the hot carrier device concept to such deviations.

[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] A. Lebris et al. APL 2010

[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)

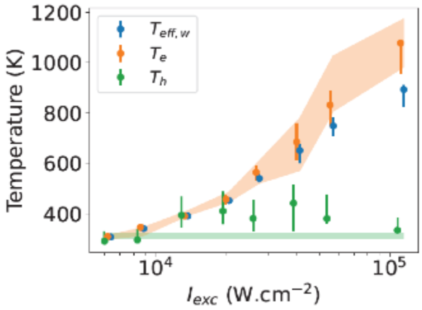

Figure 1: distinction of electrons and holes temperatures as a function of the excitation intensity

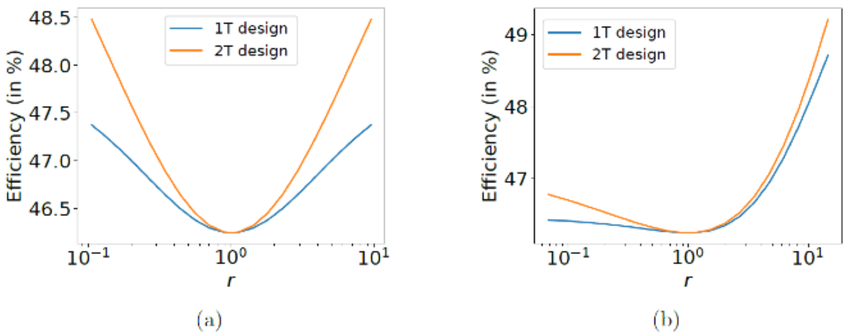

Figure 2: one-temperature and two-temperature HCSC efficiencies as a function of the temperature ratio r=T_e/T_h and for two carrier effective masses mismatch (a) ξ=1/2 and (b) ξ=1/11 (like in most III-V's)