Hot carrier solar cell: from efficiency simulation to hot carrier detection by photoluminescence

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1 Introduction

Hot Carrier Solar Cells (HCSC) would convert a large part of the incident power into electric power, by reducing the thermal losses in the absorber. Existing models for HCSC, based on detailed balance model for solar cell, consider all characteristics of the cell to be ideal: no electron-phonon interaction, no non radiative recombination, ideal energy selective contacts. Previous work [1-4] has shown the thermodynamic limit of HCSC conversion efficiencies to lie around 85% in the case of an ideally non interacting phonon-electron population. On the experimental side, hot carrier cooling was measured in a variety of materials, including Si, Ge and GaAs where carrier confinement and high injection were found to be essential for an hot phonon bottleneck effect leading to slowed down carrier cooling. A hot carrier cell absorber must maintain populations of hot photogenerated carriers long enough for them to be transmitted through narrow energy filter contacts. [1,2] This requires a very dramatic reduction in thermalization from the picoseconds timescale common in semiconductors. The present work is trying to incorporate available material data into models for hot carrier solar cells with the aim to identify most critical issues on the path to their practical realisation. The influence of thermal losses on the efficiency predictions of the model is investigated here. As HCSC would best work under concentrated light and small absorbing volume, the potential structures for absorption enhancement, allowing a reduced material thickness, are also studied. Finally, several heterostructures (quantum wells based on antimonide compounds) were grown and their thermalisation properties measured

2 Hot carrier solar cell model

Hot carrier solar cells rely on absorption of light in a thin absorber where carriers are extracted through energy selective contacts before they thermalise with the lattice. The carriers in the absorber can be described by Fermi distribution , with a temperature T_H and chemical potential μ_H different from those of the carriers extracted (figure 1). Electron-phonon interaction reduction comes from a bottleneck effect on phonon emission in low dimension structures, for high carrier density, and then shall only occur with thin layer for absorber and highly concentrated sunlight. In a HCSC one also needs to prevent heat flow when contacting the hot carrier reservoir with a cold one in metallic electrodes. This is done by using a energy selective contact allowing only electrons at a specific energy to be extracted [4]. Best performances are obtained with perfectly energy selective contacts, but real systems would have a finite width.

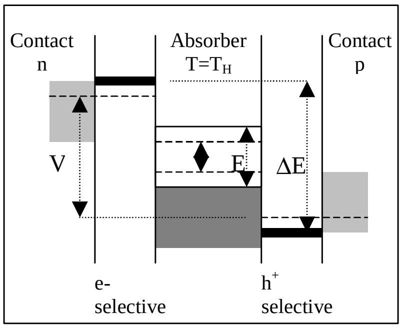

Figure 1: Schematics of a hot carrier solar cell. Dashed lines are quasi Fermi levels (QFL).

3 Results

The influence of the different parameters (light concentration, carriers cooling rate, contact properties, absorption) on a device efficiency is investigated in the current work. In particular we introduced non ideal energy selective contacts and a model for carrier cooling representing the electron-phonon interaction. We were then able to quantify the impact of these effects, and to determine how critical they are. Numerical calculations served to calculate the absorption by the layer, and a structure is proposed to enhance absorption.

We also tested antimony-based heterostructures to evaluate their potential as a HCSC absorbing layer. Continuous photoluminescence is used to determine the carrier temperature in the sample as a function of the incident power. These measurement are then used to determine the thermalization properties in the material.
The main result is the dependence of a device efficiency on its thermalization properties (figure 2). Such data have been produced for different concentration and for different contacts properties. These indicates that a improvement on concentration of light or on absorbing thickness allows to relax the constraint on cooling rate for instance. It also shows that the narrowness of contacts is not as critical as expected before. Results on CW-PL (figure 3) show the PL signal measured for a sample at different incident laser intensity. The slope on the high energy side is related to the carriers temperature, and this enables to measure the heating of the electron population [5].

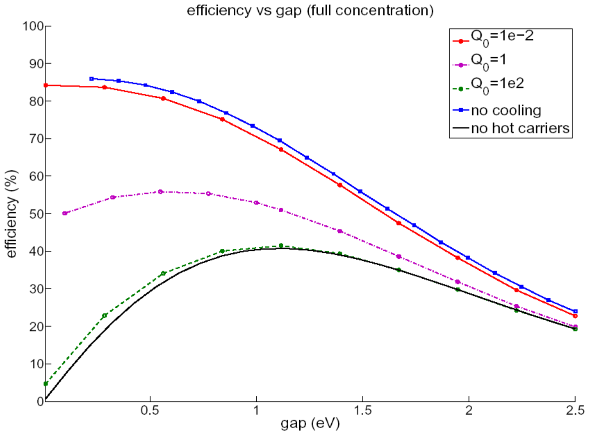

Figure 2: efficiency as a function of the absorber bandgap, for different thermalization rate. $Q_0=1$ (dash-dotted line with solid circles) corresponds to a reference cooling rate measured in GaAs QW. $Q_0=0.01$ (solid line with solid circle) and $Q_0=100$ (dashed line with solid circles) corresponds respectively to a cooling 100 times slower and 100 times faster. The limit cases of ideal HCSC (solid squares) and fully thermalized cell (solid line) are represented. The calculation is done for full solar concentration and a contact width of 0.1 eV.

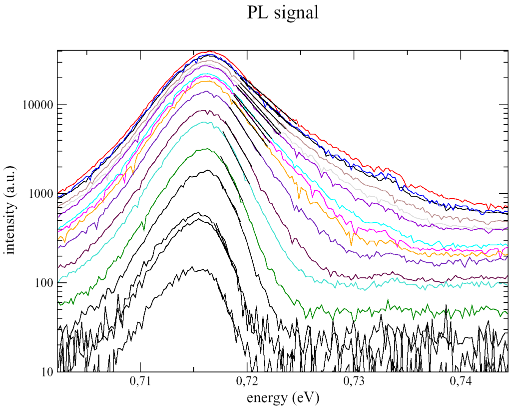

Figure 1: PL spectra for different incident laser intensities (0.1 to 30 W/cm²). When the incident intensity is increased, the shape of the signal changes on the high energy side of the peak.

Conclusions:

Using the HCSC model, one can determine the required properties of material and structure in order to produce a HCSC. The current investigations shows that carrier thermalisation, whether in the absorber by phonon emission or in the contacts due to their finite width, are not as overwhelming a problem as initially thought [1-3]. Projected device efficiency in the 50% range are consistent with both our model and experimental data.

References

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