Two-temperature hot carrier distribution reveiled by steady-state photoluminescence

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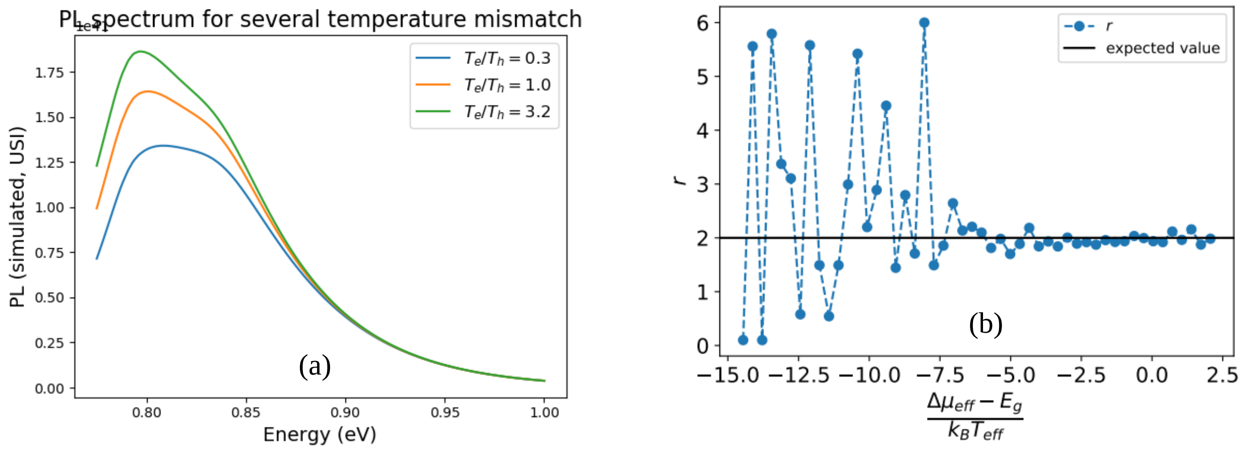
Hot carrier solar cells (HCSC) have been proposed to increase the efficiency of photovoltaic devices beyond Shockley-Queisser (SQ) limit (~33%) [1]. In this type of solar cells, the excess energy of photons as compared to the bandgap is conserved as kinetic energy of excited carriers, resulting in high temperature distributions. To date, most studies regarding hot carrier solar cells assume that electrons and holes have the same temperature [2], [3].

However, electrons and holes receive unequal fractions of the absorbed photon energy, and may have different relaxation dynamics. Electron and hole temperatures (T_e and T_h respectively) may thus be different. A theoretical description of the photoemission of a device with $T_e \neq T_h$ was proposed [4]. It shows that the high energy tail of photoluminescence (PL) spectra can be simply described with an effective temperature T_{eff} and quasi-Fermi level splitting (QFLS) $\Delta\mu_{eff}$. However, it should be possible to determine T_e and T_h individually from the low energy side of the spectrum (see Figure (a)).

In this work, we first study the theoretical requirements to be able to determine separately T_e and T_h from PL spectra through the signature of band filling. We quantify the order of magnitude of band filling necessary to be able to distinguish T_e from T_h (see Figure (b)) and then provide comprehensive understanding of the physical boundaries of the fitted coefficients. Finally, we prove the experimental relevance of our method by determining separate temperatures for electrons and holes of a hot carrier absorber.



Figures : (a) Simulation of PL spectra with same effective temperature but different ratio $r = T_e/T_h$. The effect of the distinct temperature for electrons and holes is mostly visible on low energy side. (b) Fitting results with simulated PL spectra of increasing QFLS. We recover a proper estimate of $r = T_e/T_h$ only when QFLS is sufficiently close to the bandgap.

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