A scaling law for the time derivative of TR-PL allows for a quantitative assessment of radiative and non-radiative recombination parameters of perovskite materials

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Perovskite-based solar cells are the subject of intense study today because of their promise in terms of high efficiency, easy and low-cost fabrication. To gain insight on the behavior of carriers inside the perovskite layer, time resolved photo luminescence (TR-PL) and time resolved fluorescence imaging (TR-FLIM) are used[1]. However, owing to their long lifetimes (~1µs) and slow diffusion ($D \sim 1e^{-2} cm^2 s^{-1}$) the acquired signals require specific care for interpretation.

In a previous work[2], we showed how these properties can be exploited to derive a scaling-law for the normalized time derivative of the TR-PL signal just after the laser pulse $1/\tau°$. This scaling links the derivative to the material parameters: interface and bulk non radiative recombination, radiative recombination, and diffusion. Our previous focus showed the impact of the laser fluence on the derivative and its use to obtain among others the external radiative recombination coefficient.

In this work we extend the possibility of our previous technique to separate surface and bulk contributions using the impact of the laser wavelength on the scaling of $1/\tau°$ through its impact on the spatial distribution of photogenerated carriers. The absorption coefficient of the material at the laser wavelength plays a crucial role in the scaling. We use theoretical computations as well as drift-diffusion simulation to analyze the range of applicability of our technique. We apply experimentally our methodology on perovskite samples with a pulsed laser of varying wavelength. The aim is to determine quantitatively the bulk, front and bottom surface non radiative recombination in order to separate these contributions. We show experimental validation of the scaling on perovskite material. We investigate both interfaces (bottom and front) by varying the illumination side and show how this technique allows for the quantitative comparison of non-radiative recombination at both interfaces. We discuss the experimental uncertainty coming from the experimental measurements.

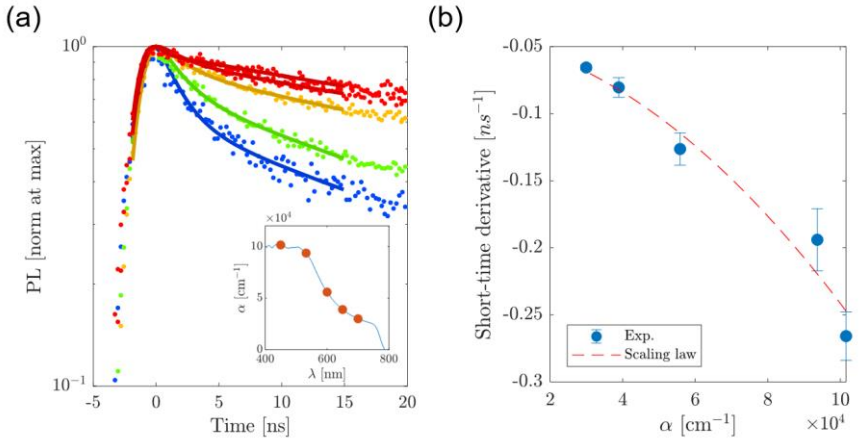

Figure 1: *TR-PL acquisition on perovskite absorber on glass at different wavelengths. (a) Zoom on the decays on the first 20ns. Points are experimental data, while the lines correspond to bi-exponential convoluted fits of the data points. (a-inset) Absorption coefficient as a function of wavelength, the x-data represent wavelengths used in this study. (b) Derivative at short time as a function of the absorption coefficient.*

1. Kirchartz, T., Márquez, J. A., Stolterfoht, M. & Unold, T. Photoluminescence-Based Characterization of Halide Perovskites for Photovoltaics. *Adv. Energy Mater.* 1904134 (2020) doi:10.1002/aenm.201904134.

2. Vidon, G. *et al.* Disentangling processes in transient photoluminescence experiments (TR-PL and TR-FLIM) on lead halide perovskite absorbers thanks to novel analysis of short time dynamics. *https://doi.org/10.1117/12.2576855* **11681**, 116810H (2021).