

(How well) Do *time-resolved* measurements reflect *steady-state* properties of Halide perovskites ?

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Many (mostly optical) measurements that provide the data, from which we extract, or on the basis of which we deduce physical properties of the Halide Perovskites (HaPs), use excitations of short time-duration, while the properties that we are interested in for all PV and most LEDs are those that are valid for steady-state conditions. While in some cases we do not have much of a choice (measuring sub- μs carrier lifetimes is not really practical with CW excitation, short laser pulses bombard the studied HaP layer with a very high concentration of supra-band gap photons, for a very short period of time, typically in the order of 0.1 – 1000 ps. For many other, earlier studied systems this approach has been very successful, but with the HaPs undesirable non-linear effects may occur under strong illumination, inducing local damage and maybe even evaporation of part of the material, that require to consider the title question.

Analysis of experimental results obtained using transient methods is often considered as equivalent to steady-state conditions, and it is assumed that the same recombination processes dominate in both types of excitations. However, it is quite clear that the physical asymmetry between the two experimental approaches requires one to scrutinize if the material properties, deduced from the transient measurements are indeed relevant for describing the behavior of the PV and LED system, operating under steady-state conditions.

The most common parameter that is extracted from transient measurements such as time-resolved photoluminescence, TRPL, is assumed to be the minority carrier lifetime, τ_{min} . Although τ_{min} can serve as an excellent probe for a semiconducting material's optoelectronic quality and for material optimization in the *same* laboratory, a wide variety of values exists in the literature, ranging from several ns to few μs . Moreover, usually τ_{min} can be (and often is) pulse intensity-dependent, making it even harder to compare results between laboratories, especially with the unfortunately usually poor experimental description of the pulsed excitation parameters in the literature.

Another important parameter that is often extracted from transient measurements such as THz conductivity and time-of-flight, TOF, (electrical) measurements is the electronic carrier mobility, μ . Here, again, a wide spread of values exists in the literature, ranging from 10^{-3} to 10^2 cm^2/Vs . Often these two parameters, deduced from transient measurements, are combined using the Einstein relation to calculate the steady state diffusion length of the charge carriers in the studied HaP, with no proper justification.

Even if the mobility-lifetime product values are obtained using steady-state methods such as Electron Beam-Induced Current, EBIC, or steady-state photocarrier grating, SSPCG, it is tempting to extract the steady-state mobility or lifetime from the experimentally derived mobility-lifetime product. However one would need to measure *independently* the mobility or the lifetime, under the *same excitation conditions* as those used in the steady-state method, to properly extract the other parameter. To our knowledge, although different laboratories measured the steady-state mobility, no one has measured (or deduced properly) the steady-state lifetime from combined steady-state photoconductivity, diffusion length and mobility data on the same layers under similar excitation parameter. This is probably due to experimental limitations and the need to have all the experimental methods at hand in the same laboratory, and does present an obvious challenge to the community.

Because of our use of EBIC and SSPCG we can compare steady state diffusion lengths with those derived from time-resolved measurements in other laboratories, and see in how far the values agree with one another. To our great relief, for polycrystalline films, prepared in different laboratories via different preparation routes, we find that the diffusion lengths measured by both methods are quite similar, and of comparable order of magnitude, ranging between 0.1 - 2 μm .

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