Observing charge trapping in metal halide perovskites using time-resolved photoluminescence to assess material quality for photodetector application

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Abstract:

Metal halide perovskite (MHP) materials have arisen in the past decade as a highly promising high-efficiency, low-cost technology for many semiconductor applications such as ionization radiation detection, photodetectors, and photovoltaics. Particularly, MHP photodetectors have demonstrated high detectivity with fast response times. The performance of MHP devices is highly dependent on the material quality. Time-resolved photoluminescence (TRPL) is frequently used to quickly assess the quality of metal halide perovskite (MHP). Often these photoluminescent transients can be misinterpreted in that decay lifetimes are directly assigned to be the charge carrier lifetime. Here using excitation intensity and temperature dependent TRPL measurements of both MAPbI3 and perovskites with mixed cations (MA+, FA+, Cs+) and anions (I-, Br-), we observe the strong influence of charge carrier trapping on the TRPL curves, which is strongly dependent on both film quality and experimental conditions. Films with higher trap densities measured by thermal admittance spectroscopy can actually demonstrate longer TRPL lifetimes, suggesting that longer PL decay lifetimes do not necessarily equate to perovskite films with improved optoelectronic properties. We adapt a model of a charge trapping, detrapping, and recombination processes in semiconductors to demonstrate the strong influence on the TRPL transients made by trap state distributions and capture mechanisms, which in the presence of very strong trapping manifest as strict biexponential decay transients. To more effectively utilize TRPL as an assessment of perovskite film quality, we suggest the decay measurements be presented with the full context of experimental conditions and other techniques such as steady-state PL intensity and trap density measurements, to ensure the proper conclusions are reached regarding charge carrier recombination and trapping within the perovskite thin films. Better understanding of how to properly interpret the TRPL transients of MHP materials provides the ability to quickly assess material quality and thus their potential application as a photodetector.