The Influence of Transport Layers on Bulk Recombination in Perovskites

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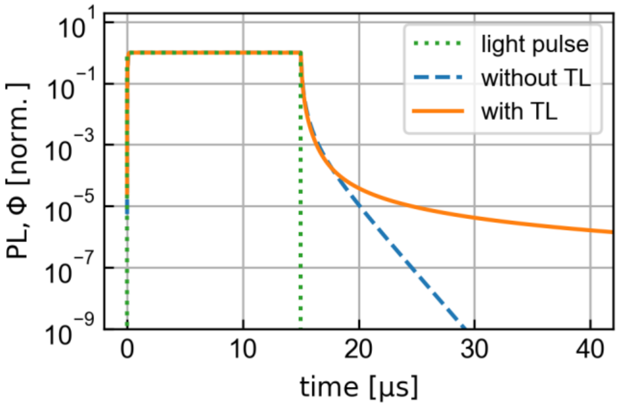
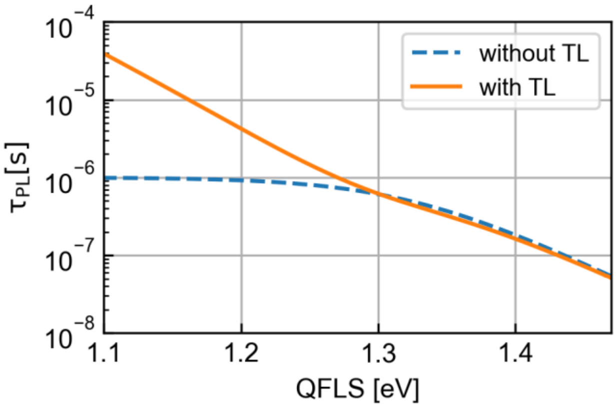
Introduction

The effective lifetime is the holy grail of device characterization in silicon solar cells. In the world of perovskites, the level of understanding to fully utilize this concept is yet to be reached.

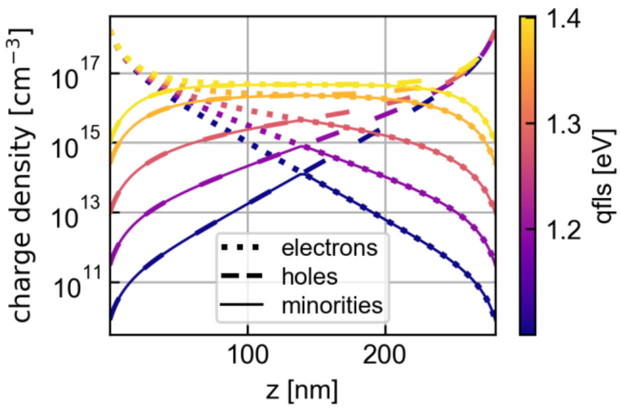
Results

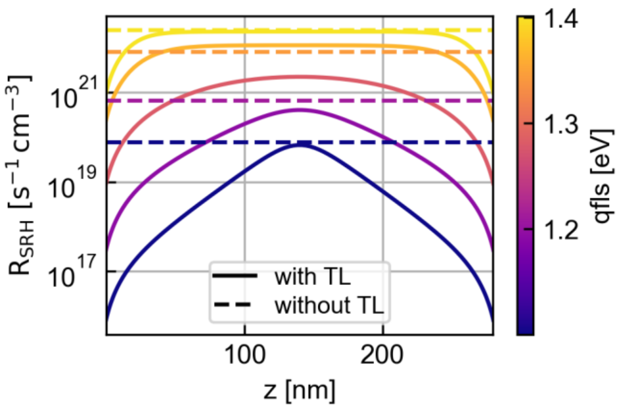
We show with Quokka 3 simulations that a PL-signal decays significantly faster in a pure perovskite (without transport layer (TL)) when compared to a system with TLs. This effect shows in the SRH-limited regime, below a quasi-Fermi level split (QFLS) of $\approx 1.28\ eV$, and leads to a drastically improved PL-decay time.



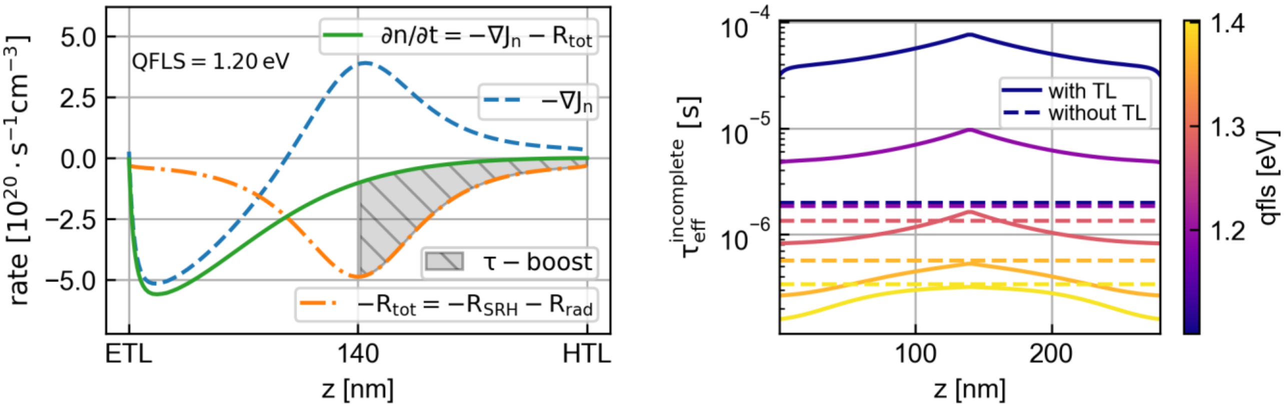


With TLs, equilibration of Fermi-levels throughout the system induces a charge carrier gradient, making electrons minorities at the HTL and vice versa. The high ratio between majorities and minorities reduces the absolute SRH-recombination rate close to the transport layers with respect to the case without TL. The difference grows as the system relaxes towards its dark state (low QFLS), where the carrier gradients are the largest.

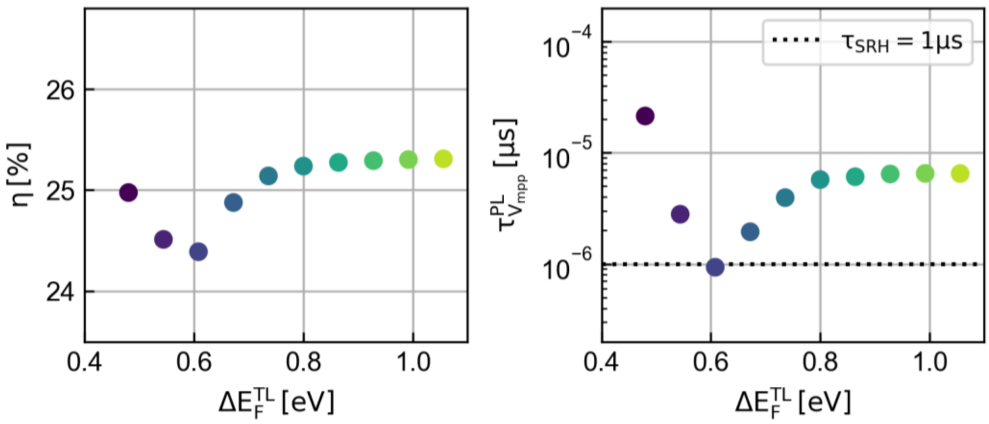




Upon inspecting the charge carrier dynamics with TLs in more detail, the high relevance of transport of carriers through the absorber becomes apparent. The orange curve shows the depth dependent recombination at $QFLS = 1.20\ eV$. Its impact on the charge carrier dynamics (depicted by the continuity equation, green) is significantly counteracted by the transport of electrons from the ETL to the HTL (blue curve) and vice versa (not shown). This transport effectively refuels the minority carrier concentration by depleting the majority carrier concentration from the opposite end of the device stack. Only by incorporating this transport effect do we obtain the effective lifetime that correctly reflects the minority charge carrier decay and therewith the PL-decay time. The value of the effective minority lifetime is strongly boosted by the transport effect, showcasing (i) that the effective lifetime is not solely characteristic to recombination properties and (ii) that effective TLs can induce a tolerance to bulk defects in perovskites.



The boost in effective lifetime by this transport effect also influences full cell performance. We show this by varying the offset between Fermi-level of the ETL/HTL and the intrinsic perovskite ($\Delta E_F^{TL} = E_F^{ETL} - E_F^{pero} = E_F^{pero} - E_F^{HTL}$). This variation tunes the severity of the carrier gradient at the QFLS relating to the maximum power point under AM1.5G operation. The clear correlation between the effective lifetime extracted at $QFLS_{MPP}^{AM1.5G}$ and the efficiency in cell simulations proves the relevance of our results for device performance.



Conclusion

The intrinsic nature of perovskite makes is susceptible to carrier accumulation reaching far into the bulk. This affects the charge carrier profiles and therewith the recombination properties. On the one hand, this obscures the interpretation of the effective lifetime as a figure of merit solely determined by recombination activity. On the other hand, the transport effect also leads to a defect tolerance in perovskites that influences the performance of the full device.