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Impact of Interface Recombination on Time Resolved Photoluminescence Decays (TRPL) in CdTe solar cells (Numerical Simulation Analysis)

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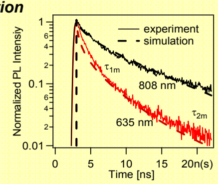
Abstract

Using Sentaurus Device Software, we analyze how bulk and interface recombination affect time-resolved photoluminescence (TRPL) decays in CdTe solar cells. This modeling analysis could improve the interpretation of TRPL data and increase the possibility of rapid defect characterization in thin-film solar cells. By illuminating the samples with photons of two different wavelengths, we try to deduce the spatial origin of the dominant recombination loss. Shorter-wavelength photons are more affected by the interface recombination and drift compared to the longer ones. Using the two-wavelength TRPL characterization method, it may be possible to determine whether a specific change in deposition process has affected the properties of interface or the bulk of the absorber.

Introduction

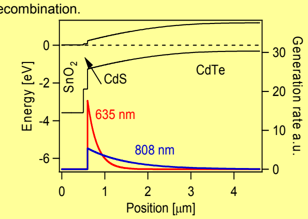
- TRPL is a contactless and quick method to determine the carrier lifetime in CdTe absorbers.
- The decay shape is affected by complex carrier dynamics, including drift, diffusion, and recombination.
- The bi-exponential nature of the decay is pronounced for λ = 635 nm.
- For λ = 635 nm, more carriers are generated close to the junction where the electric field is the strongest, and many of them are separated quickly.
- For λ = 808 nm, the difference between τ_{1m} and τ_{2m} is much smaller, and the decay appears more single-exponential.



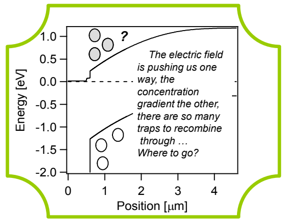
Experimental and numerically simulated TRPL decay for two excitation wavelengths. The decay is measured at 840 nm with excitation through junction. The simulations match the experimental data well.

Light absorption in CdTe devices

- For typical doping levels of CdTe cells, 10^{13} cm^{-3} to 10^{15} cm^{-3}, most of the light is absorbed within the depletion region.
- The junction field plays a significant role in the decay.
- The 635 nm illumination generates 3.3 times more carriers next to the CdS/CdTe interface.
- The decay generated by 635 nm illumination is expected to be more influenced by drift and interface recombination.

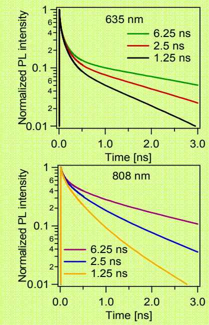


Simulated equilibrium band diagram and generation profiles for λ = 635 nm and 808 nm

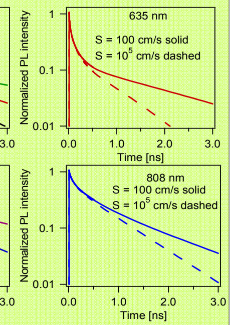


Interface and bulk recombination on TRPL decay

- The slower part of the bi-exponential decay, τ_{2m}, is more affected by the recombination in CdTe.
- The variation in τ_{2m} for both wavelengths 635 nm and 808 nm is comparable, because the defect density is assumed to be uniform throughout the absorber.
- In a case of 635 nm illumination, more carriers are generated next to the heterointerface, and the decay is significantly more affected by the recombination at the interface.
- Interface recombination has a stronger influence on the slower part of the decay, where τ_{2m} is deduced.



Simulated carrier decays for τ_i = 1.25 ns, 2.5 ns, and 6.25 ns, for λ = 635 nm and λ = 808 nm

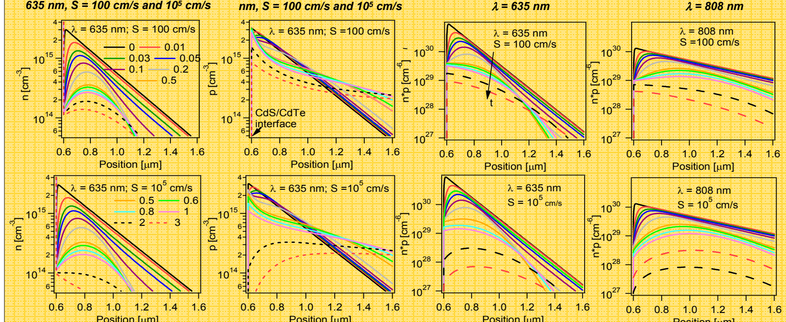


Simulated decays for S = 100 cm/s, S = 10^5 cm/s, for λ = 635 nm and 808 nm

Where do the carriers go?

- The maximum electron density shifts away from the interface in the first 0.5 ns, and then slowly toward the interface.
- For low S, the maximum hole density remains close to the interface.
- The recombination at the interface reduces hole density during the slower part of the decay.
- The electron and hole densities after 808 nm excitation are more widely distributed.

Calculated electron density for λ = 635 nm, S = 100 cm/s and 10^5 cm/s | *Calculated hole density for λ = 635 nm, S = 100 cm/s and 10^5 cm/s* | *Calculated n*p product λ = 635 nm* | *Calculated n*p product λ = 808 nm*

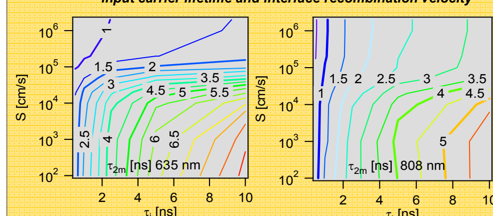


The different curves correspond to times: 0, 10 ps, 30 ps, 50 ps, 0.1 ns, 0.2 ns, 0.5 ns, 0.6 ns, 0.8 ns, 1 ns, 2 ns, and 3 ns.

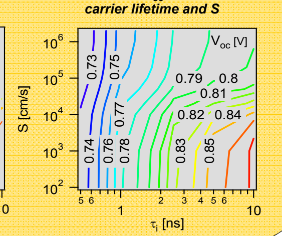
The decay slope and device properties

- Both interface and bulk recombination accelerate the carrier decay.
- In a case of 635 nm illumination, the decays are affected by interface recombination stronger than for the longer wavelengths.
- If S < 10^4 cm/s, its impact on the TRPL decay becomes significant for τ_{2m} > 5 ns.
- When S is low, τ_{2m} for 635 nm excitation is higher than τ_{2m} for 808 nm excitation and for S >10^5 cm/s the $\tau_{2m(808nm)} > \tau_{2m(635nm)}$.
- The V_{oc} can be predicted from the decay slope.

Contour plots of simulated decay times (τ_{2m}) as a function of input carrier lifetime and interface recombination velocity



Contour plot for V_{oc} dependence on carrier lifetime and S



Conclusions

Carrier decays after a short-light pulse illumination have been simulated to enhance the interpretation of TRPL measurements. The TRPL decays in thin-film devices are influenced by the carrier dynamics, including drift, diffusion, interface and bulk recombination. We have found that at 635 nm illumination, the decay is affected more by the interface properties compared with the 808 nm decay. We have also calculated the n*p product at different moments during the decay to show that the interface recombination affects the second, slower part of the decay. By comparing the decays at different wavelengths, it may be possible to estimate whether the dominant recombination is located at the interface or in the bulk.

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