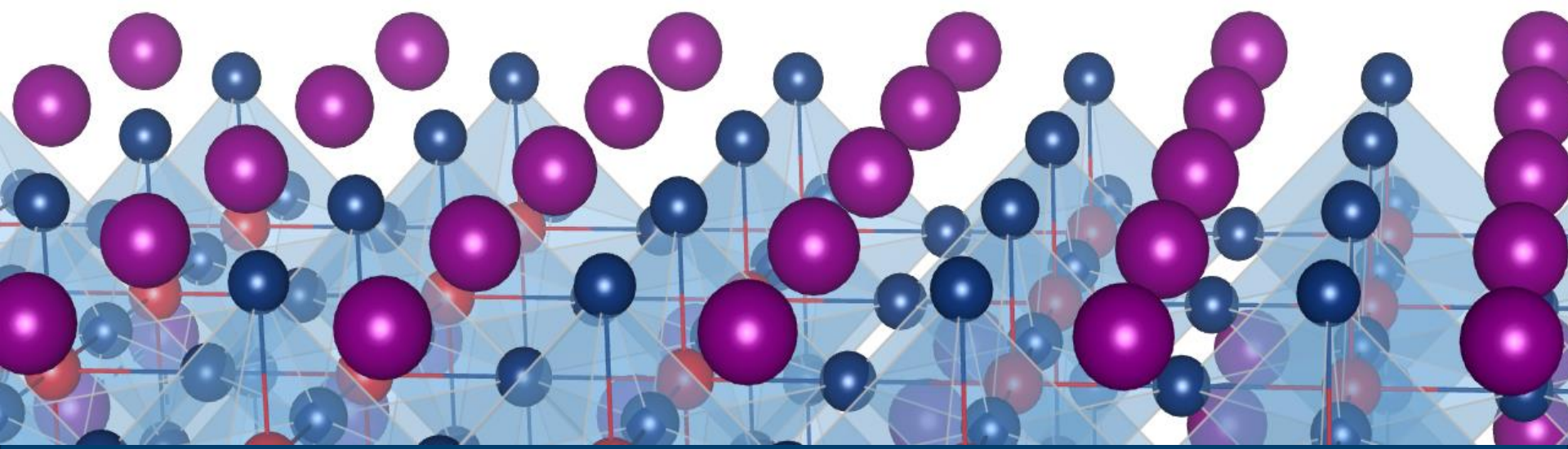

CHARGE CARRIER LIFETIMES IN LEAD-HALIDE PEROVSKITE SOLAR CELLS

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[2]NST and CENIDE, Universität Duisburg-Essen

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

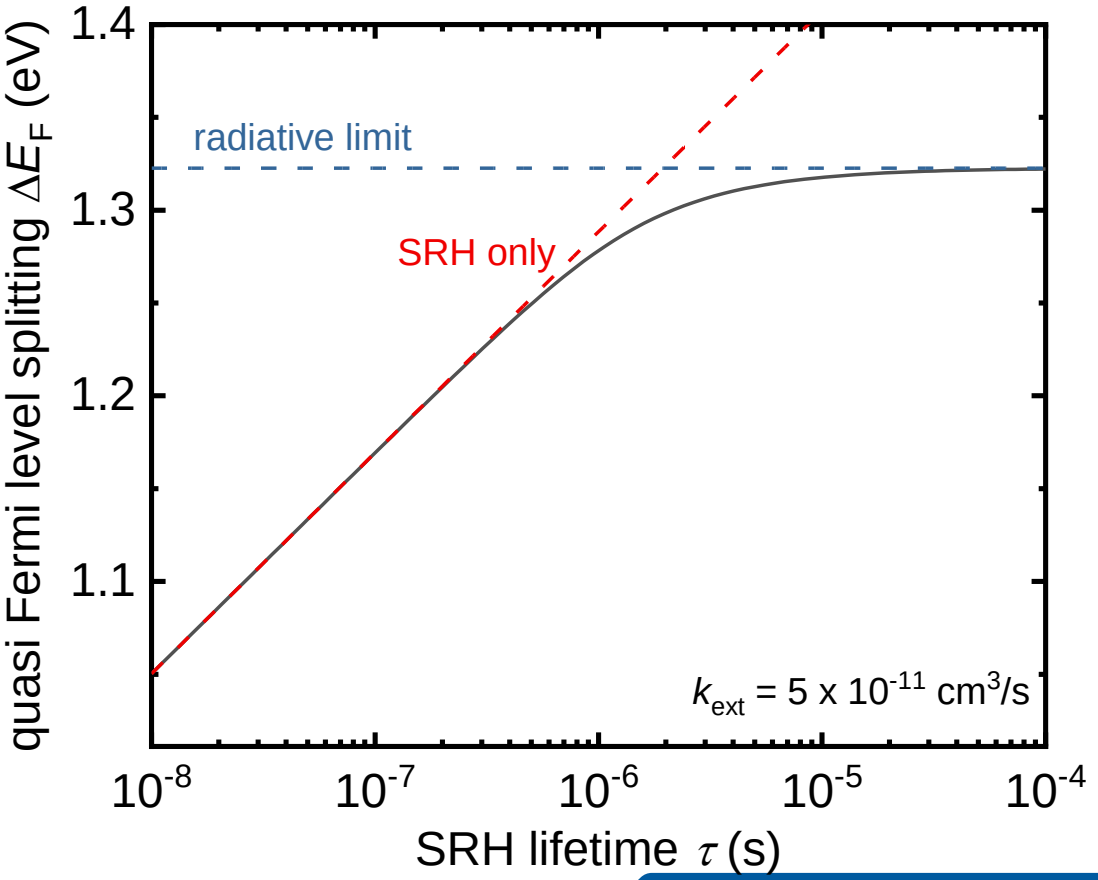
JÜLICH Forschungszentrum

Why are charge carrier lifetimes relevant?

@ open circuit

$$G = kn^2 + \frac{n}{\tau}$$

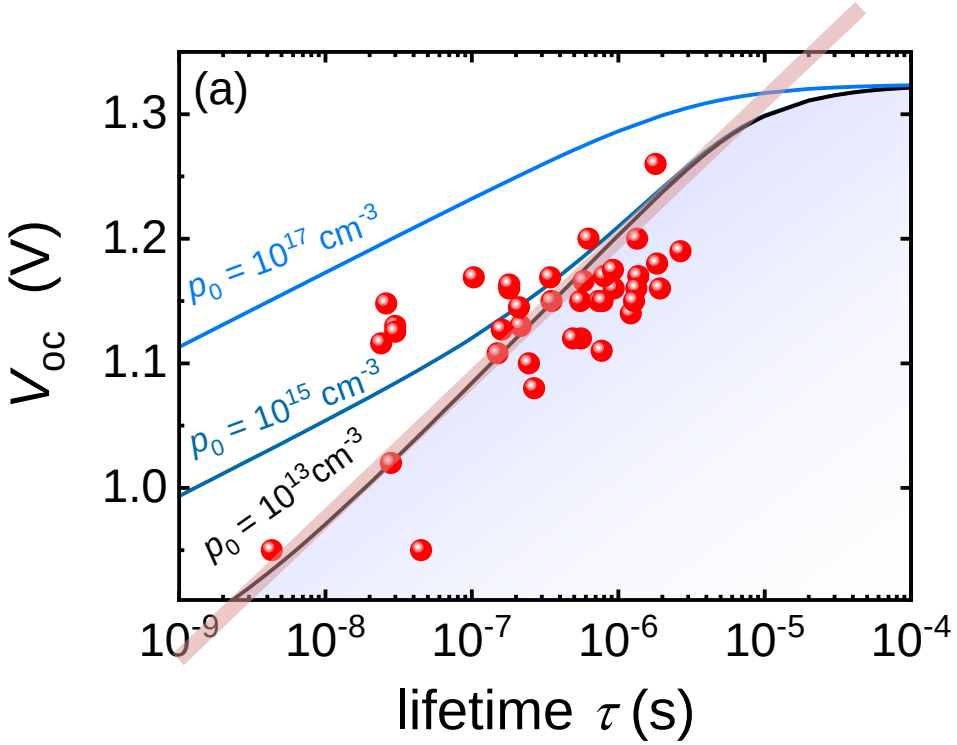
$$\Delta E_F = kT \ln\left(\frac{n^2}{n_i^2}\right)$$



Kirchartz et al. Adv. Energy Mater. 2020

Why things are more difficult in reality than in theory?

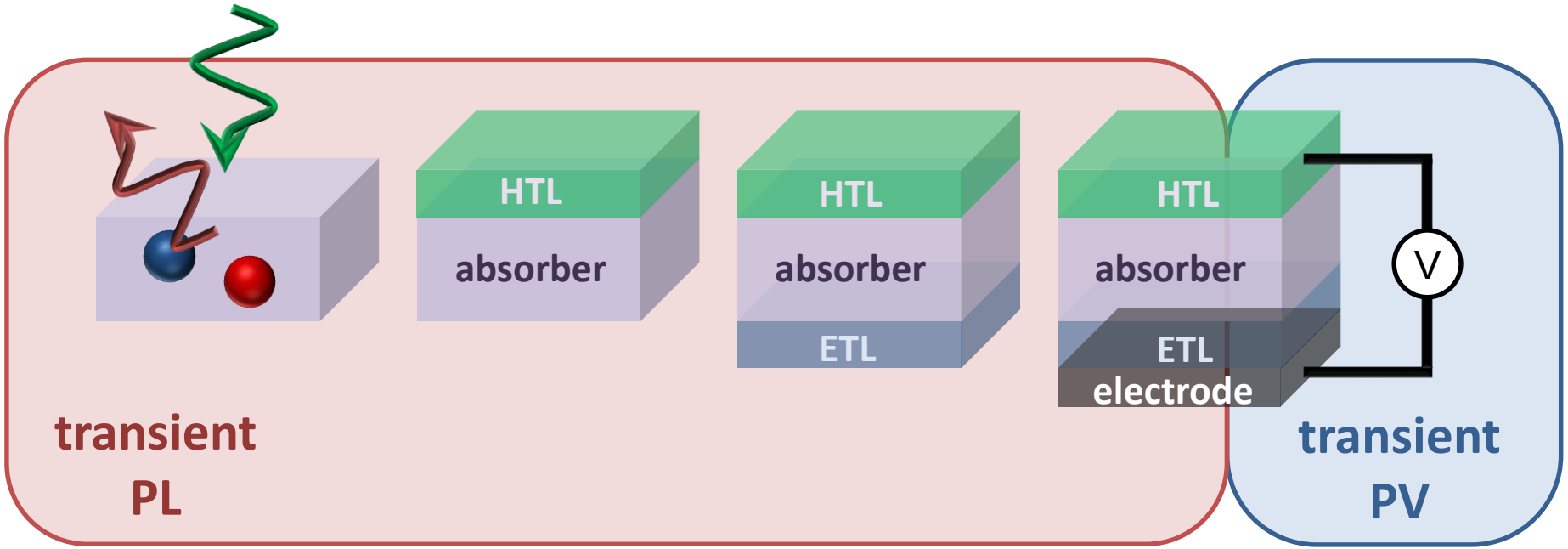
$$\Delta E_{\mathrm{F}} = 2kT \ln\left(\frac{G\tau}{n_{\mathrm{i}}}\right)$$



Kirchartz et al. Adv. Energy Mater. 2020

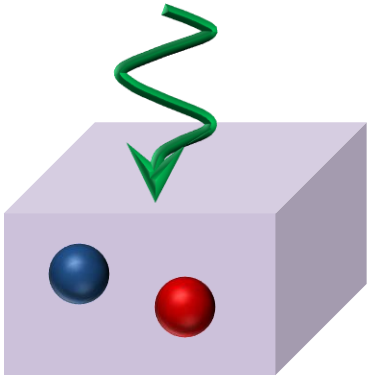
How can transient methods help…

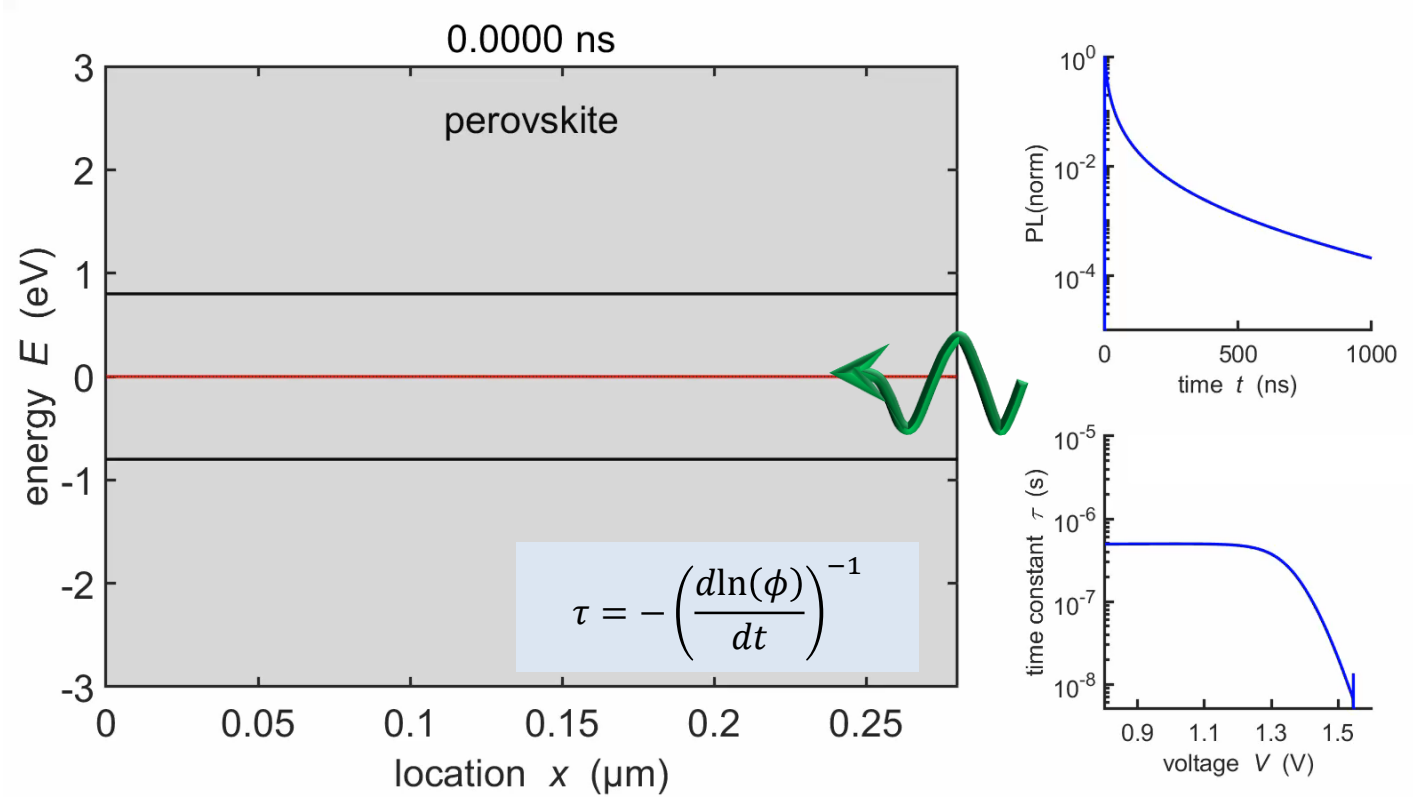
…to study recombination and voltage losses



Transient Photoluminescence

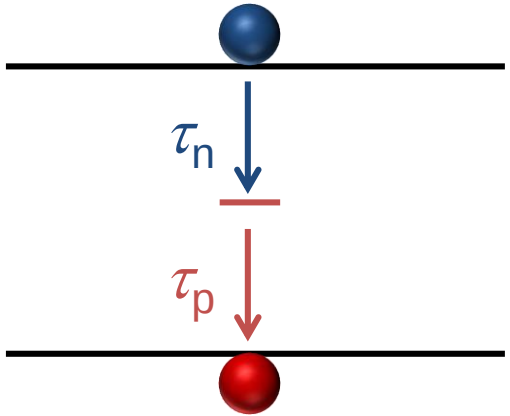
Layer on glass - Video





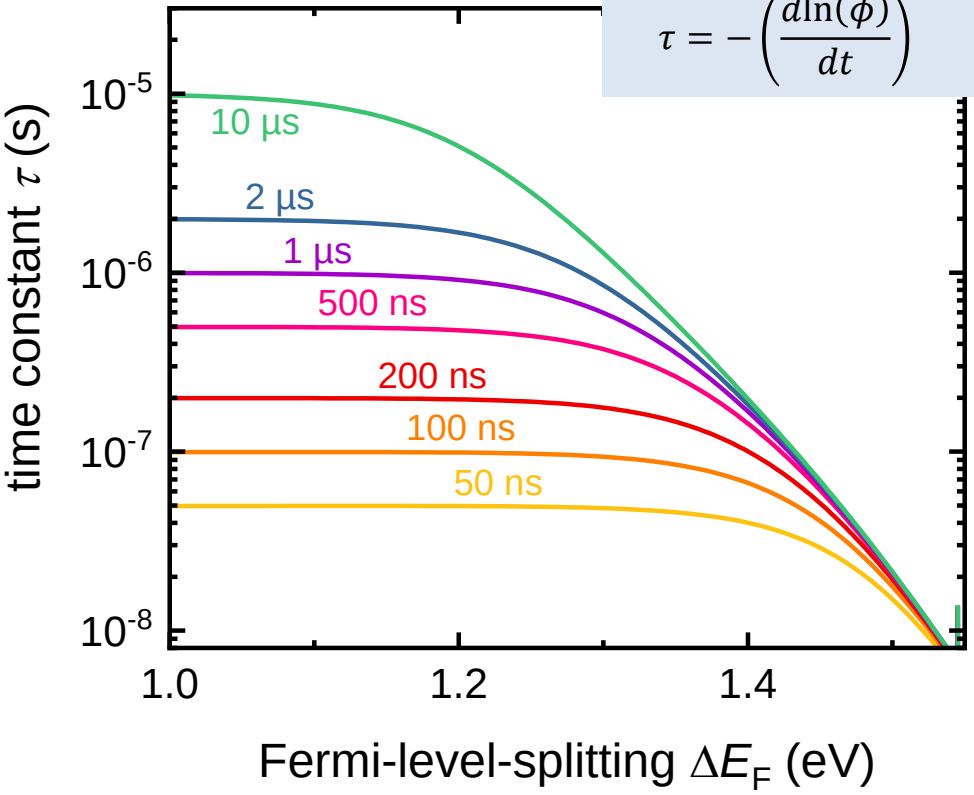
Transient Photoluminescence

Layer on glass – Bulk recombination



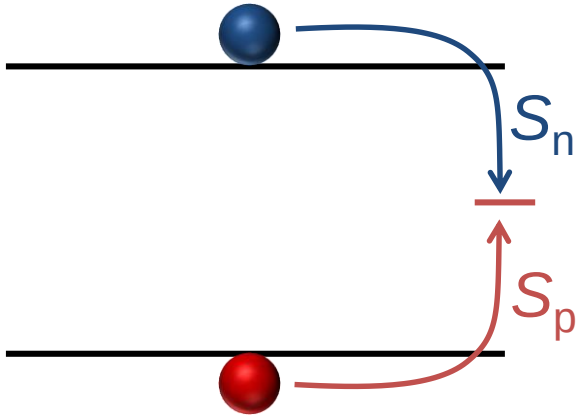
$$\frac{dn}{dt} = -knp - \frac{np}{\tau_p n + \tau_n p} - C(np^2 + n^2 p)$$

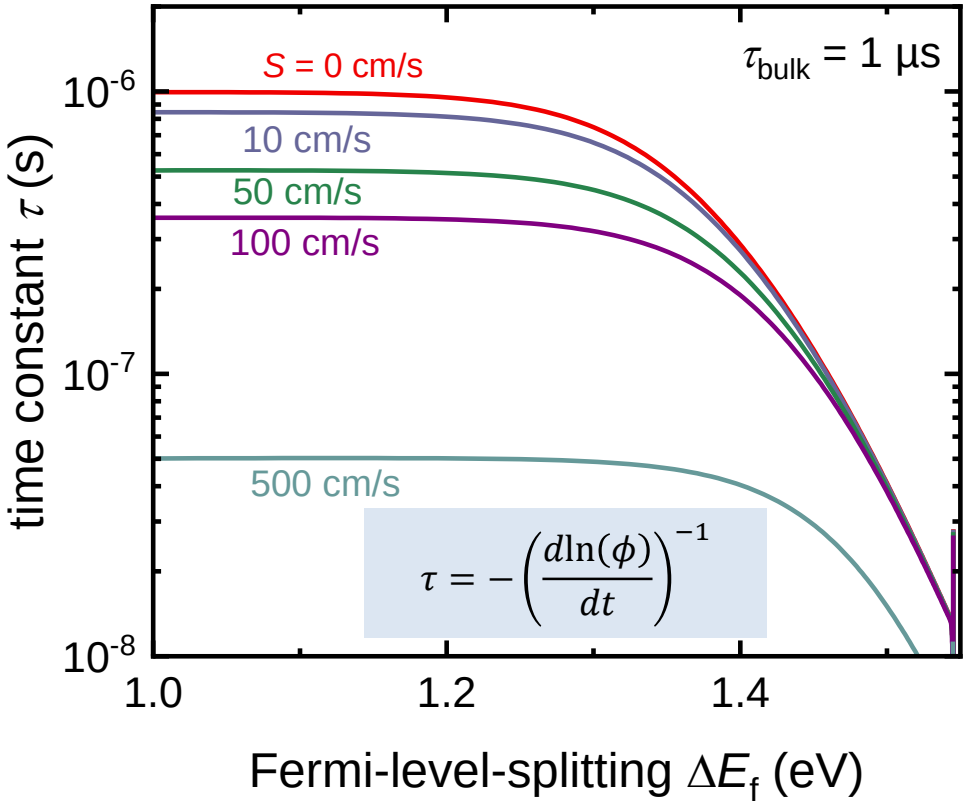
$$\tau = -\left(\frac{d\ln(\phi)}{dt}\right)^{-1}$$



Transient Photoluminescence

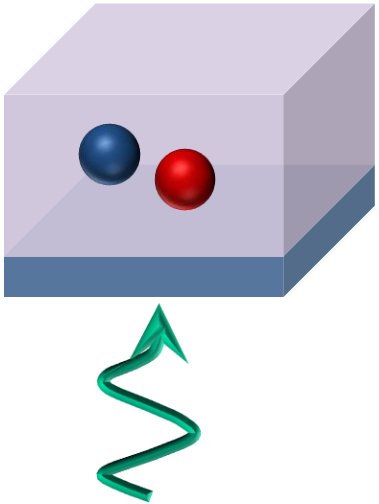
Layer on glass – Surface recombination

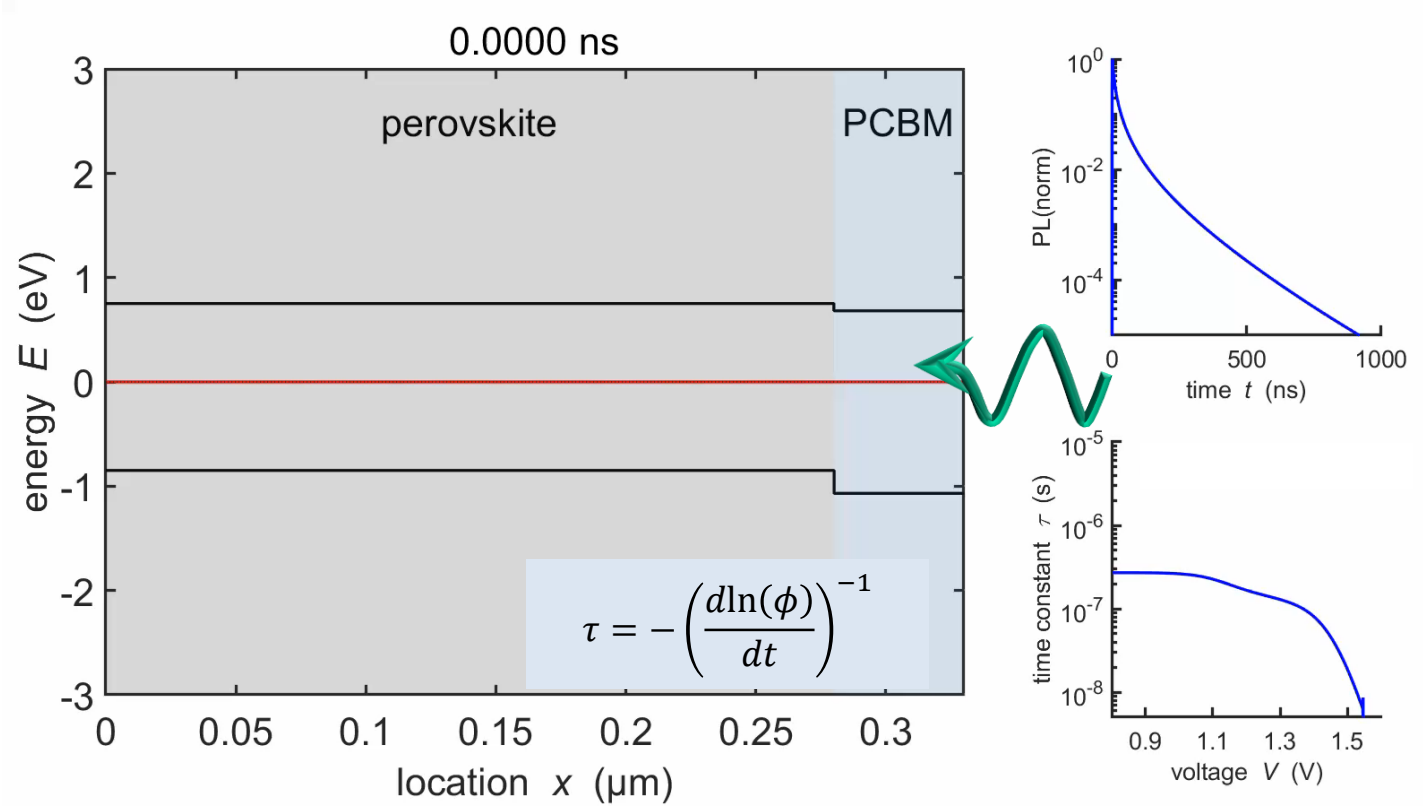




Charge transfer and recombination

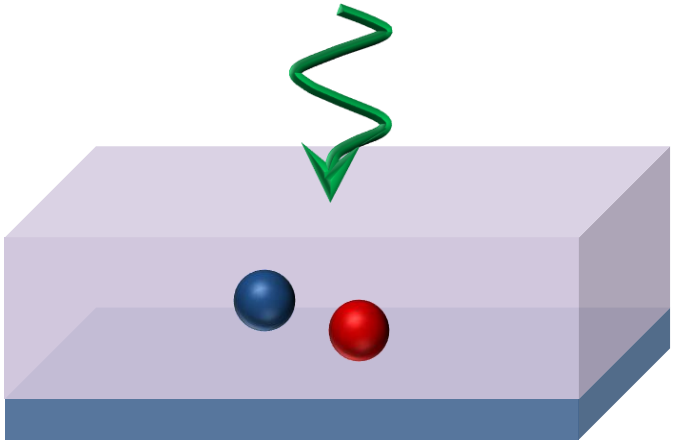
General idea

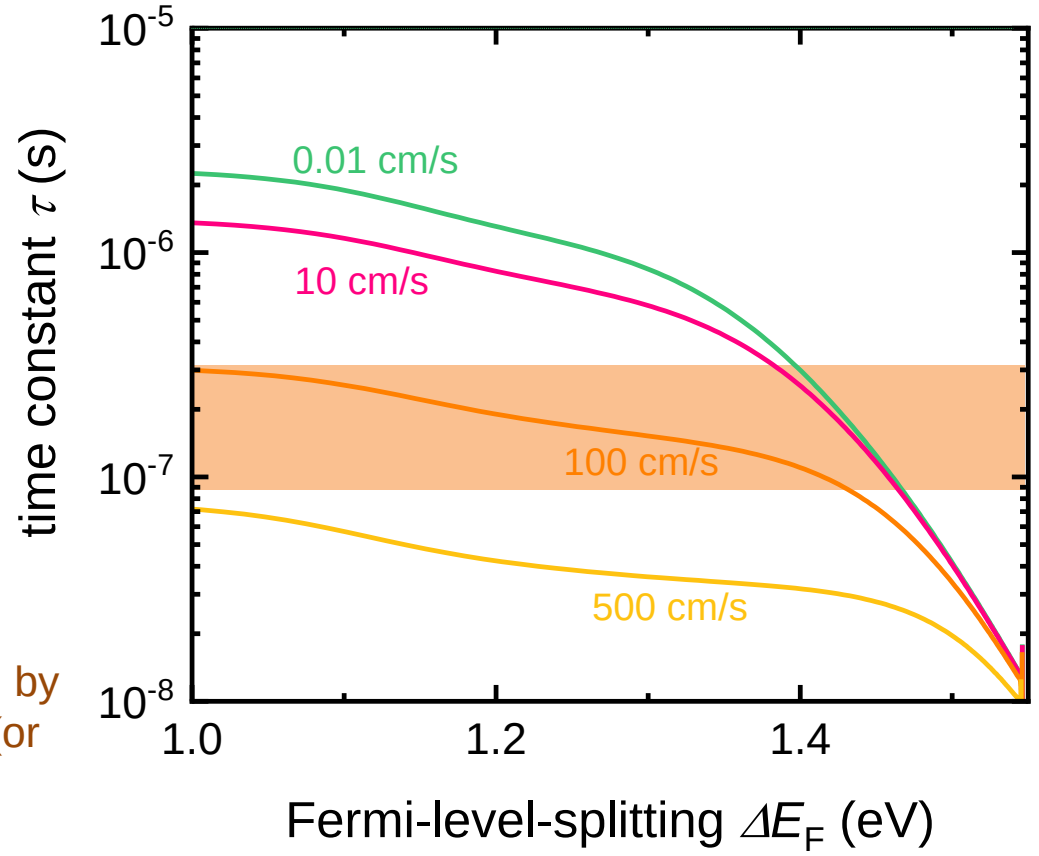




Charge transfer and recombination

Data

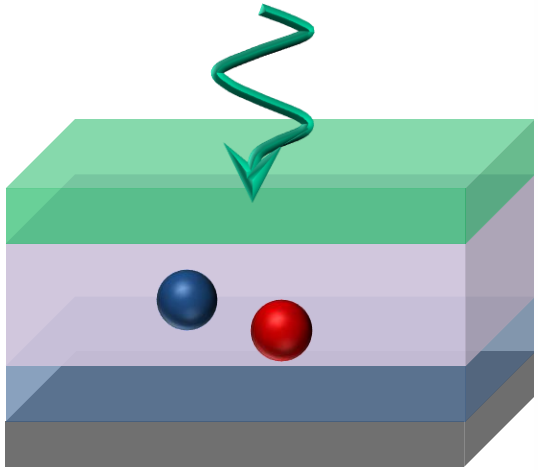




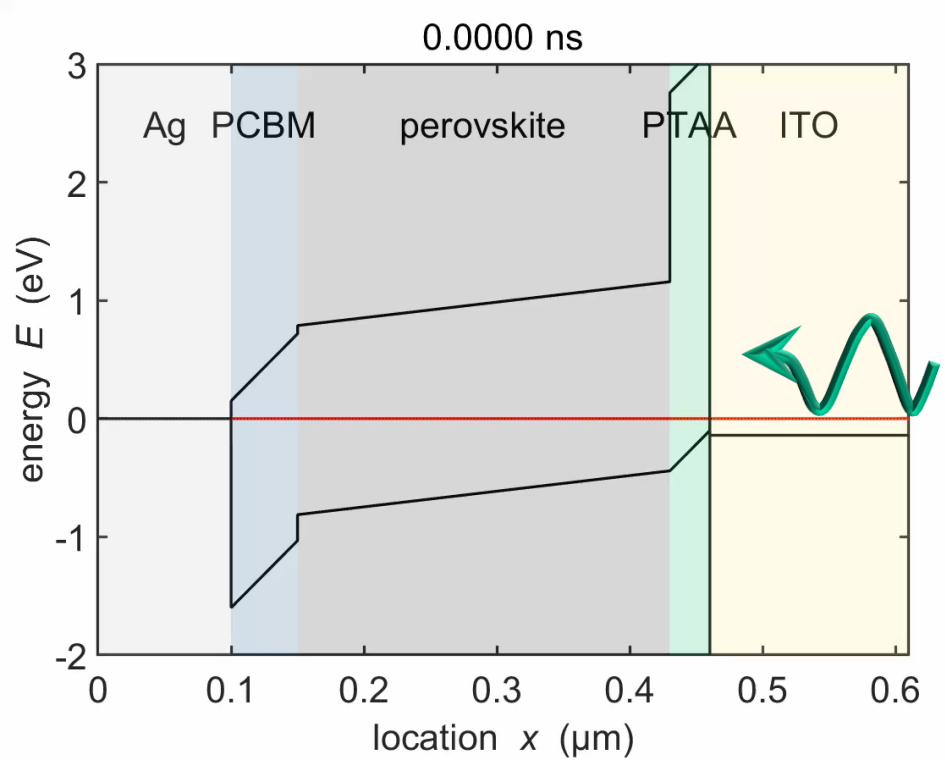
Time constant affected by band offsets and ETL (or HTL) thickness

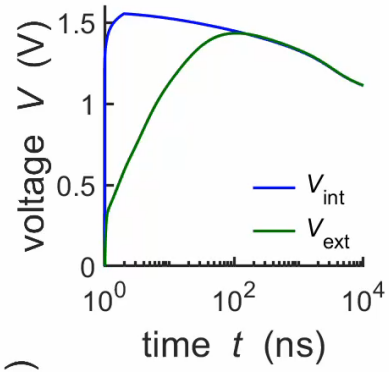
Transient Photoluminescence – Solar Cell

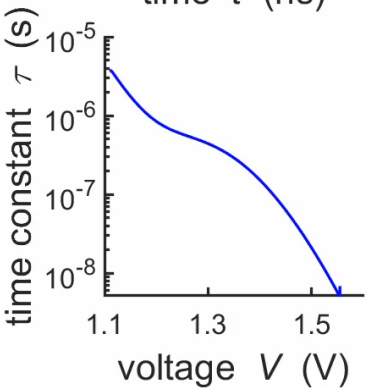
Video



$$-\frac{dn}{dt} = kn^2 + \frac{n}{\tau} + \frac{C}{qd}\frac{dV}{dt}$$

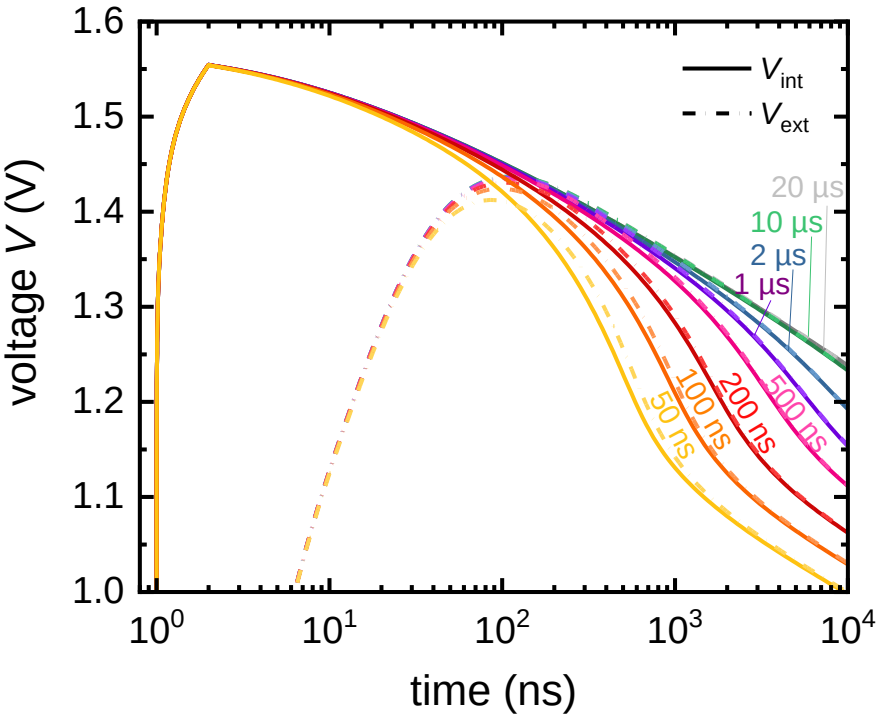


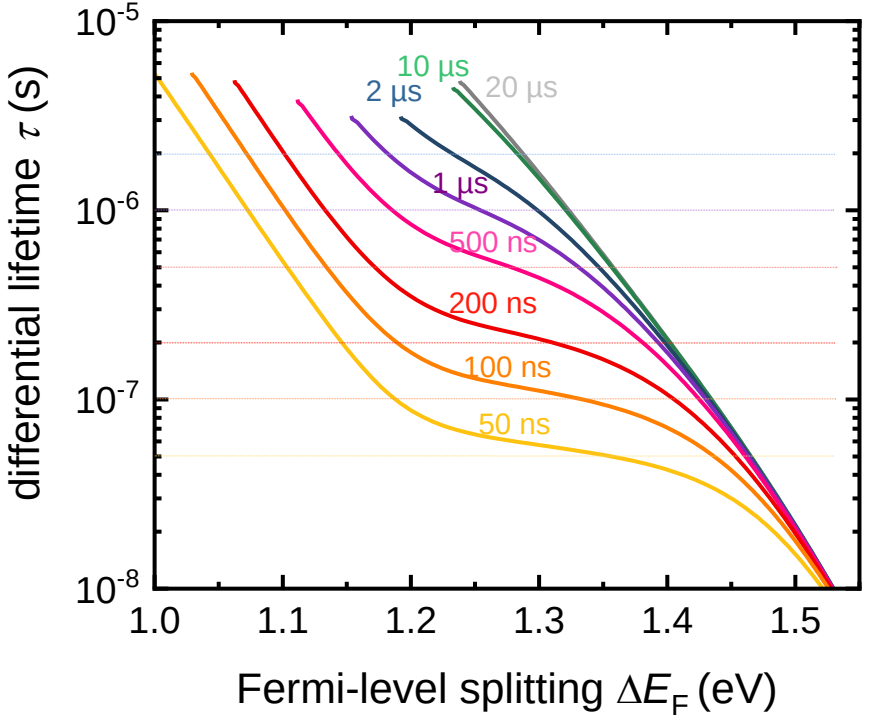




Large signal lifetime from TPL (wo bias)

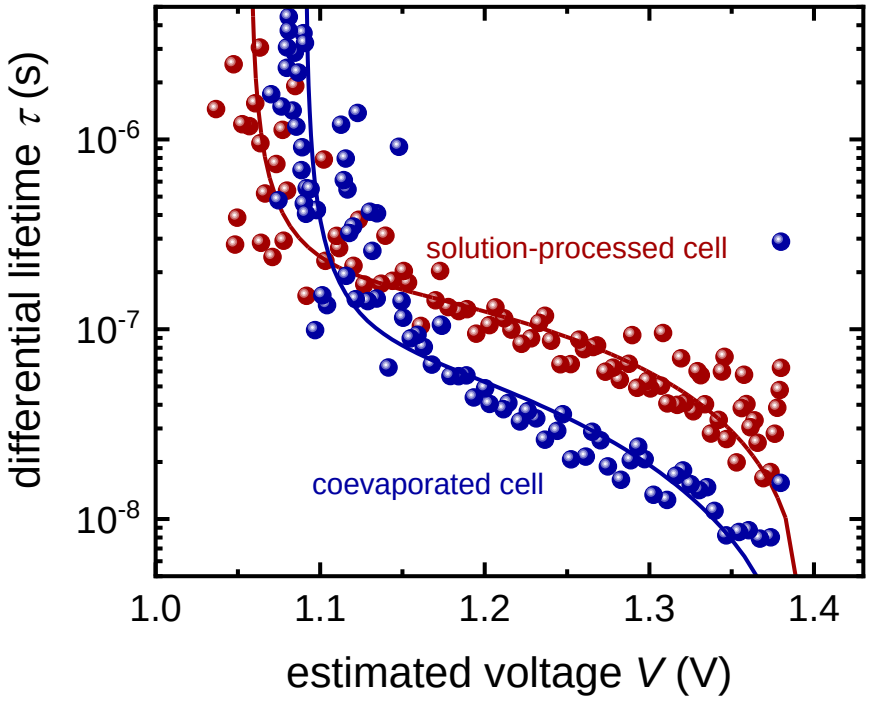
Bulk lifetime variation, *S*=0.1 cm/s, laser fluence 10 µJ/cm²

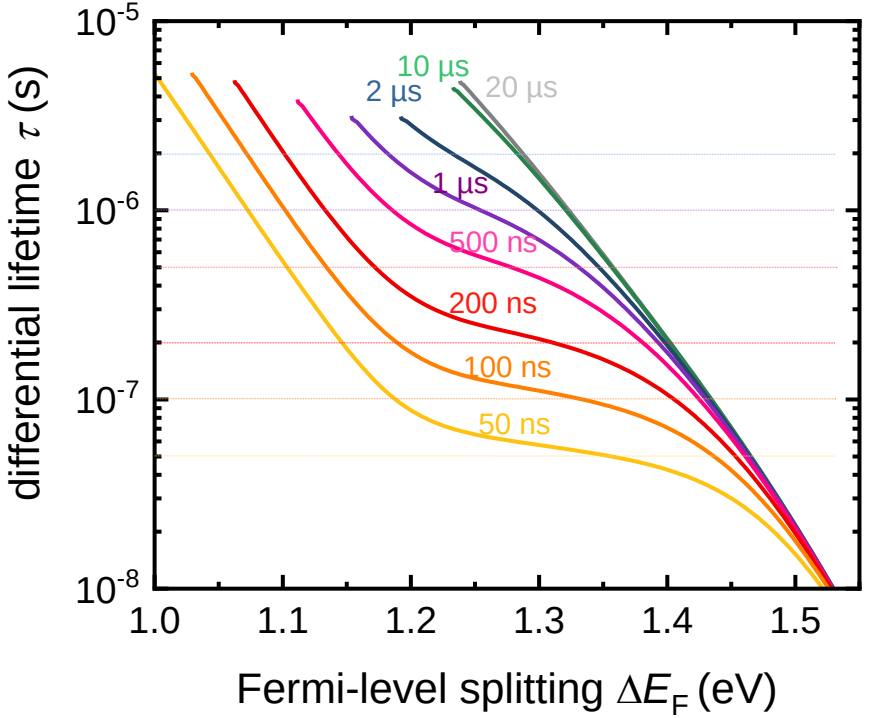




Large signal lifetime from TPL (wo bias)

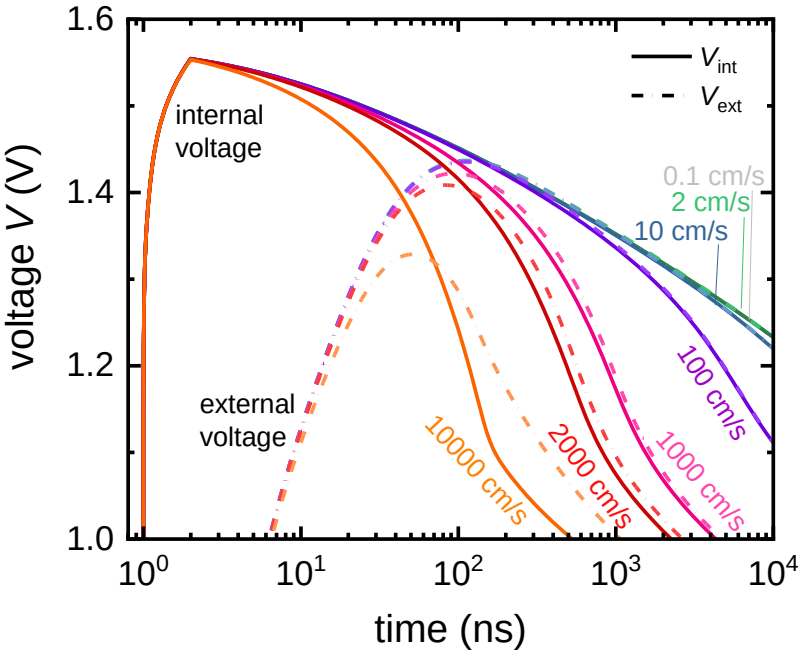
Experiment vs. Simulation

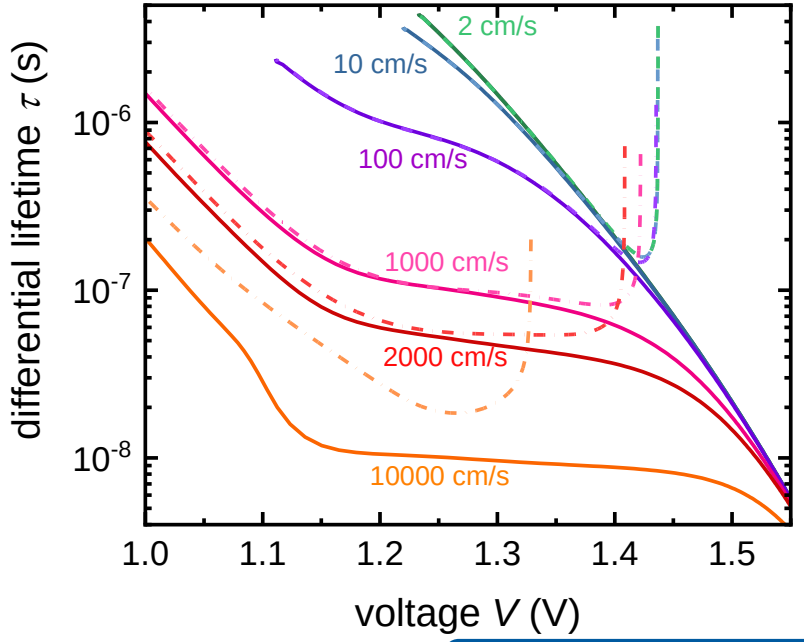




Large signal lifetime from TPL (wo bias)

Bulk lifetime 10 µs, laser fluence 10 µJ/cm²



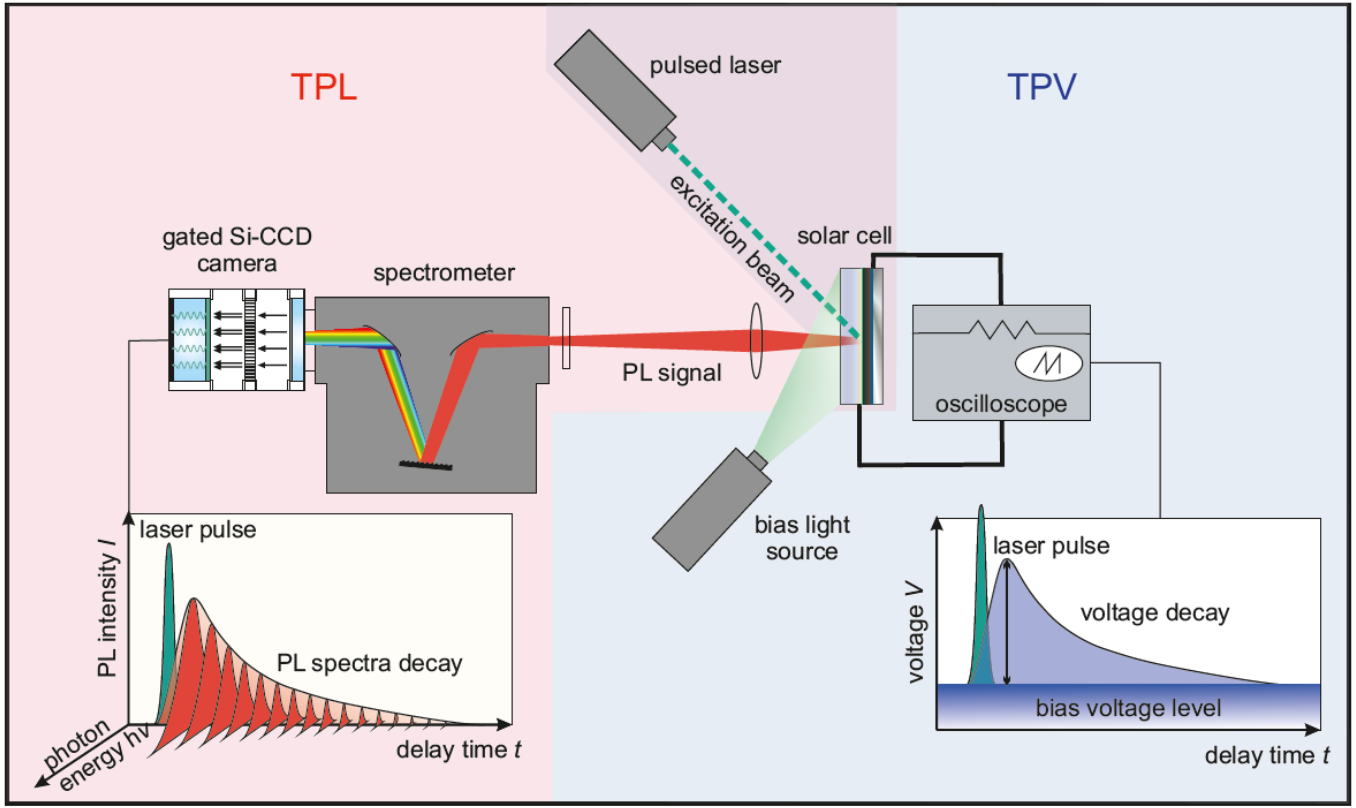


Transient Photoluminescence (TPL)

measures the luminescence decay

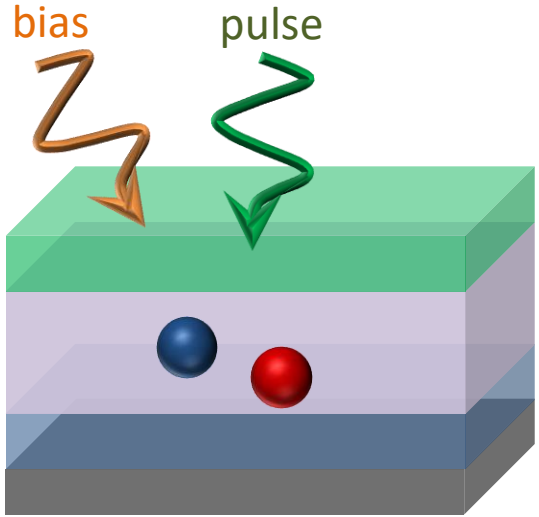
Transient Photovoltage (TPV)

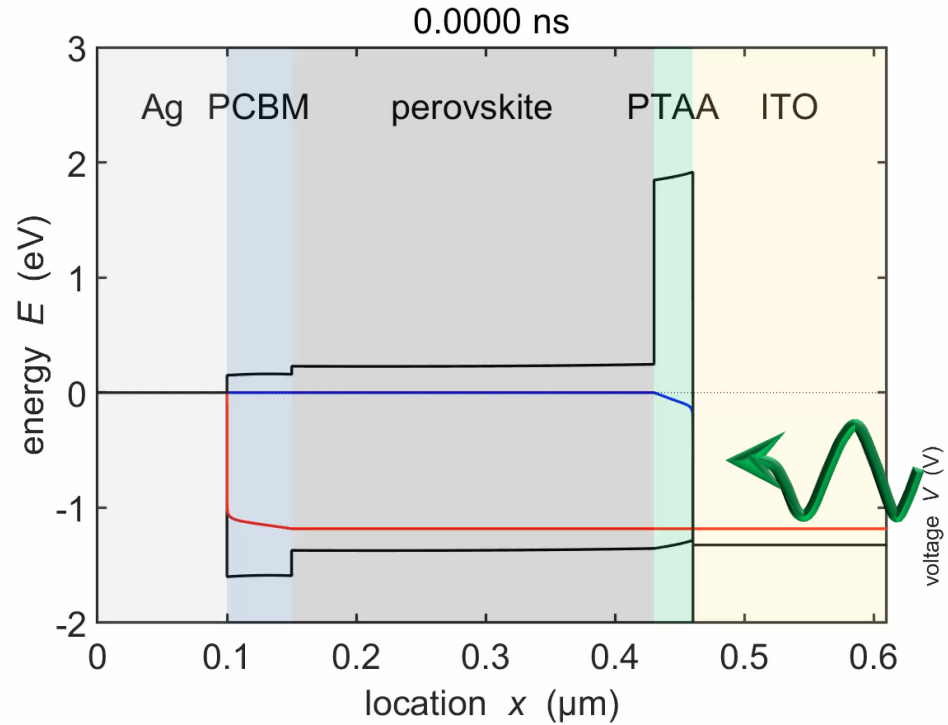
measures the decay of an external voltage

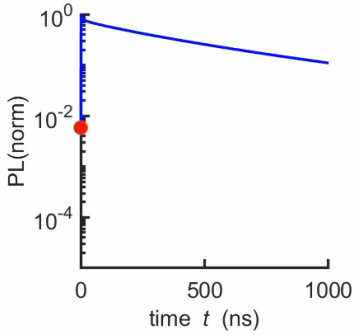


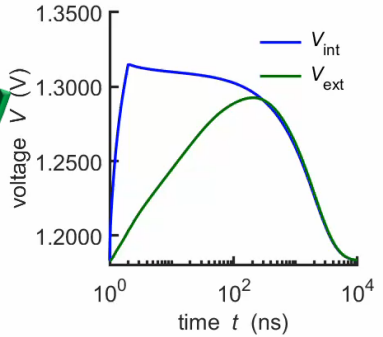
Transients with bias light

Video TPV vs. TPL



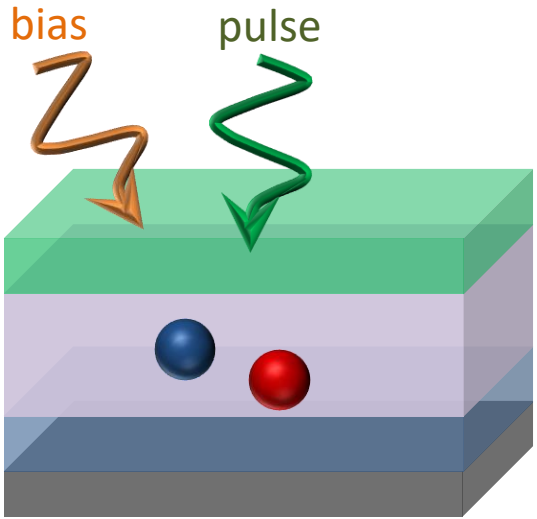




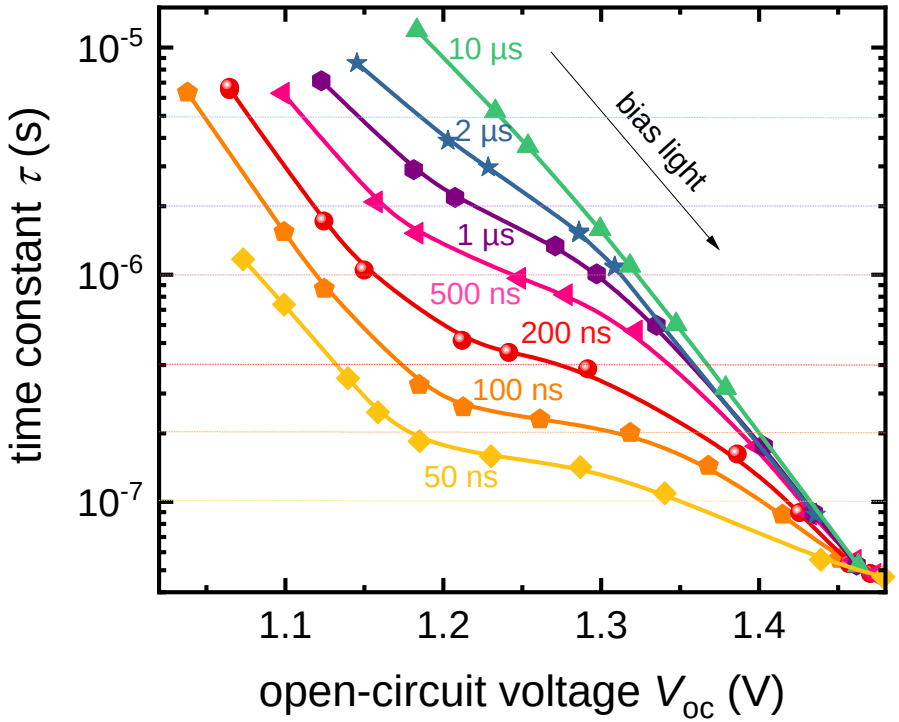


TPV Decay Constants

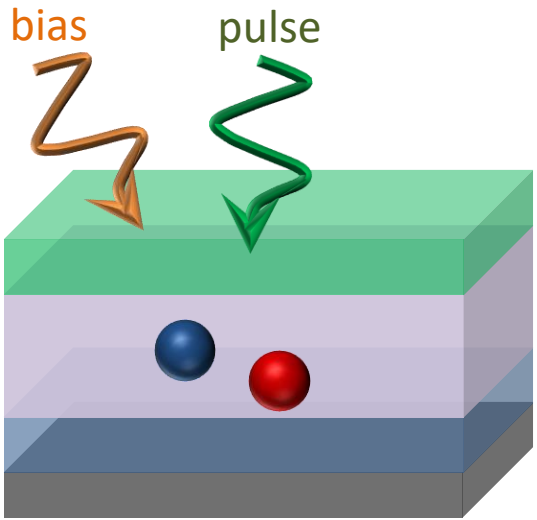
Small signal transients

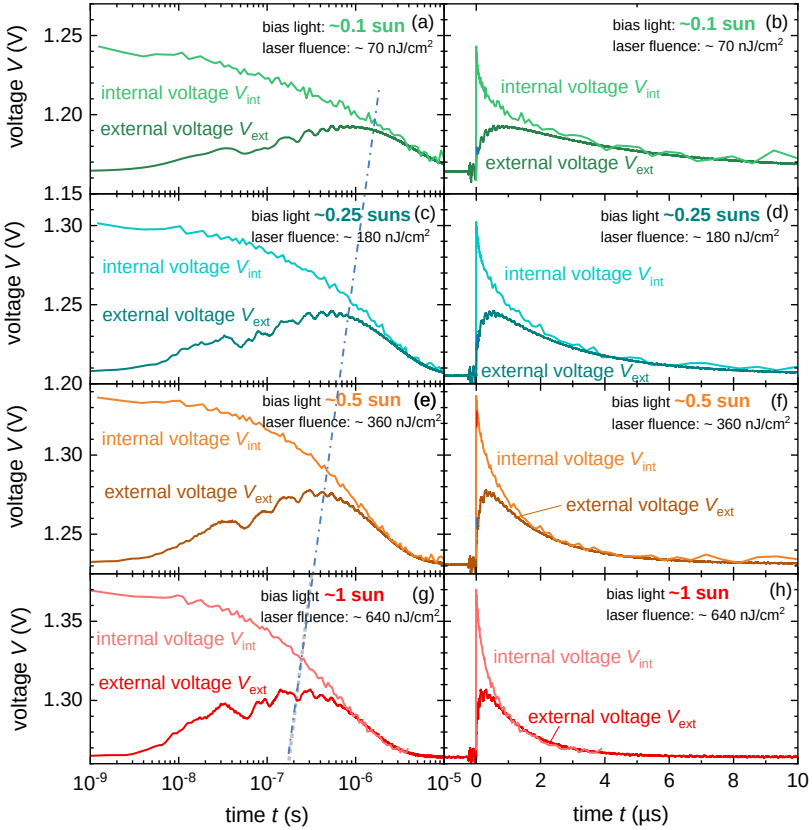


$$-\frac{dn}{dt} = kn^2 + \frac{n}{\tau} + \frac{C}{qd}\frac{dV}{dt} - G_{\text{bias}}$$



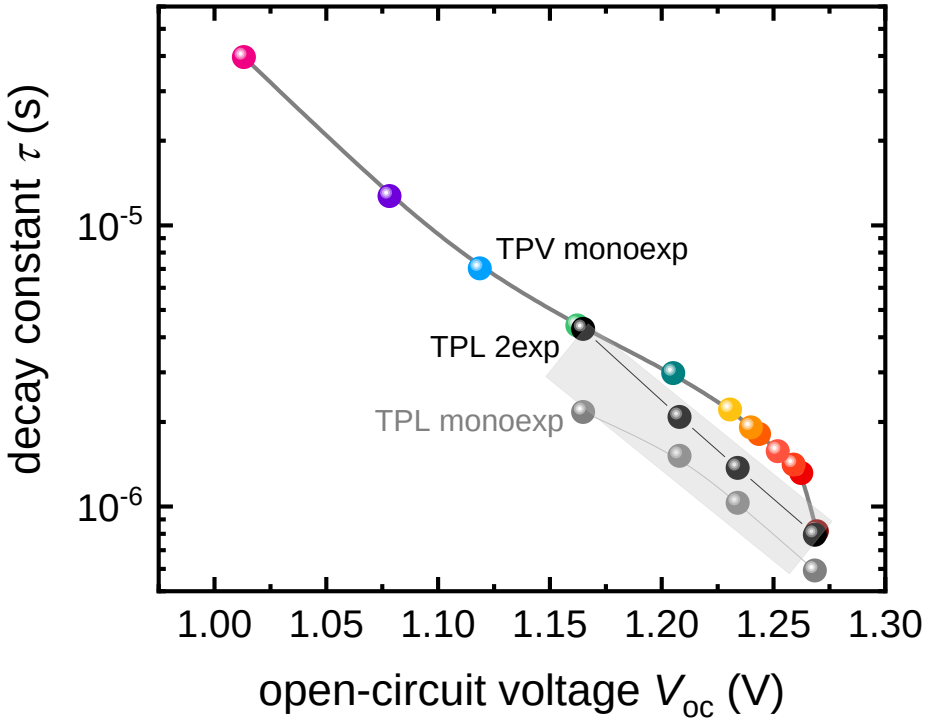
Experimental data – internal vs. external voltage

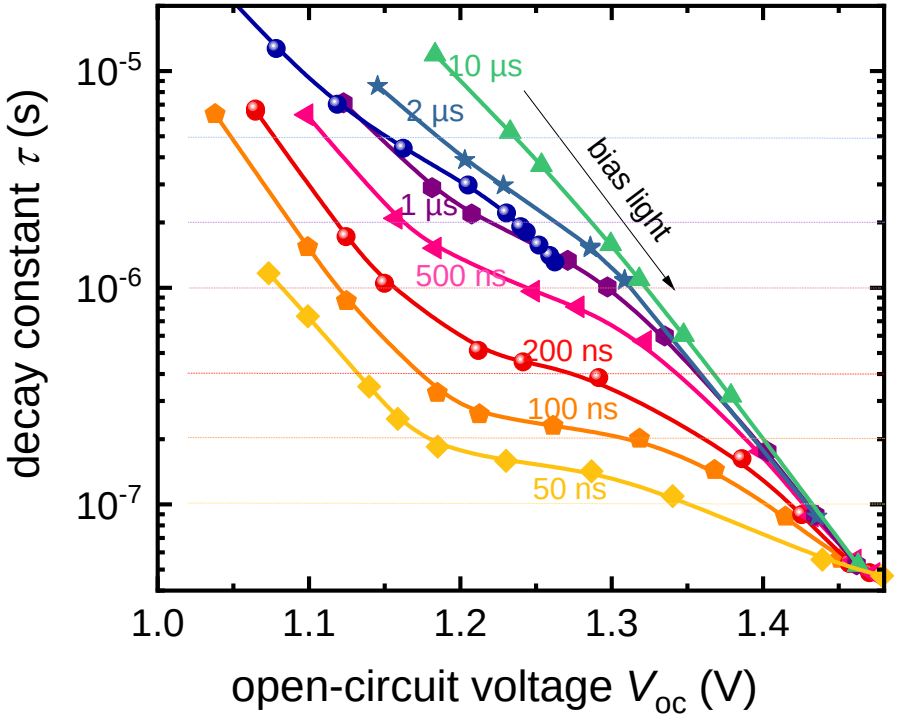




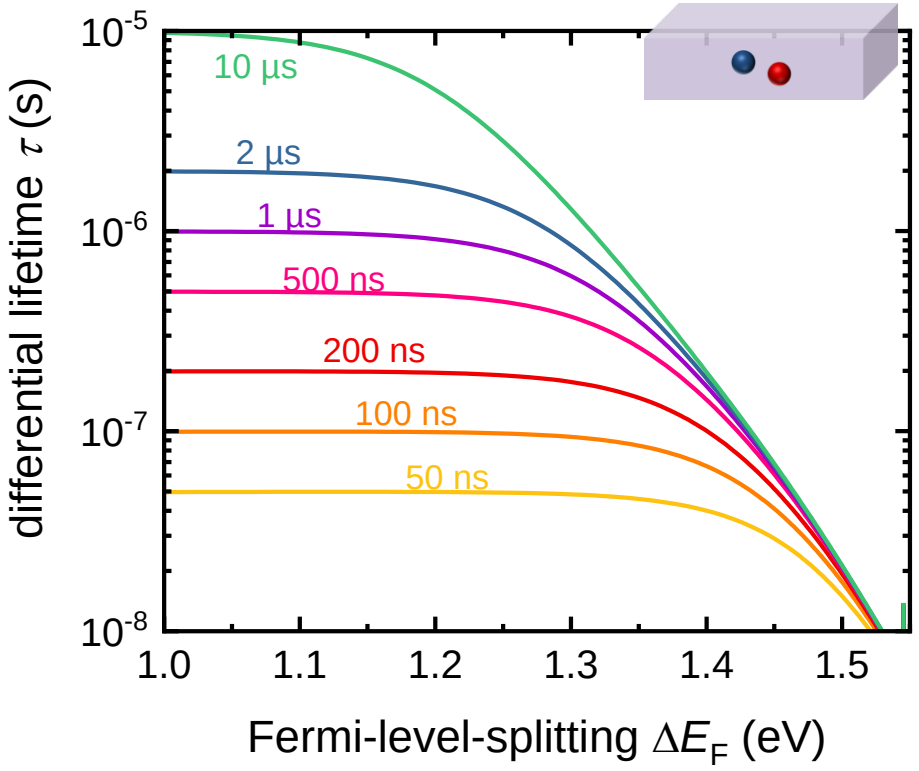
TPV Decay Constants

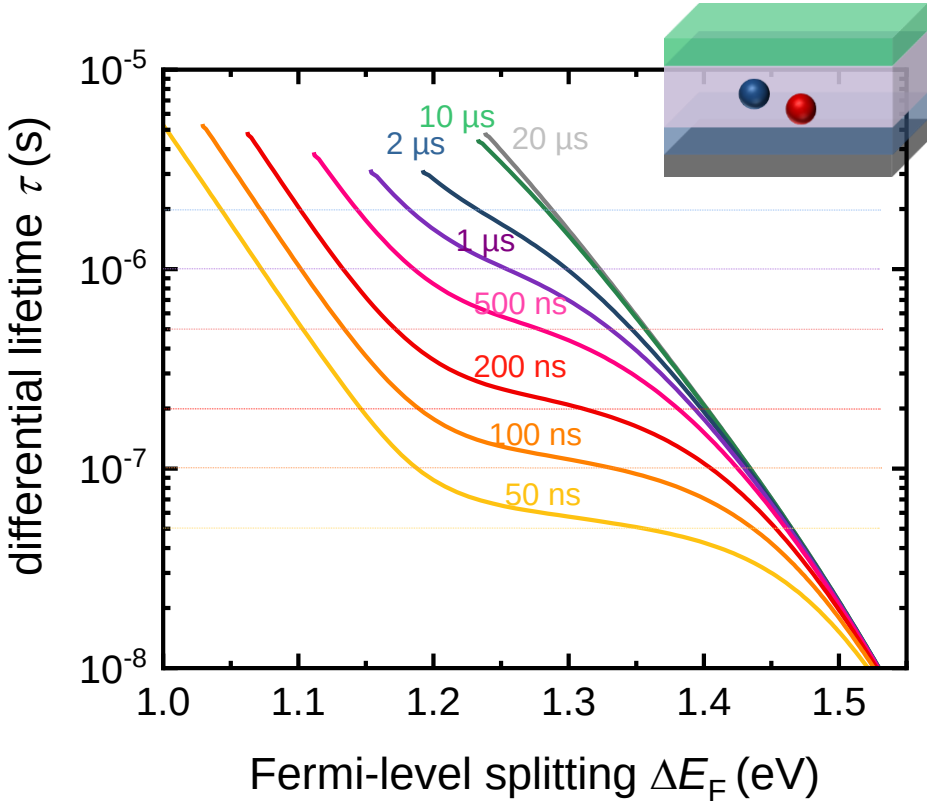
Experiment vs. Simulation





Summary


differential lifetime τ (s)
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10 µs
2 µs
1 µs
500 ns
200 ns
100 ns
50 ns
1.0
1.1
1.2
1.3
1.4
1.5
Fermi-level-splitting ΔE_F (eV)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10^{-5}
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50 ns
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1.1
1.2
1.3
1.4
1.5
Fermi-level splitting ΔE_F (eV)

Thanks to
Thomas Unold
Jose Marquez
Martin Stolterfoht
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Thank you for your attention