Impact of Transient Trapping on Quasi-Steady-State Photoconductance Lifetime Measurement

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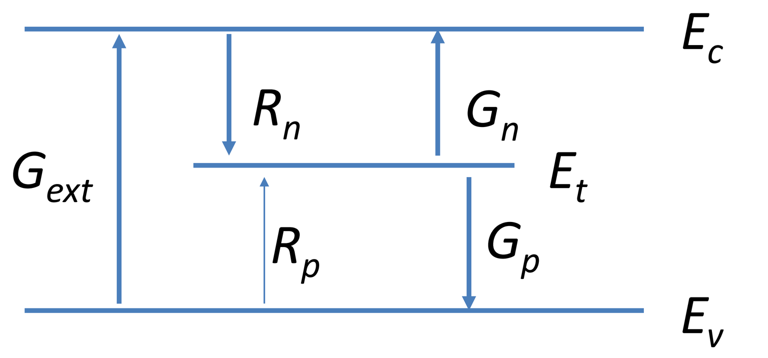
Introduction

- Artificially high apparent lifetime in low and even medium injection level is often observed in quasi-steady-state photoconductance (QSSPC) measurements due to minority carrier trapping.
- Currently most research, including the widely-used bias-light method for trap correction [1] assumes that the trapping is in a steady state regime during the QSSPC measurement.
- In this work, we will demonstrate that:
  - In some cases the trapping is actually in a transient regime during conventional QSSPC measurement;
  - The behavior of trap in transient regime is different from the quasi-steady-state regime.
  - The trap parameters can be potentially extracted from a transient measurement of the trap.

Methods

- Model:
  - Numerically solve the continuity equation set [2]:



$$\frac{dn}{dt} = G_{ext} + G_n - R_n \quad (1)$$

$$\frac{dp}{dt} = G_{ext} + G_p - R_p \quad (2)$$

$$\frac{dn_t}{dt} = R_n - G_n - R_p + G_p \quad (3)$$

  - The apparent lifetime is calculated from the apparent excess carrier density:

$$\Delta n_{app} = \frac{\mu_n \Delta n + \mu_p \Delta p}{\mu_n + \mu_p} = \Delta n + \frac{\mu_p}{\mu_n + \mu_p} \Delta n_t \quad (4)$$

$n(p)$: Free electron (hole) concentration

n_t: Electron concentration in a defect level

G_{ext}: Generation rate due to external excitation

$G_{n(p)}$: Emission rate of electron (hole) from defect

$R_{n(p)}$: Capture rate of electron (hole) to defect

$\mu_n(\mu_p)$: Electron (hole) mobility

- Measurement:
  - Czochralski (Cz) silicon *n*-type wafers (430 µm thickness, 0.48 Ω·cm), double side passivated by plasma-enhanced chemical vapour deposition silicon nitride.
  - QSSPC and quasi-steady-state photoluminescence (QSSPL) [3] measurement.

Results

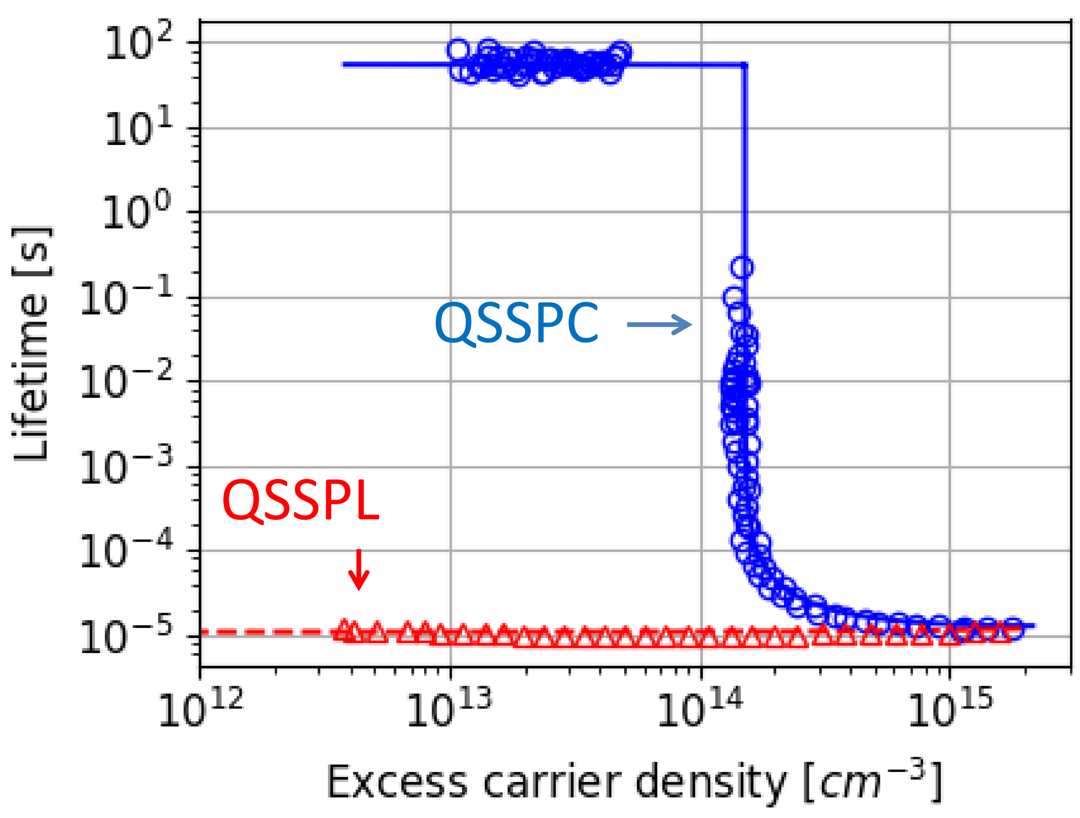


Fig. 1 : QSSPC and QSSPL measurement results of an *n*-type wafer with a strong trapping effect, the solid curves are the fitted lifetime. The plateau of the QSSPC curve is obtained from the exponential decay of the photoconductance, by extending the acquisition time.

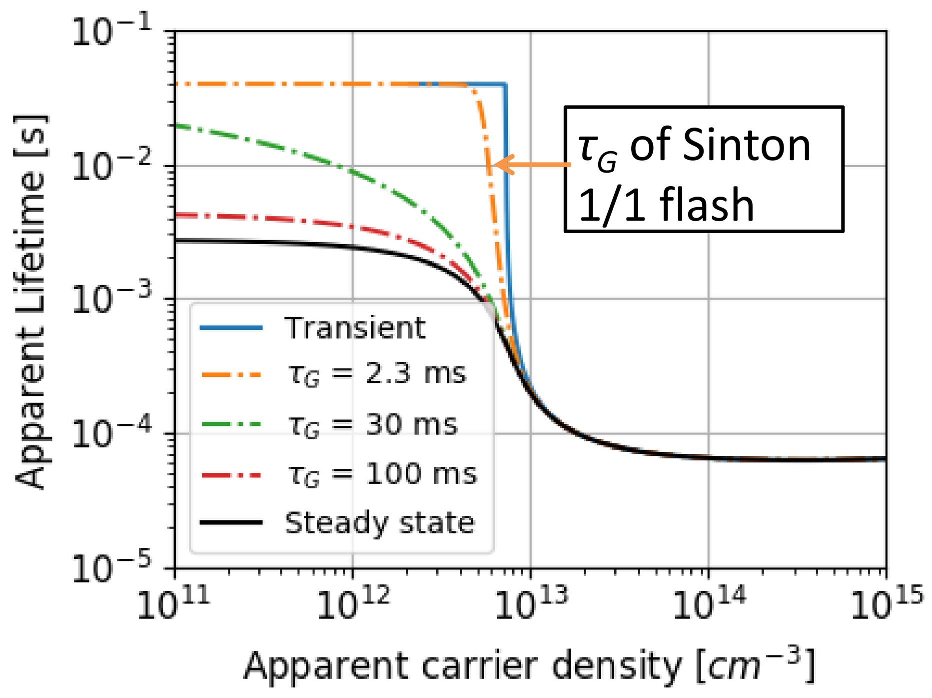
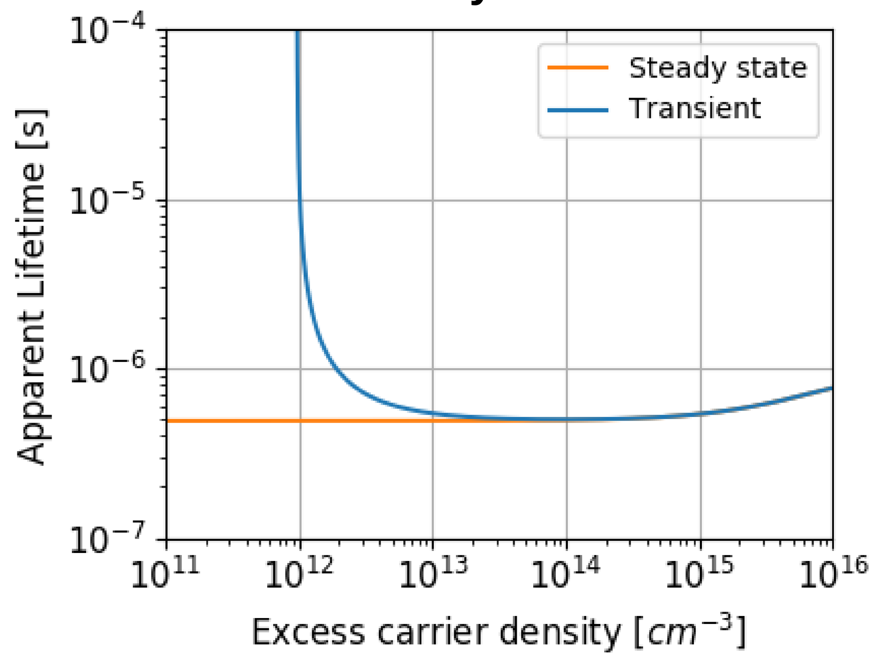


Fig. 2: Simulation of the PC lifetime measurement with various illumination decay time constants. The simulated trap parameters are: E_t - E_i = -0.3 eV, σ_n = 7×10^{-26} cm^2, σ_p = 1×10^{-25} cm^2. **The orange curve corresponds to the illumination decay time constant of Sinton lifetime tester and the result is closer to the transient lifetime instead of steady state lifetime.**



"Trapping" occurs when Δn_t becomes comparable with Δn, and this is easier happen in transient measurement than in steady state measurement

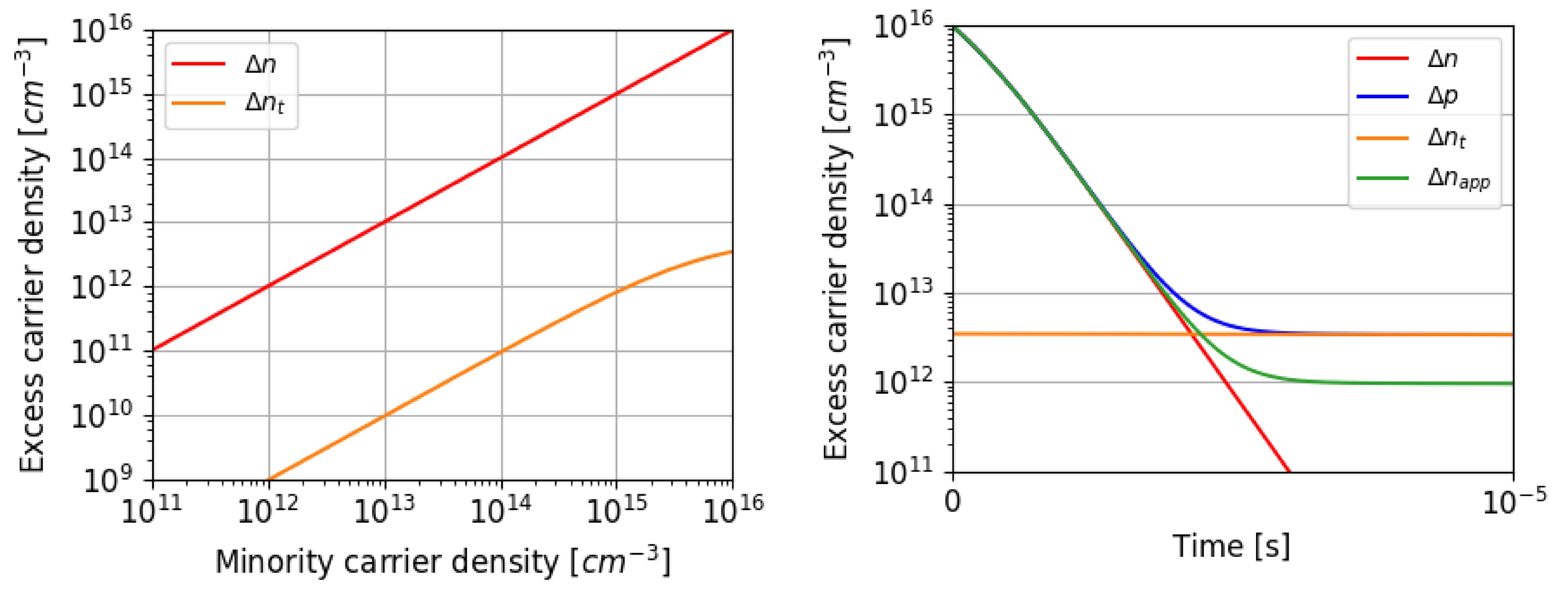


Fig. 3: (a) Simulation of photoconductance lifetime with a trap (E_t - E_i = 0.3 eV, σ_n = σ_p = 1×10^{-20} cm^2) in transient and steady state. (b) and (c) are the comparison of Δn_t and Δn in the steady state and transient case respectively.

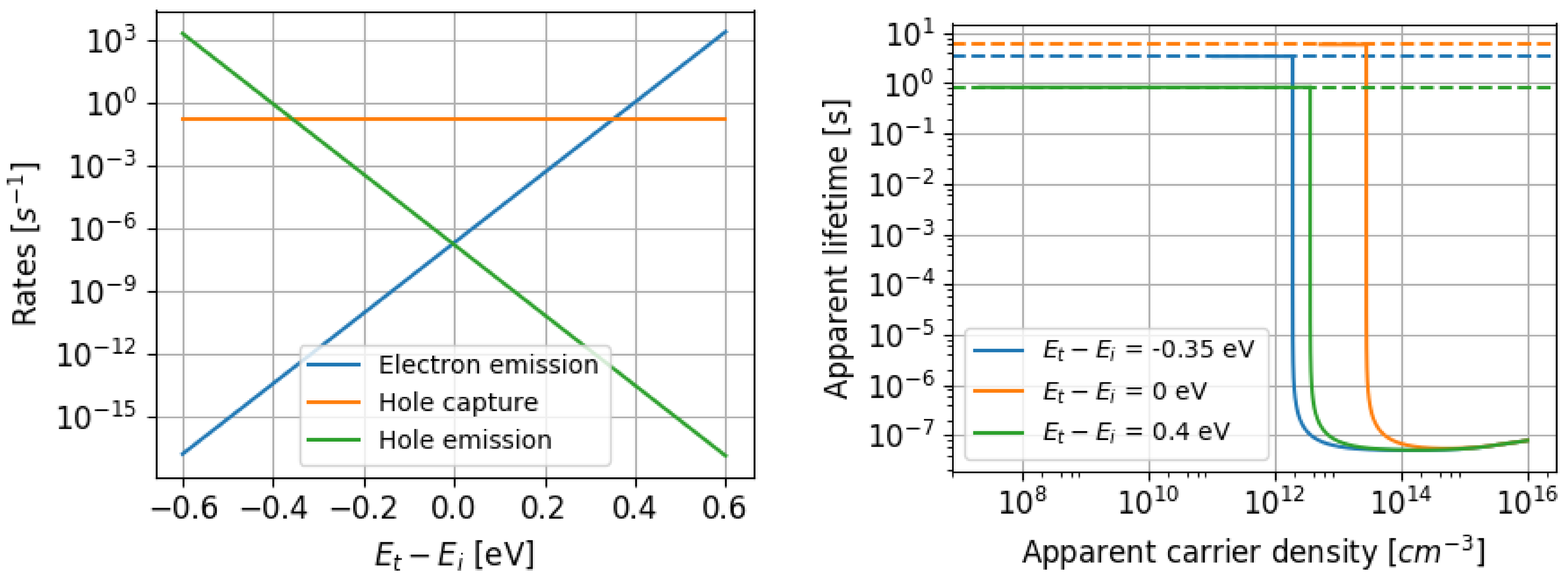


Fig. 4: (a) Comparison of the rates of three dominant processes in the transient photoconductance decay: electron emission, capture and hole emission. (b) Simulated transient photoconductance lifetime with a trap of σ_n = σ_p = 1×10^{-26} cm^2 and various E_t. The dashed line indicates the decay time constant $\tau = 1/(\sigma_n v_n n_1 + \sigma_p v_p p_1 + \sigma_p v_p p_0)$. When certain processes become less dominant, this equation can be further simplified. **By measuring the plateau of apparent lifetime, the majority carrier capture cross section and energy level of the trap can be potentially extracted.**

Conclusions

- Defects with slow time constants can results in transient trapping behaviour for typically assumed QSS measurements.
- Special care needs to be taken for transient trapping as the conventional bias-light correction method may lead to inaccurate correction of the lifetime data.
- The defect parameters of the trap can be potentially extracted from the photoconductance decay time constant, *i.e.*, the plateau value of the transient lifetime.

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[2] W. Shockley and W. T. Read, *Phys. Rev.*, **87**, 835–842, (1952).
[3] T. Trupke and R. A. Bardos, *31st IEEE PVSC*, 903-906, (2005).

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