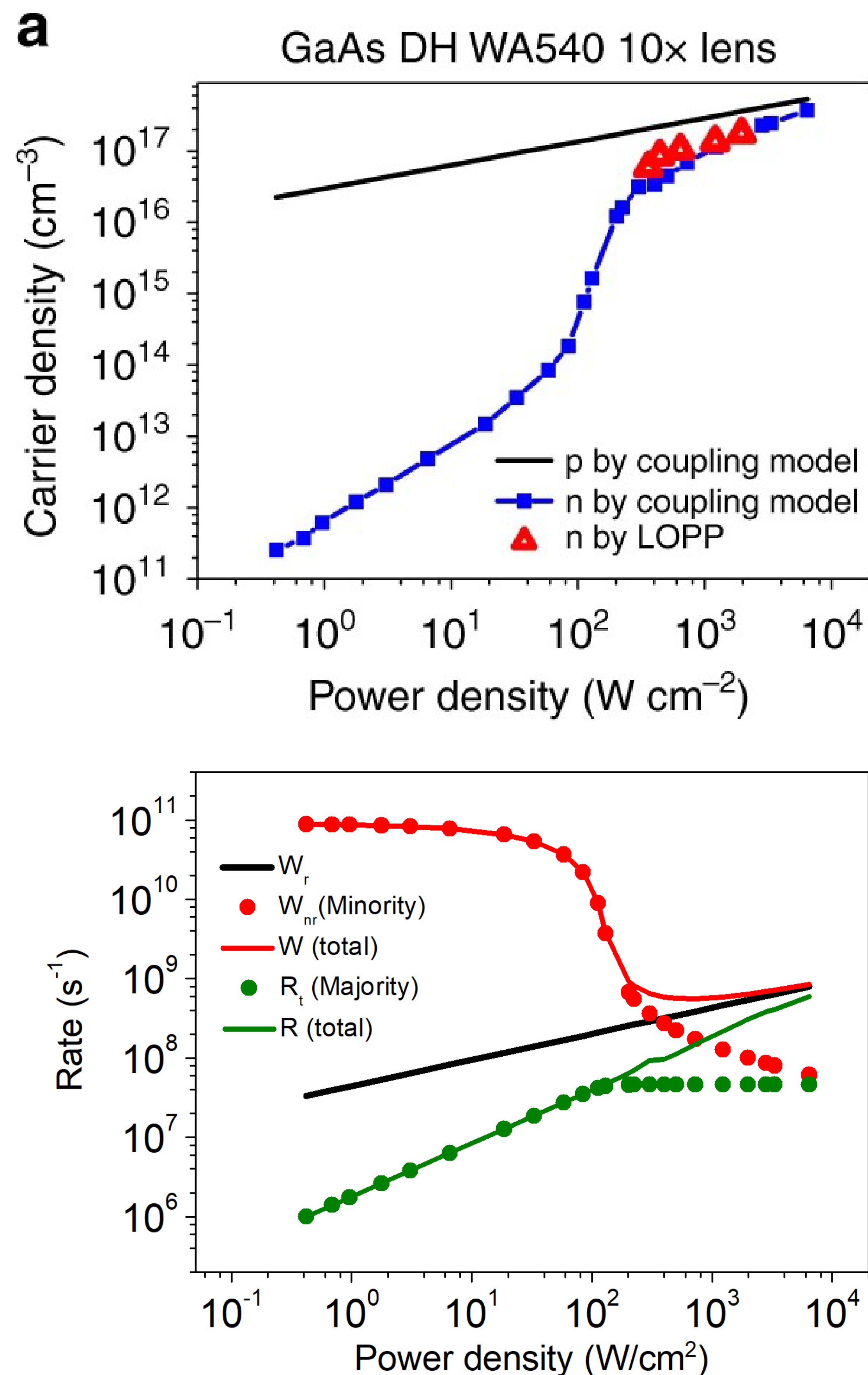


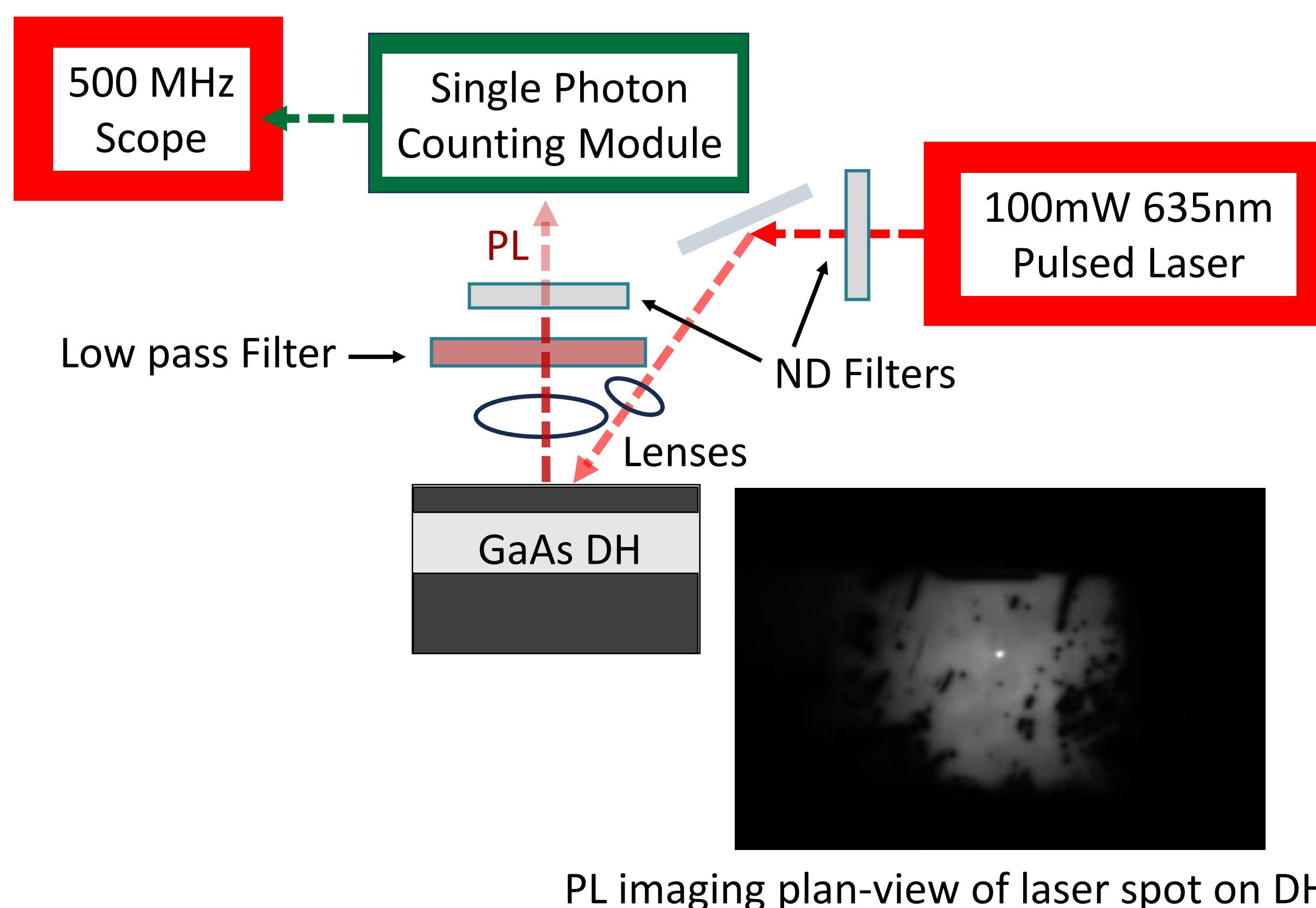
Connecting Recombination Rates with Carrier Density in GaAs

Motivation: Prior Work



We have recently developed an all-optical approach for analyzing radiative and nonradiative recombination rates in GaAs, relying primarily on steady-state photoluminescence measurements. [Figures adapted from *Light: Sci & Appl.* **11**, 137 (2022)]

Transient Photoluminescence Experiment

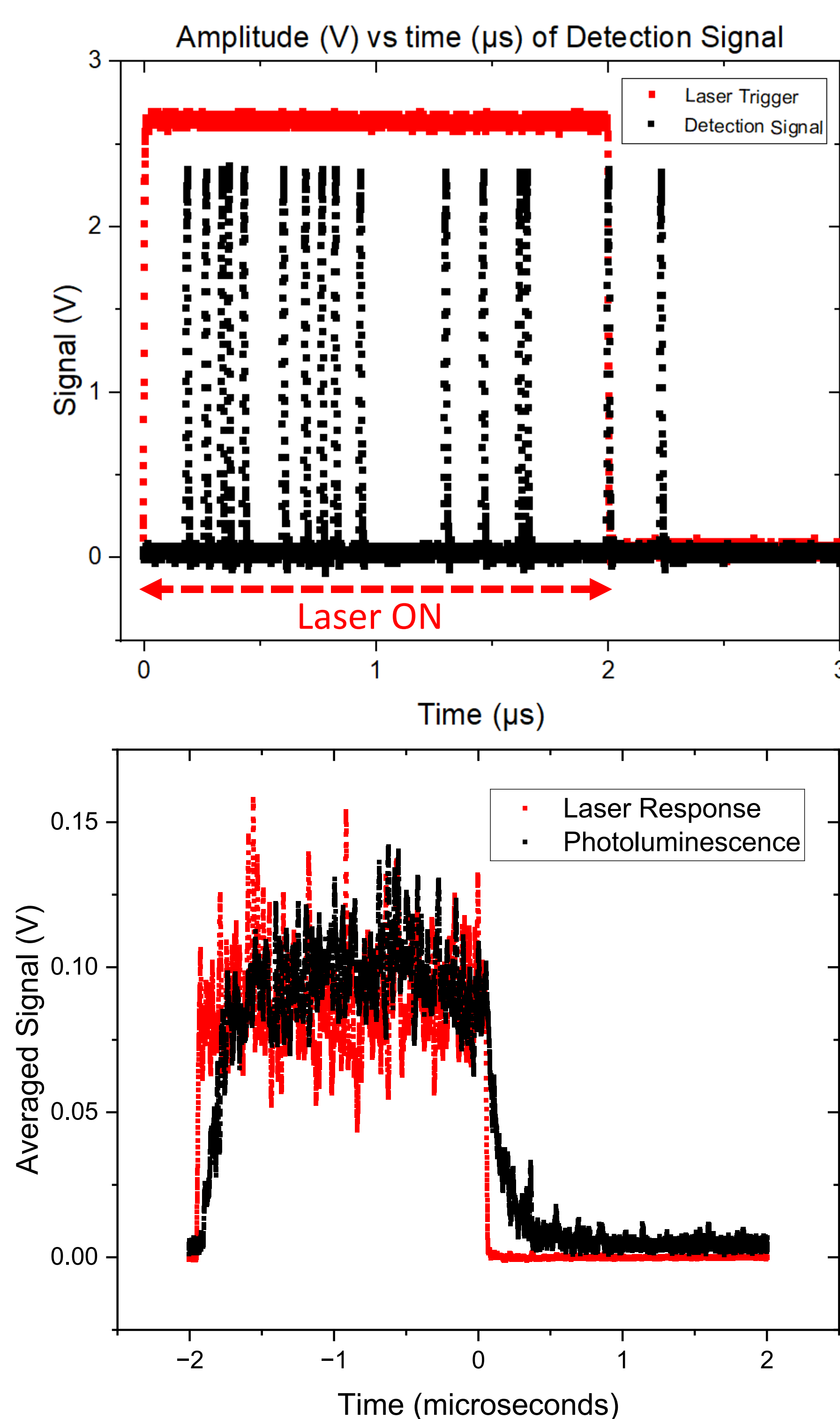


We seek to test this model with complementary transient photoluminescence measurements on the same GaAs double heterostructure (WA540).

Abstract

The characterization of defects and their impact on recombination rates in solar cells is crucial for evaluating and improving photovoltaic performance. Injection-dependent lifetime spectroscopy is a sensitive and commonly used technique for investigating recombination rates in semiconductors. However, determination of the photoexcited carrier density during the lifetime experiment and making comparisons with steady-state measurements can be challenging. We employ a new dynamic calibration approach, which relies on a combination of quasi-steady state and transient measurements, to obtain the lifetime as a function of charge carrier density in a GaAs/GaN heterostructure. We find that detection constraints limit the utility of the experiment in its current configuration.

Transient PL Signal: Single and Averaged



Single-shot and averaged transient PL signal under low laser excitation (approximately 10 W/cm² in the ON state) showing the slow rise and fall relative to the system response (with laser control and averaged signal measurement in red).

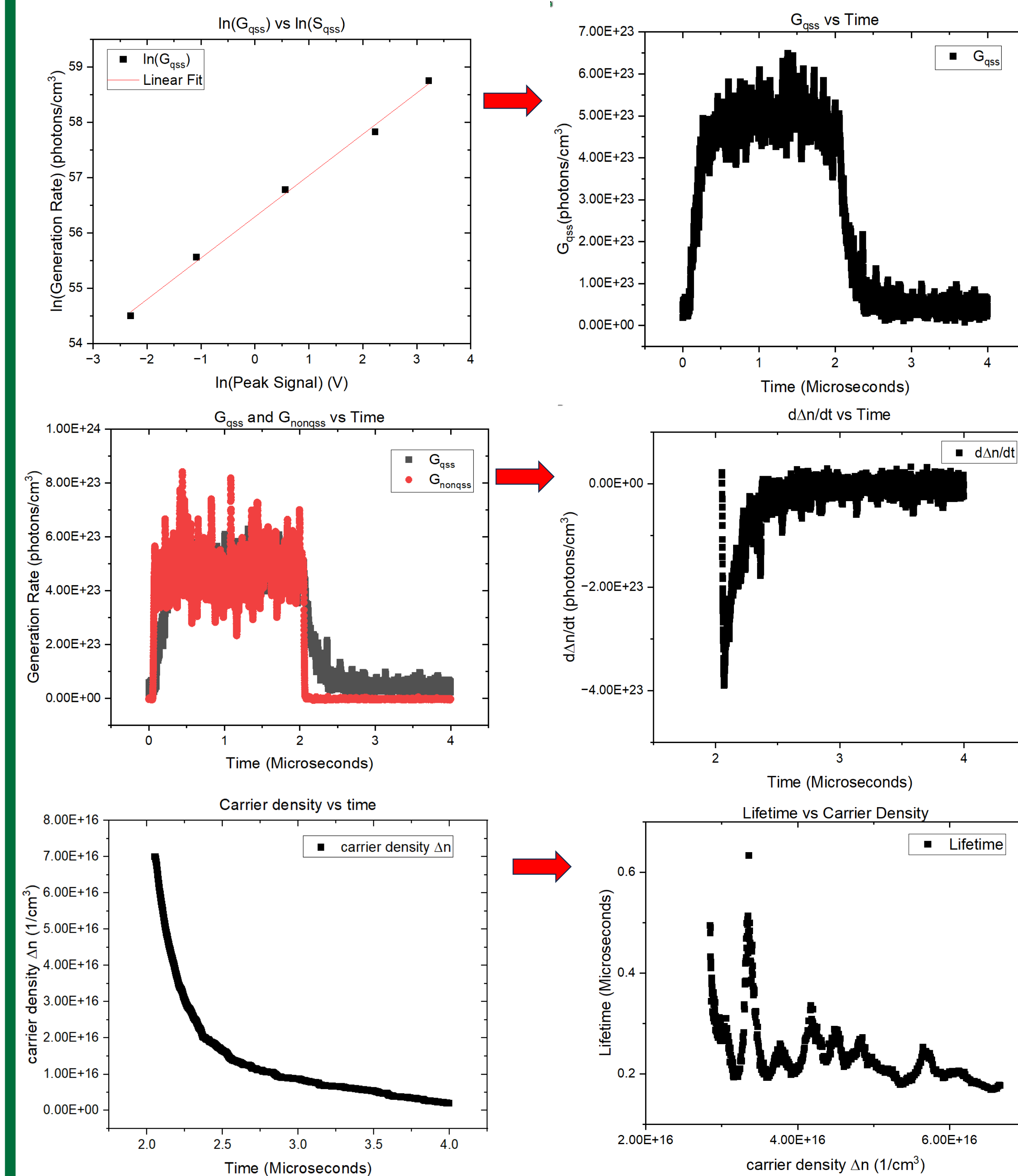
Dynamic Lifetime Calibration Method

Under illumination $G(t)$, the excess carrier densities Δn and Δp are related to their effective lifetimes τ_n and τ_p by the continuity equation:

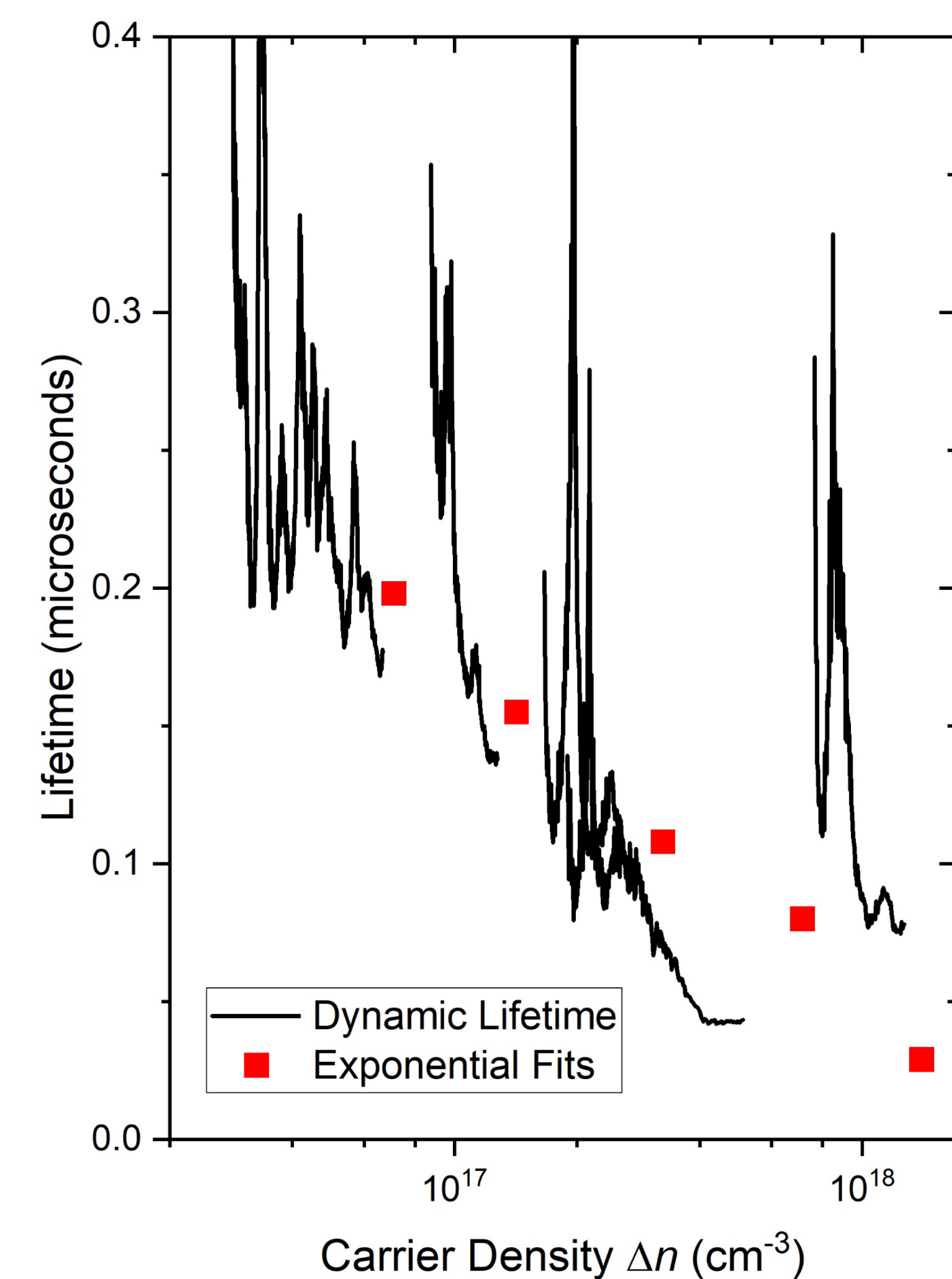
$$\text{For example: } \frac{d\Delta n}{dt} = G(t) - \frac{\Delta n(t)}{\tau_n(\Delta n)} \rightarrow \tau_n(\Delta n) = \frac{\Delta n(t)}{G(t) - d\Delta n/dt}$$

The dynamic calibration method combines quasi-steady-state [$d\Delta n/dt = 0$] measurements with transient [$G(t) = 0$] measurements to obtain the effective lifetime as a function of injection carrier density. [Y. Zhu *et al.*, "Dynamic calibration of injection dependent carrier lifetime from time-resolved PL," 50th IEEE PVSC (2023)]

Calibration Analysis Pipeline



Calibration Results



Dynamic lifetime vs. photoexcited carrier density in GaAs DH WA540 for $G(t) = 10 - 10^3$ W/cm². Our dynamic densities are consistent with prior estimates of majority carrier densities but our measured lifetimes ($\sim 10^{-7}$ s⁻¹) are an order of magnitude slower than the expected radiative recombination rates ($\sim 10^8$ s⁻¹).

Conclusion

The calibration approach is viable, but smaller detector pulses coupled with a higher vertical resolution oscilloscope will yield cleaner results.