Electronic Supplementary Material (ESI) for Journal of Materials Chemistry C.


# Suplementary Information: Nonlinear photocarrier dynamics and the role of shallow traps in mixed-halide mixed-cation hybrid perovskites

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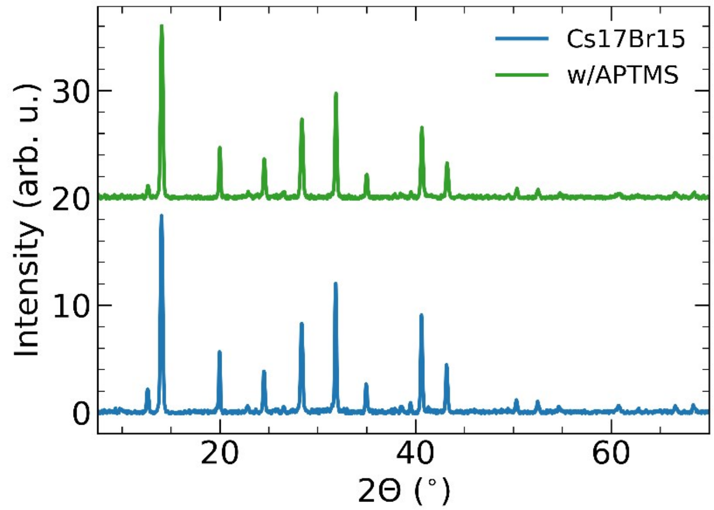



**Figure S1**. X-ray diffraction of Cs17Br15 control (blue) and APTMS passivated (green) perovskite thin films.

## 1. X-ray diffraction

## 2. Excitation Correlation Photoluminescence schematic setup:

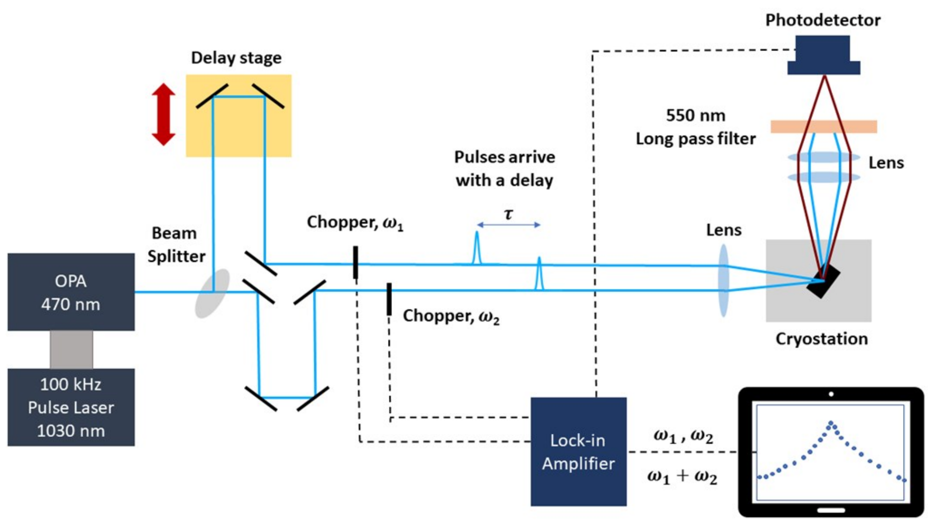



**Figure S2**. Excitation correlation photoluminescence experiment schematic setup.

**3. Temperature dependent Photoluminescence:**

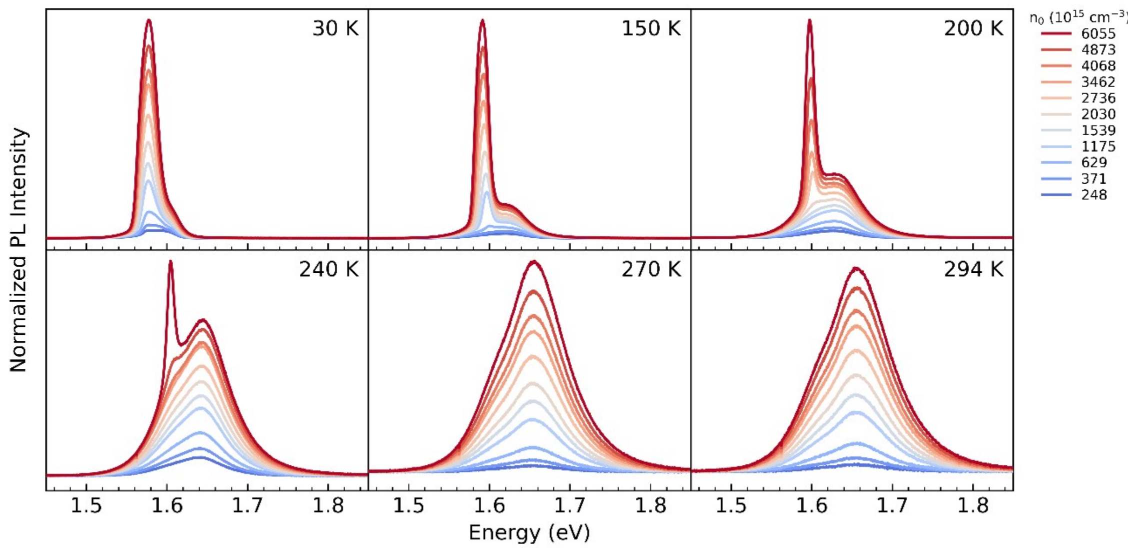



**Figure S3.** Fluence dependent photoluminescence at various temperatures for a control sample.

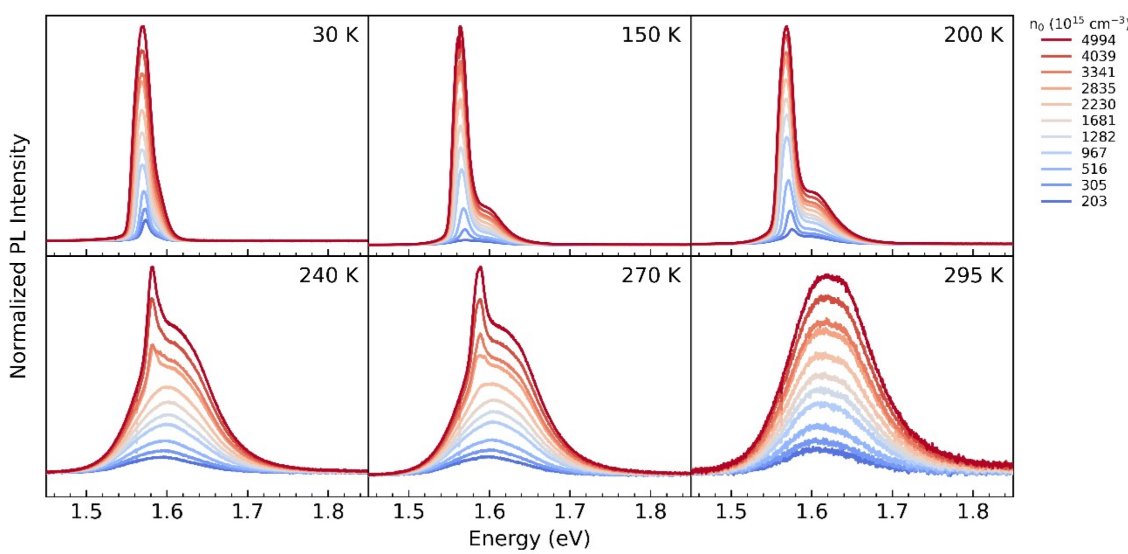



**Figure S4.** Fluence dependent photoluminescence at various temperatures for a passivated sample.

## 4. Complete temperature dependent ECPL.

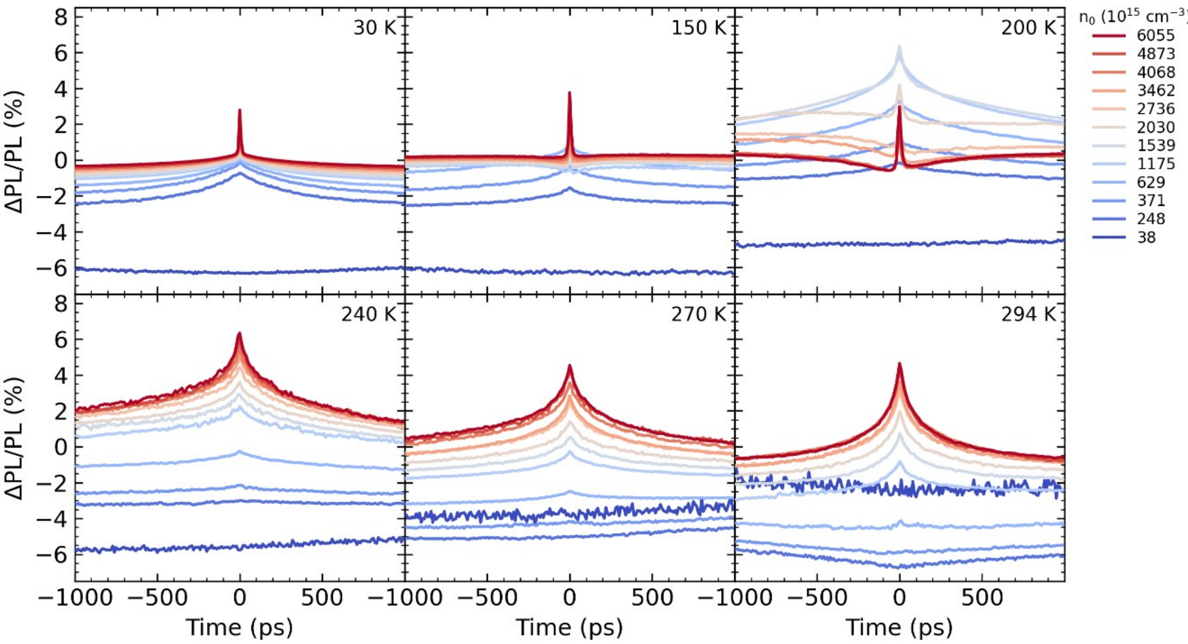



**Figure S5.** Temperature dependence on the ECPL Dynamics for control sample.

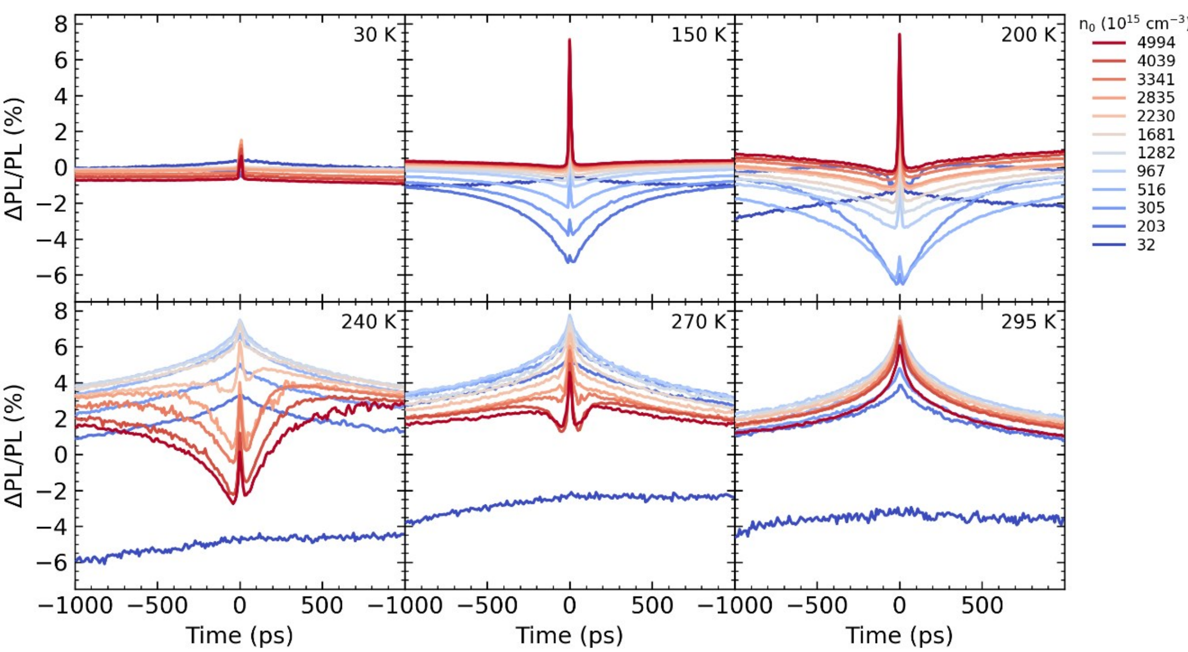



**Figure S6.** Temperature dependence on the ECPL Dynamics for passivated sample.

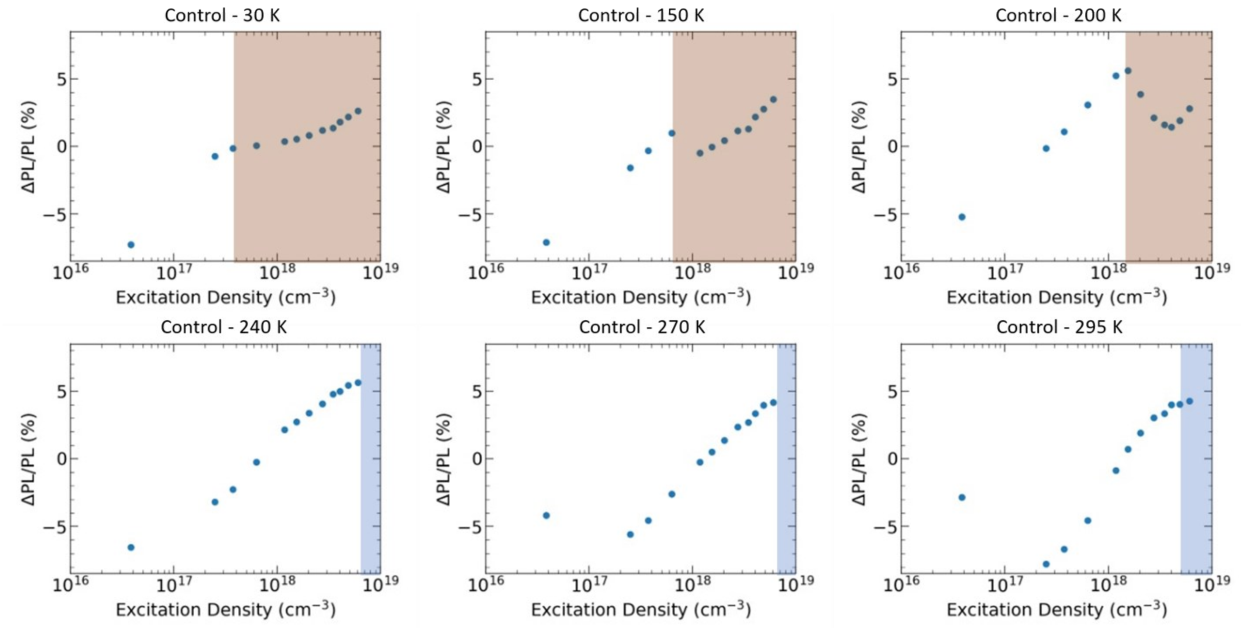



**Figure S7.** ECPL(t=0 ps) for control sample. Light orange region, ASE contribution dominates. Light blue region, saturation occurs, Auger recombination start to dominate.

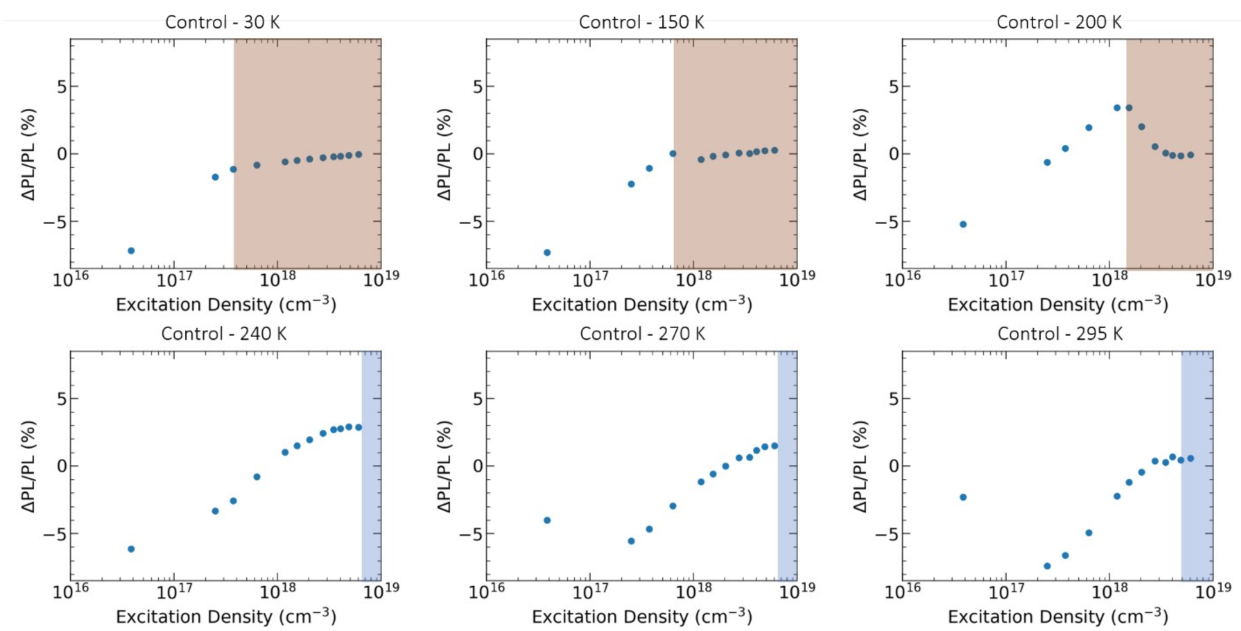



**Figure S8.** ECPL(t=250 ps) for control sample. Light orange region, ASE contribution dominates. Light blue region, saturation occurs, Auger recombination start to dominate.

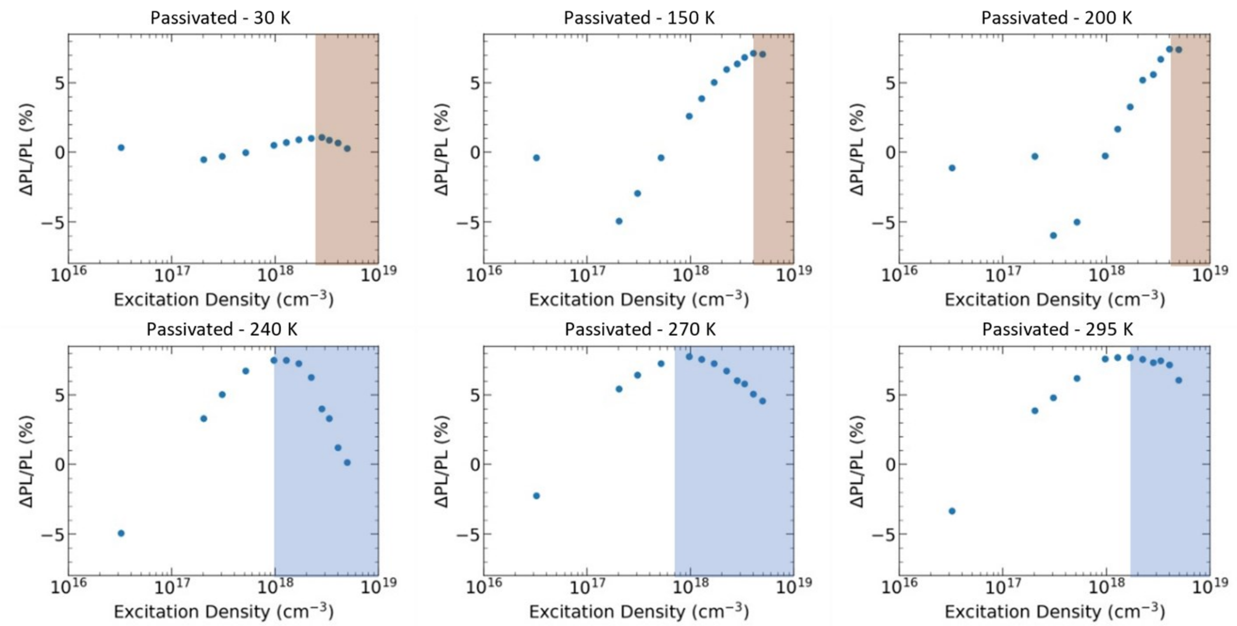
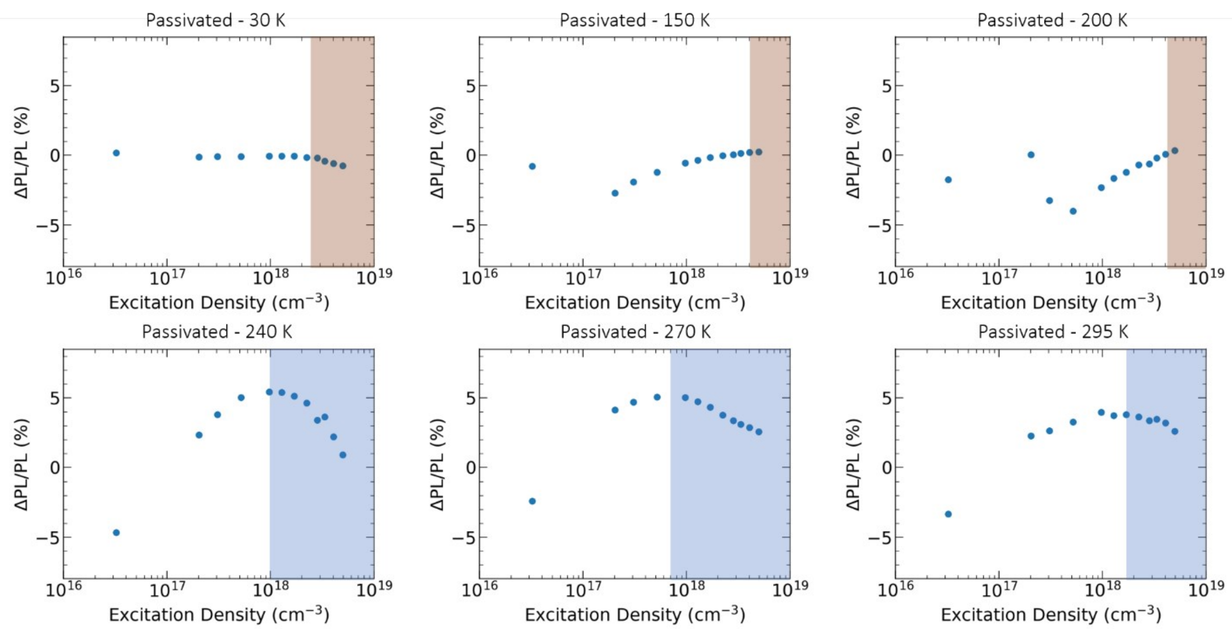



**Figure S9.** ECPL(t=0 ps) for passivated sample. Light orange region, ASE contribution dominates. Light  blue region, saturation occurs, Auger recombination start to dominate.

**Figure S10**. ECPL(t=250 ps) for passivated sample. Light orange region, ASE contribution dominates. Light blue region, saturation occurs, Auger recombination start to dominate.



## 5. Simulations

Our simulation of the ECPL signal solves the initial value problem created by the rate equations following a pulse interaction. This problem is then solved repeatedly over a range of delays and processed to extract simulated ECPL data. As the difference between positive and negative delay times is strictly due to the time-ordering of the pulses, the simulation only simulates positive delay times, and this result is then reflected across the zero-delay line to show negative delay times. This process is repeated for a defined set of parameters based on similar materials. The resulting images are either qualitatively compared to experimental data or studied to determine the qualitative effects of each parameter on ECPL data, depending on the exact simulation run and parameter sets chosen.

The simulation relies on several assumptions. Firstly, pulses are treated as though they interact instantaneously. This is a valid assumption to make as long as we recognise that the simulation will be inaccurate at timescales on the order of the pulse width. We also assume total absorption of the pulse to calculate the excitation density. This is inaccurate as we can observe remnants of the excitation pulse reflecting off the sample and transmitting through the sample. However, we are mainly interested in the qualitative behaviour at various excitation densities, so this is sufficient for our purposes

*Table S1. DeepTrap. Simulation Parameters:* The deptrapping term is set to zero by selecting a very high trap depth.

| **Parameters** | **Value** |
|---|---|
| $B\ /\ cm^{-3}s^{-1}$ | $1 \times 10^{-11}$ |
| $\gamma_r\ /\ cm^3s^{-1}$ | $1 \times 10^{-10}$ |
| $N_t\ /\ cm^{-3}$ | $1 \times 10^{16}$ |
| $\gamma_t\ /\ cm^3s^{-1}$ | $1 \times 10^{-12}$ |

*Table S2. Shallow Traps. Simulation Parameters*

| **Parameters** | **Value** |
|---|---|
| $B\ /\ cm^{-3}s^{-1}$ | $1 \times 10^{-11}$ |
| $\gamma_r\ /\ cm^3s^{-1}$ | $1 \times 10^{-8}$ |
| $N_t\ /\ cm^{-3}$ | $2 \times 10^{18}$ |
| $\gamma_t\ /\ cm^3s^{-1}$ | $1 \times 10^{-12}$ |
| $E_b\ /\ meV$ | 20 |

Note: Changes in this conditions are specified in each figure.

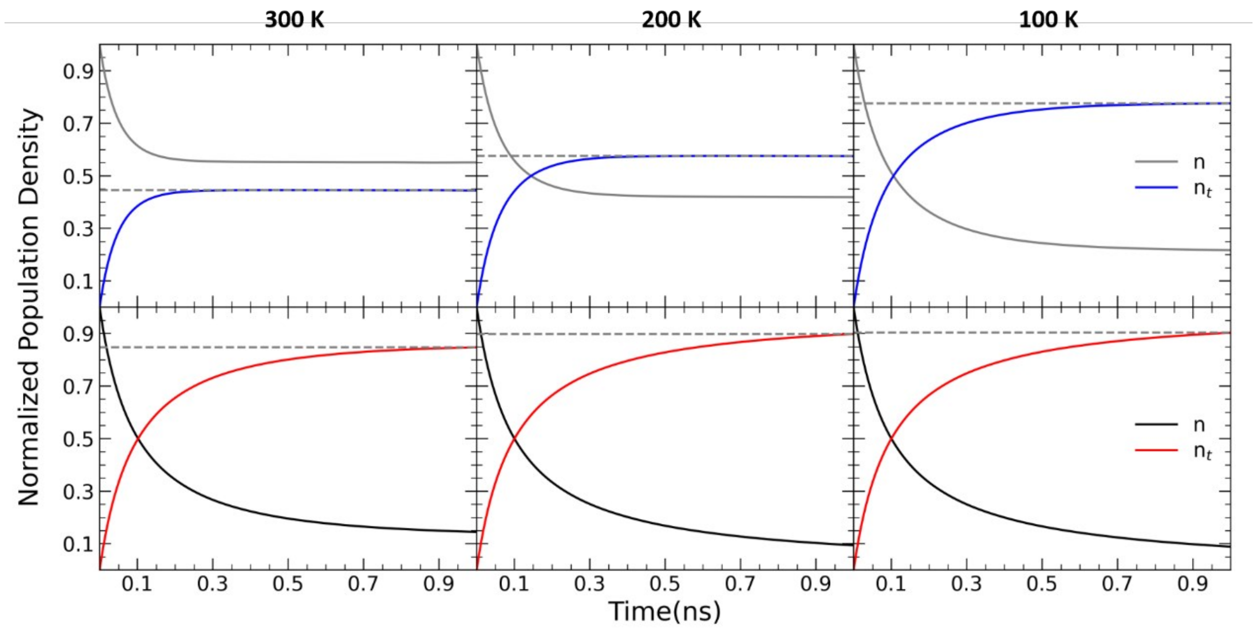



**Figure S11.** Electron and trap electron population evolution during the first nanosecond assuming shallow traps with fast trapping. (Top) Trap depth of 10 meV. (Bottom) Trap depth of 100 meV. Simulation performed at 300 K (left), 200 K (middle) and 100 K (right).

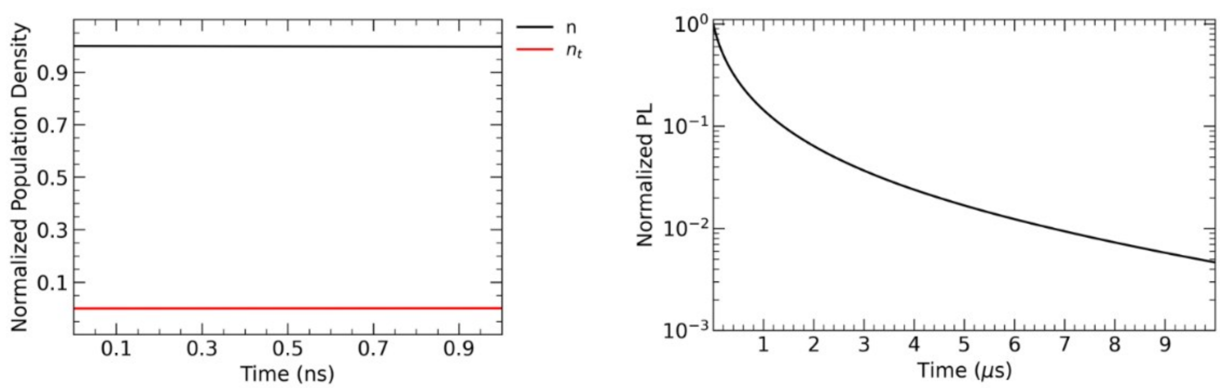



**Figure S12.** (Left) Electron and trap electron population evolution during the first nanosecond assuming deep traps with slow trapping (Table 1). (Right) Simulated Pholuminescence.

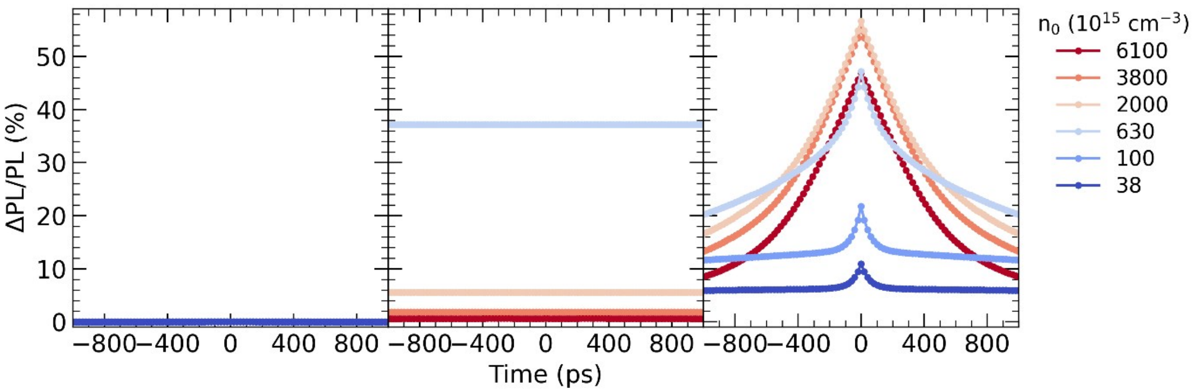



**Figure S13:** Simulation of the ECPL response for distinct defect scenarios. (a) No traps, (b) Deep Traps and (c) Shallow Traps.

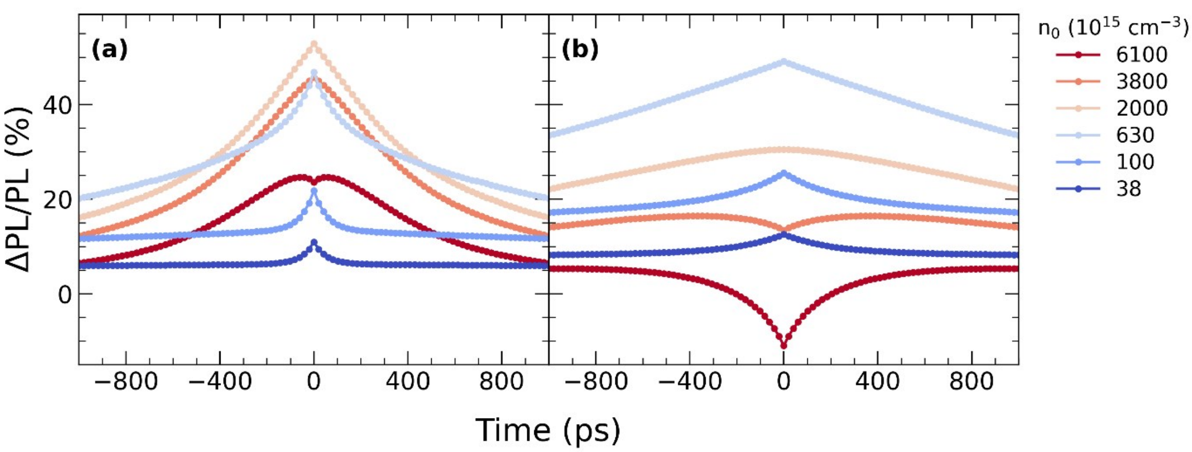



**Figure S14.** Simulation of ECPL shallow traps with a trap density of (a) $2 \times 10^{18}$ cm$^{-3}$ and (b) $5 \times 10^{17}$ cm$^{-3}$.