Supplementary information for: Interpreting Time-Resolved Photoluminescence of Perovskite Materials

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1. Generalities

Note S1: Calculation of the diffusion time and the intrinsic carrier concentrations

For a 200 nm thick thin film, and given a $D = 0.07 \ cm^2/s$ diffusion coefficient², carriers can diffuse into the film within $t_D = L_D^2/D = 5.7 \ ns$. Carriers thus diffuse much faster than they can recombine and the assumption that the carriers are homogeneously distributed into the film after excitation is correct.

The intrinsic carrier concentrations at room temperature ($T_R = 300K$) were calculated from the electron and hole effective masses reported in¹ ($m_e = 0.14m$ and $m_h = 0.18m$ with m the free electron mass) and a $E_g = 1.6 \ eV$ band-gap energy:

$$n_i = \sqrt{N_C N_V e}^{-\frac{E_g}{2k_B T}}$$

where N_c and N_v are respectively the electron and hole effective density of states:

$$N_C = 2 \left(\frac{2\pi m_e k_b T_R}{h^2} \right)^{3/2} \qquad N_V = 2 \left(\frac{2\pi m_h k_b T_R}{h^2} \right)^{3/2}$$

where k_b and h are respectively the Boltzmann's and Planck's constants.



Figure S1: Schematic representation of the simulation and fitting procedure exemplified with the bimolecular trapping model. Given a set of parameters k_T , k_B , N_0 and RP the rate equation is solved to calculate the carrier concentrations after the first excitation pulse p = 1. If multiple excitation pulses are simulated (multiple pulse approximation), the carrier concentration $n^{p=1}(RP)$ just before the second pulse p = 2 is used to calculate the initial carrier concentration of the second pulse. This iterative process continues until the relative difference between the carrier concentration between a pulse and the next one is lower than a certain threshold. The TRPL intensity is then calculated from the carrier concentration. In the case of fitting, the simulated TRPL intensity is compared to the decay investigated by calculating the residue SS_{res} . If it does not fit, the input parameters are changed and the whole operation is repeated until correct fitting.

Note S2: Extended methodology

The time-scales (repetition period, scale and number of points) used for the simulations (Figure 2 & 4) were chosen such that the total number of carriers recombined determined from the sum of the contributions is

equal to the carrier concentration N_0 with less than 0.01 % difference (**Figure S2**). Time periods of $RP = 1 \,\mu s$ for the BT model and $RP = 200 \,\mu s$ for the BTD model were found to be suitable while a logarithmic scale with 10⁴ points was found to properly define fast processes just after the excitation pulse and slower processes while keeping the calculation time low.



Figure S2: Maximum error of the contributions calculated over a range of excitation fluences with the **a**)-**b**) BT $({}^{N_0}\sim 10^{14} - 10^{20} \text{ cm}^{-3}})$ and **c**)-**d**) BTD $({}^{N_0}\sim 10^{12} - 10^{17} \text{ cm}^{-3}})$ models, for **a**) & **c**) different time scales (linear or logarithmic) and different number of points (the repetition period is fixed at $RP = 1 \ \mu s$ for the BT model and $RP = 200 \ \mu s$ for the BTD model) and for **b**) & **d**) different repetition periods (the time scale is fixed at 10^4 points, logarithmic scale). Red boxes indicate the parameters chosen for the simulations allowing fast calculation while maintaining a high level of precision.

Note S3: Contribution of the recombination processes

Within the BT model, the relative trapping $({}^{\%}T)$ and bimolecular $({}^{\%}B)$ contributions are given by:

$$\%T(t) = \frac{T(t)}{T(t) + B(t)} \qquad \%B(t) = \frac{B(t)}{T(t) + B(t)}$$

A graphical example of the calculation of the total and relative contributions is shown in **Figure S3**. Within the BTD model, the relative trapping (${}^{\%}T$), bimolecular (${}^{\%}B$) and detrapping (${}^{\%}D$) contributions are given by:



Figure S3: Graphical representation of the calculation of the total **a**) trapping and **b**) bimolecular contributions ($^{T} \& ^{B}$ respectively), **c**) relative contributions ($^{\%}T \& ^{\%}B$ respectively) and **d**) relative total contributions ($^{\%}T \& ^{\%}B$ respectively).



Figure S4: Comparison of TRPL decays at different excitation fluencies N_0 a) simulated with the bimolecular-trapping model ($k_B = 50 \times 10^{-20} \text{ cm}^3/\text{ns}$, $k_T = 1.7 \times 10^{-3} \text{ ns}^{-1}$), b) simulated with Poisson noise and c) experimentally measured.

Note S4: Fitting

The best fit was found using the least-square method. For a decay containing N points, the residue S_{res} is:

$$SS_{res} = \sum_{i}^{N} (y_i - F(x_{i\nu}A))^2$$

where y_i is the intensity associated with x_i at point i, F is the fit model and A are its parameters. The quality of the fit is estimated using the coefficient of determination R^2 :

$$R^2 = 1 - \frac{SS_{res}}{SS_{total}}$$

where SS_{total} is the sum of the squared difference between each point and the average of all the curves \bar{y} :

$$SS_{total} = \sum_{i}^{N} (y_i - \bar{y})^2$$

In order to investigate the limitation of the BT and BTD models, they were used to fit TRPL decays simulated with the same model with added noise. For single pulse fitting, the fitted decays were simulated with the single pulse approximation with added noise and the time window RP was chosen such that $I_{TRPL}(RP)/I_{TRPL}(0) = 10^{-4}$. For multiple pulse fitting, the fitted decays were simulated with the multiple pulse approximation with added noise and the time window was chosen such that $I_{TRPL}(RP)/I_{TRPL}(0) = 10^{-4}$. For multiple pulse fitting, the fitted decays were simulated with the multiple pulse approximation with added noise and the time window was chosen such that $I_{TRPL}(RP)/I_{TRPL}(0) = 0.25$ for the BT model and $I_{TRPL}(RP)/I_{TRPL}(0) = 10^{-4}$ for the BTD model (where I_{TRPL} corresponds to the TRPL intensity after the last simulated excitation pulse). These two values were chosen as they lead to carrier accumulation and therefore lead to TRPL decays that cannot be fitted with the single pulse approximation. For both single and multiple pulse approximations, the following protocol was followed:

- 1) Simulate TRPL decay with the chosen approximation (single or multiple pulse) and parameter values (*e.g.* k_T , k_B , N_0 , RP for the BT model);
- 2) Add noise to the decay and normalise it to its initial intensity;
- 3) Fit the decay by recursively simulating the TRPL with different parameter values and the approximation used in (1). Note that a lower threshold of 10^{-4} was used to calculate the stabilisation of the charge carrier concentration(s) (**Equation 21**) with the multiple pulse fit in order to keep the calculation cost down.
- 2. Bimolecular-trapping model

Note S5: Analytical solution of the bimolecular-trapping rate equation

Assuming that $k_T > 0$ and $k_B > 0$, the carrier concentration n(t) after a pulse exciting n(0) carriers is given by:

$$n(t) = \frac{k_T}{e^{k_T t} (k_T / n(0) + k_B) - k_B}$$

Note S6: Demonstration that the normalised carrier concentration is lower at any time for a higher initial carrier concentration as predicted by the bimolecular-trapping model

Let us define the initial carrier concentrations n(0) and n(0) such that:

$$n(0) < n(0)$$

Multiplying by k_B and adding k_T on each side, we get:

$$k_b n(0) + k_T < k_b n'(0) + k_T$$

Factoring by the initial carrier concentration and multiplying each side by $e^{k_T^t}$, we get:

$$n(0)e^{k_{T}t}\left(\frac{k_{T}}{n^{p}(0)}+k_{b}\right) < n^{p}(0)'e^{k_{T}t}\left(\frac{k_{T}}{n(0)}+k_{b}\right)$$

Finally, we take the inverse of each side and multiply it by k_T , thus reversing the inequality:

$$\frac{k_T}{n(0)e^{k_T t} \left(\frac{k_T}{n^p(0)} + k_b\right) - k_b} > \frac{k_T}{n^p(0)' e^{k_T t} \left(\frac{k_T}{n'(0)} + k_b\right) - k_b}$$

From Note S5, we get:

 $\frac{n(t)}{n(0)} > \frac{n'(t)}{n'(0)}$

Therefore, the normalised carrier concentration (and therefore TRPL intensity) is lower at any time for a higher initial carrier concentration



Figure S5: c) TRPL decay with increasing amount of noise ($N_0 = 1.1 \times 10^{17} \text{ cm}^{-3}$). b) Trapping k_T and c) bimolecular k_B rate constants obtained from fitting the TRPL decays simulated with added noise at increasing excitation fluences and normalised to the values used in the simulations ($R^2 > 0.998$). A value of 1 or close to 1 indicates that the constant value is accurately retrieved. As the noise level is increased the accuracy of k_T at high fluences and k_B a low fluence decreases.

Table S1: Summary	y of the excitation	regimes pre	edicted by the	bimolecular-trappir	ng model.
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Fluence regime	Low	Medium	High
Dominant	Tranning	Bimolecular,	Bimolecular
process(es)	naphing	trapping	(trapping)
TRPL decay			
profile	No	Yes	Yes
fluence	NO		
dependent			

TRPL decay	Mono-	Non-	Non-
profile	exponential	exponential	exponential



Figure S6: Carrier concentration $n^{p}(t)$ (full lines) and TRPL intensity $I_{TRPL}^{p}(t)$ (dashed lines) after multiple consecutive pulses and normalised with respect to **a**) & **b**) their initial intensity after the first pulse and **c**) & **d**) their initial intensity after each pulse, in the **a**) & **c**) low fluence regime ($N_0 = 10^{14} cm^{-3}$) **b**) & **d**) high fluence ($N_0 = 10^{18} cm^{-3}$) regimes. The repetition period was chosen such that $I_{TRPL}(RP)/I_{TRPL}(0) = 0.25$.

Note S7: Multiple pulse fitting

TRPL decays were simulated using the single and multiple pulse approximations of the BT model at different excitation fluences and with added noise, and were fitted using the same approximation as per **Note S4**. The simulated TRPL decays are shown in **Figure S7a**. The trapping and bimolecular contributions to the change in the TRPL intensity are shown in **Figure S7b** for both cases. The multiple pulse case present a lower trapping contribution over the whole range of fluences due to the loss of trapping information from the TRPL decay tail as well as the increased initial carrier concentration due to carrier build-up. Comparing the rate constants obtained from single and multiple pulse fitting show that k_T is not accurately retrieved at $N_0 > 6.5 \times 10^{16} \text{ cm}^{-3}$ with the multiple pulse fit while it can be retrieved up to $N_0 = 1.6 \times 10^{18} \text{ cm}^{-3}$ with the single pulse fit (given a maximum 10% error) (**Figure S7c**). In both cases, the bimolecular rate constants k_B can only be accurately retrieved down to $N_0 = 1.4 \times 10^{16} \text{ cm}^{-3}$. The region where both rate constants can be accurately retrieved is thus much shallower with the multiple pulse approximation than with the single pulse approximation. Measuring TRPL decays reaching zero which can be fitted with the single pulse approximation is thus preferable compared to truncated decays which need to be fitted with the multiple pulse approximation.



Figure S7: Comparison of single pulse and multiple pulse fitting. **a)** TRPL decays calculated after a single pulse (the repetition period is determined such that the normalised intensity satisfies $I_{TRPL}(RP)/I_{TRPL}(0) = 10^{-4}$, full lines) and multiple pulse $(I_{TRPL}(RP)/I_{TRPL}(0) = 0.25)$, dashed lines) at increasing excitation fluences, and **b)** corresponding total trapping ${}^{\%}0^{T}{}_{PL}$ and bimolecular ${}^{\%}B^{}_{PL}$ contributions to the change in the TRPL intensity. **c)** Bimolecular k_{B} and trapping k_{T} rate constants obtained from single and multiple pulse fitting of the TRPL decays with added noise, and normalised to the values used in the simulations ($R^{2} > 0.989$). A value of 1 or close to 1 indicates that it is accurately retrieved.

3. Bimolecular-trapping-detrapping model

Note S8: Expected behaviour in the low fluence regime as predicted by the BTD model

In the low fluence regime ($^{N_0} \ll N_T$), three cases are distinguished depending on the ratio of $k_b[\Delta n_h(t) + p_0]$ and $k_T N_T$ and the value of the doping concentration p_0 .

Case 1: $p_0 \gg N_0 \ge \Delta n_h$ and $k_B[\Delta n_h + p_0] \approx k_B p_0 \sim k_T N_T$. Both bimolecular and trapping contribution present a monomolecular behaviour and the hole concentration can be assumed constant (*e.g.* Figure S8b & d):

$$\frac{dn_e}{dt} \approx -\Delta n_e(t) [k_B p_0 + k_T N_T] \Rightarrow \frac{I_{TRPL}(t)}{I_{TRPL}(0)} \approx e^{-(k_B p_0 + k_T N_T)t}$$

Case 2: $p_0 \gg N_0 \ge \Delta n_h$ and $k_B[\Delta n_h + p_0] \approx k_B p_0 \gg k_T N_T$ and The trapping contribution is negligible and the bimolecular contribution follows a monomolecular behaviour as the hole concentration remains constant over time (*e.g.* Figure S8a & d):

$$\frac{dn_e}{dt} \approx -k_B \Delta n_e(t) p_0 \Rightarrow \frac{I_{TRPL}(t)}{I_{TRPL}(0)} \approx e^{-k_B p_0 t} \approx e^{-(k_B p_0 + k_T N_T)t}$$

Case 3: $k_b[\Delta n_h + p_0] \ll k_T N_T$. Bimolecular recombinations are negligible compared to trapping and the hole concentration can be assumed constant within the TRPL decay time frame (*e.g.* Figure S8c & d):

$$\frac{dn_e}{dt} \approx -k_T \Delta n_e(t) N_T \Rightarrow \frac{I_{TRPL}(t)}{I_{TRPL}(0)} \approx e^{-k_T N_T t} \approx e^{-(k_B p_0 + k_T N_T)t}$$



Figure S8: Evolution of the photoexcited electron Δn_e , hole Δn_h and trapped electron n_t concentrations with **a**) low ($p_0 = 10^{12} cm^{-3}$), **b**) medium ($p_0 = 5 \times 10^{16} cm^{-3}$) and **c**) high ($p_0 = 10^{18} cm^{-3}$) doping concentration at low excitation fluence ($N_0 = 10^{12} cm^{-3}$). For each, the relative bimolecular, trapping and detrapping contribution to the carrier concentration and TRPL intensity variations are shown. **d**) Associated TRPL decays.

Note S9: Fitting of simulated TRPL decays at different excitation fluences

Figure S9a shows the values of the parameters extracted from single pulse fitting of TRPL decays simulated for a wide range of excitation fluences (see **Note S4** for more details). In the low fluence regime, only the sum of products $k_M = k_B p_0 + k_T N_T$ can be accurately retrieved while in the high fluence regime, only k_B can be retrieved. All the parameters can be accurately retrieved (with less than 50% error) over a shallow range of excitation fluences in the medium fluence regime. Multiple pulse fitting of TRPL decays subjected to carrier accumulation was also carried at different excitation fluences. The results are similar in the low and high fluence regimes compared to single pulse fitting but no excitation fluence allow to accurately retrieve all the parameters. This highlight that the multiple pulse approximation may be less suitable than single pulse fitting of TRPL decays not affected by carrier accumulation.



Figure S9: **a)** & **c)** Rate constant and concentration values and **b)** & **d)** associated contributions from fitting of TRPL decays simulated at different excitation fluences and with added Poisson noise using the **a)** & **b)** single pulse and **c)** & **d)** multiple pulse approximations ($R^2 > 0.995$). The double arrow indicates the range of fluences where all the parameters are accurately retrieved with less than 50% relative error.

Note S10: Determination of the trap state concentration without fitting

In the case where the initial trapping is much faster than the other recombination processes, it is possible to extract the trap state concentration from TRPL decays without fitting. The electron concentration is given by:

$$\frac{d\Delta n_e}{dt} \approx -k_T \Delta n_e(t) [N_T - n_t(t)]$$

Since the hole concentration can be assumed constant during the trapping phase, the TRPL intensity is proportional to the hole concentration:

$$I_{TRPL}(t) \propto \Delta n_e(t) \Rightarrow \frac{I_{TRPL}(t)}{I_{TRPL}(0)} = \frac{\Delta n_e(t)}{\Delta n_e(0)} = \frac{\Delta n_e(t)}{N_0} = e^{-k_T N_T t}$$

When the trapped electron concentration is equal to the trap state concentration at $t = t_{sat}$, the TRPL decay slows down. The trap state concentration can thus be approximately determined as (**Figure S10**):

$$N_T \sim \left[I_{TRPL}(0) - I_{TRPL}(t_{sat}) \right] N_0$$

Similarly, it is possible to extract the trapping rate from the initial TRPL decay using a mono-exponential fit (while the TRPL decay remains mono-exponential *i.e.* the trap states can be considered empty $n(t) \ll N_T$).



Figure S10: Determination of **a**) the trap state concentration and **b**) trapping rate and trap state concentration product from the initial fast trapping phase after an excitation pulse $N_0 = 2 \times 10^{14} cm^{-3}$.

Note S11: Fitting with different guess values

In order to ensure that only a unique solution to the fit exists, simulated single pulse TRPL decays with added noise were fitted with multiple sets of parameter guess values $(10^{-19}, 10^{-18}, 10^{-17}, 10^{-16} cm^3/ns)$ for the rate constants and $10^{13}, 10^{14}, 10^{15}, 10^{16} cm^{-3}$ for the concentrations). In order to keep the number of fits down, only sets of guess values satisfying $k_T > k_B$ and $k_T > k_D$ were considered. This analysis is applied to low ($N_0 = 10^{12} cm^{-3}$), medium ($N_0 = 3.5 \times 10^{14} cm^{-3}$, chosen for its high detrapping contribution) and high ($N_0 = 10^{17} cm^{-3}$) excitation fluence simulated TRPL decays with added noise. Figure S11 shows the range of values obtained from these fits. At low fluence, all the fits yield the same value $k_M = k_B p_0 + k_T N_T$ but different values of k_B, k_T, k_D, p_0 and N_T . Some of these solutions predict a high bimolecular contribution due to a high $k_B p_0$ while others predict a high trapping contribution leading to the observed wide range of trapping and bimolecular contributions in Figure S11b. At at high fluences, all the fits yield the same value of k_B but not the other parameters due to the dominant bimolecular contribution in this regime. Finally, in the medium fluence regime, the fits converge toward 2 solutions, one of them being the one used to simulate the TRPL decay.



Figure S11: \Box **a)** Range of parameter values obtained from fitting of TRPL decays simulated at low ($N_0 = 10^{12} \text{ cm}^{-3}$), medium ($N_0 = 3.5 \times 10^{14} \text{ cm}^{-3}$) and high ($N_0 = 10^{17} \text{ cm}^{-3}$) fluence (crosses are used in the

case where less than 2 solutions are found) and **b**) corresponding bimolecular ${}^{\%\bar{B_{PL}}}$, trapping ${}^{\%\bar{T_{PL}}}$ and detrapping ${}^{\%\bar{D_{PL}}}$ contributions ($R^2 > 0.985$).

Note S12: Comparison of TRPL decays obtained at different excitation fluences simulated from 2 sets of values

Figure S12 shows that different sets of parameter values can yield very similar TRPL decays with less than 1.5 % difference over a wide range of excitation fluences.



Figure S12: **a)** Evolution of the photoexcited electron, hole and trapped electron concentration calculated using the bimolecular-trapping-detrapping model and 2 sets of values A ($k_T = 12000 \times 10^{-20} \text{ cm}^3/ns$, $k_D = 80 \times 10^{-20} \text{ cm}^3/ns$, $k_B = 26 \times 10^{-20} \text{ cm}^3/ns$, $p_0 = 70 \times 10^{12} \text{ cm}^{-3}$ and $N_T = 60 \times 10^{12} \text{ cm}^{-3}$) and B ($k_T = 12000 \times 10^{-20} \text{ cm}^3/ns$, $k_D = 30 \times 10^{-20} \text{ cm}^3/ns$, $k_B = 26 \times 10^{-20} \text{ cm}^3/ns$, $p_0 = 260 \times 10^{12} \text{ cm}^{-3}$ and $N_T = 60 \times 10^{12} \text{ cm}^{-3}$) and B ($k_T = 60 \times 10^{12} \text{ cm}^{-3}$). **b)** Maximum difference of the normalised TRPL intensity and **c)** total bimolecular (${}^{90}B_{PL}$), trapping (${}^{90}T_{PL}$) and detrapping contributions (${}^{90}D_{PL}$) to the change in the TRPL intensity, calculated using both solution at different fluences.

Fluence regime	$N_0 \ll N_T$	$N_0 \sim N_T$	$N_0 \gg N_T$
Dominant process(es) (concentrations)	Trapping, detrapping	Bimolecular, trapping, detrapping	Bimolecular
Dominant process(es) (TRPL)	Trapping	Bimolecular, trapping, detrapping	Bimolecular
TRPL decay profile fluence dependence	No	Yes	Yes
TRPL decay profile	Mono-exponential	Non-exponential	Non-exponential
Carrier accumulation possible?	Yes, if negligible detrapping (<i>e.g.</i> due to low doping concentration)	Yes	No due to negligible trapping and detrapping
Carrier accumulation affects	Intensity only unless the trapped electron concentration becomes high	Intensity and profile	/

Table S2: Summary of the excitation regimes predicted by the bimolecular-trapping-detrapping model.

enough	

Note S13: Determination of the doping concentration

Assuming negligible carrier accumulation, the experimentally measured initial TRPL intensity is proportional to the radiative recombination rate constant k_R , the number of pulses measured P and the initial electron and hole concentrations N_0 :

 $I_{TRPL}(0) \propto k_R P N_0 (N_0 + p_0)$

Let us consider the initial TRPL intensity measured at N_0^A and N_0^A . Their ratio is:

$$\frac{I_{TRPL}^{B}(0)}{I_{TRPL}^{A}(0)} = \frac{k_{R}P^{B}N_{0}^{B}(N_{0}^{B} + p_{0})}{k_{R}P^{A}N_{0}^{A}(N_{0}^{A} + p_{0})}$$

$$I_{TRPL}^{B}(0)P^{A}N_{0}^{A}(N_{0}^{A} + p_{0}) = I_{TRPL}^{A}(0)P^{B}N_{0}^{B}(N_{0}^{B} + p_{0})$$

$$I_{TRPL}^{B}(0)P^{A}(N_{0}^{A})^{2} + I_{TRPL}^{B}(0)P^{A}N_{0}^{A}p_{0} = I_{TRPL}^{A}(0)P^{B}(N_{0}^{B})^{2} + I_{TRPL}^{A}(0)P^{B}N_{0}^{B}p_{0}$$

$$I_{TRPL}^{B}(0)P^{A}(N_{0}^{A})^{2} - I_{TRPL}^{A}(0)P^{B}(N_{0}^{B})^{2} = (I_{TRPL}^{A}(0)P^{B}N_{0}^{B} - I_{TRPL}^{B}(0)P^{A}N_{0}^{A})p_{0}$$

Finally:

$$p_0 = \frac{I_{TRPL}^{\ B}(0)P^A (N_0^A)^2 - I_{TRPL}^{\ A}(0)P^B (N_0^B)^2}{I_{TRPL}^{\ A}(0)P^B N_0^B - I_{TRPL}^{\ B}(0)P^A N_0^A}$$

where the number of pulses can be calculated from the measurement time M and the repetition period RP:

$$p_0 = \frac{I_{TRPL}^{B}(0) (N_0^{A})^2 M^{A} / RP^{A} - I_{TRPL}^{A}(0) (N_0^{B})^2 M^{B} / RP^{B}}{I_{TRPL}^{A}(0) N_0^{B} M^{B} / RP^{B} - I_{TRPL}^{B}(0) N_0^{A} M^{A} / RP^{A}}$$

We used this formula to calculate the doping concentration at different excitation fluences with added noise. **Figure S13** shows that the doping concentration can easily be determined when N_0^A and N_0^B used are of the same order of magnitude as p_0 . If N_0^A and N_0^B are too high, the doping has a negligible contribution to the initial TRPL and cannot be accurately retrieved. At contrary, if N_0^A and N_0^B are too low, the denominator in the previous Equation tends toward zero and the value of p_0 becomes inaccurate. However, our results suggest that by using a factor 10 difference between N_0^A and N_0^B , we obtain very accurate values even at low fluence (red curve in **Figure S13a**).



Figure S13: Doping concentration calculated from the TRPL initial intensity with added noise as a function of **a)** the ratio of the carrier concentrations N_0^B/N_0^A from 2 to 10 and **b)** noise with a fixed $N_0^B/N_0^A = 5$ ratio (see **Figure S5a** for the noise level used). The double arrows indicate the region where the doping concentration is accurately retrieved.

Rates

 k_R : Radiative direct recombination rate constant (in cm^3/ns)

 k_N : Non-radiative recombination rate constant (in cm^3/ns)

 k_T : Trapping rate constant (in cm^3/ns in the BTD model, in ns^{-1} in the BT model)

 k_D : Detrapping rate constant (in cm^3/ns)

 k_B : Bimolecular recombination rate constant (in cm^3/ns)

 $k_M = k_B p_0 + k_T N_T$: BTD monomolecular term at low fluence (in ns^{-1})

Concentrations

 N_0 : Carrier concentration generated by an excitation pulse in cm^{-3})

 n_e : total free electron concentration (in cm^{-3})

 n_h : total free hole concentration (in cm^{-3})

 Δn_e : photoexcited electron concentration (in cm^{-3})

 Δn_h : photoexcited hole concentration (in cm^{-3})

 n_0 : electron doping concentration (in cm^{-3})

 p_0 : hole doping concentration (in cm^{-3})

 N_T : Trap state concentration (in cm^{-3})

 n_t : Trapped electron concentration (in cm^{-3})

n: charge carrier concentration (in cm^{-3})

Contributions

T: Trapping contribution to the change in the charge carrier concentration

B: Bimolecular contribution to the change in the charge carrier concentration

D: Detrapping contribution to the change in the charge carrier concentration

 T_{PL} : Trapping contribution to the change in the TRPL intensity

 B_{PL} : Bimolecular contribution to change in the TRPL intensity

 D_{PL} : Detrapping contribution to the change in the TRPL intensity

%*C*: Relative contribution of recombination process C = B, *T*, *D*, B_{PL} , T_{PL} , D_{PL}

T: Total number of carriers recombined through recombination process C = B, T, D, B_{PL} , T_{PL} , D_{PL}

%C: Relative total number of carriers recombined through recombination process C = B, T, D, B_{PL} , T_{PL} , D_{PL}

Others

 I_{TRPL} : TRPL intensity experimentally measured and resulting from P excitation pulses

 I_{TRPL}^{p} : TRPL intensity after excitation pulse p

 A_i : amplitude of exponential component i

- τ_i : lifetime of exponential component *i*
- I_0 : Excitation pulse fluence (in *photons/cm*⁻²)
- *A*: Sample absorptance
- *D*: Sample thickness (in *cm*)
- t: time

RP: Excitation repetition period

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