TPL1D User Guide (Version 2)

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Introduction

TPL1D (Time-resolved Photoluminescence 1 Dimension) is a simulation program with graphical user interface [1] for calculating one dimensional transient photoluminescence (PL) response of a silicon wafer under pulsating illumination.

TPL1D assumes low level injection condition, which implies injection level independency of sample minority carrier bulk lifetime. Depth dependency of excess minority carrier generation, diffusion and surface recombination are taken into consideration [2, 3]. The lateral dimension of the silicon wafer is assumed to be much larger compared with its dimension in depth direction, allowing the use of a one dimensional model to describe depth- and time-dependent excess minority carrier density. PL intensity is by default time-resolved and spectrally-resolved [4, 5]. Users could also specify certain wavelength or time to get only time-resolved or spectrally-resolved PL intensity. Temperature dependent minority carrier diffusivity [6] and absorption coefficient of excitation and detection wavelengths are also taken into account [7].

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Graphical user interface

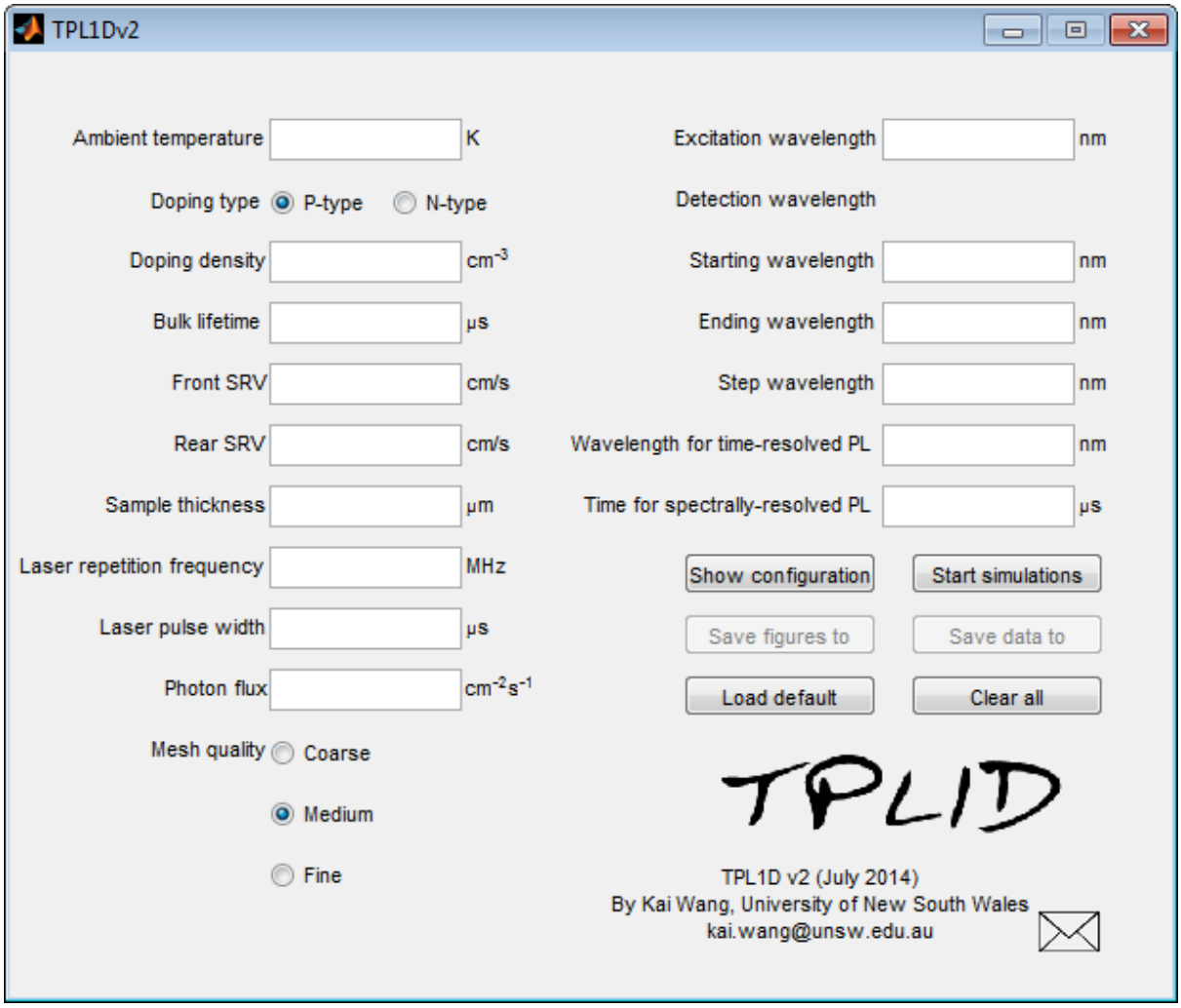

Figure 1. Graphical user interface of TPL1D version 2.

Download TPL1D from PV Lighthouse (http://www.pvlighthouse.com.au/simulation/Hosted/TPL1D/TPL1D.aspx)

Define all simulation input parameters listed in the graphical user interface.

Click the "Show configuration" button to preview the sample and setup configuration for simulation.

Click the "Start simulations" button to generate the simulation results.

The "Save figures to" and "Save data to" buttons will be enabled after simulations are completed.

Click the "Save figures to" button to save all figures to a directory specified by users.

Click the "Save data to" button to save all simulated data to a spreadsheet file with filename and directory specified by users.

Click the "Load default" button to load default input parameters for test purposes, it could also inform new users of data format and input parameter range.

Click the “Clear all” button to clear all simulation inputs, it will also disable the “Save figures to” and “Save data to” buttons.

Sample and setup configuration

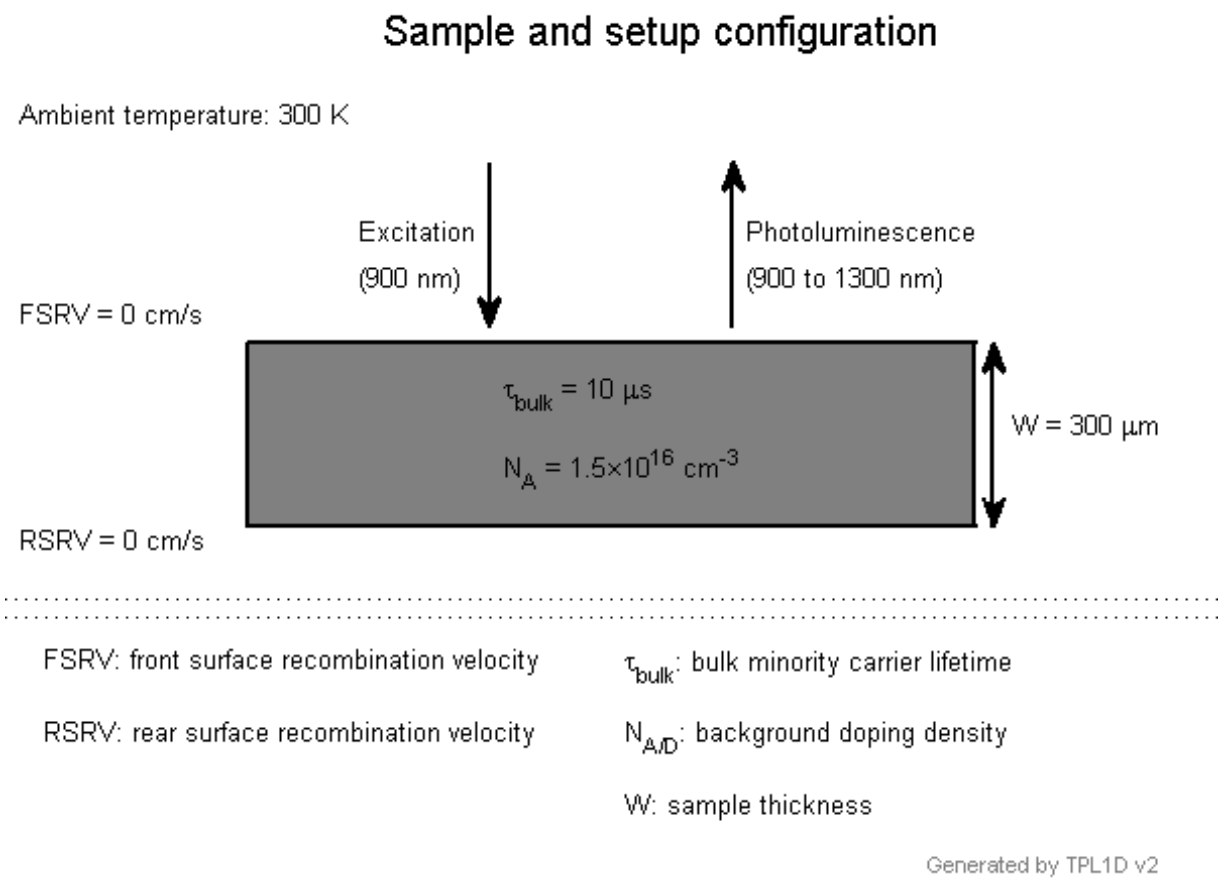

Figure 2. Sample and setup configuration generated by clicking on "Show configuration" button

The sample and setup configuration figure gives a preview of sample, excitation and detection parameters for simulations. Values of parameters shown in the sample and setup configuration will change accordingly with the input parameters in the graphical user interface.

Parameter explanations

Parameter	Explanation
Ambient temperature	Sample ambient temperature
Doping type	Sample doping type
Doping density	Sample background doping density
Bulk lifetime	Sample minority carrier bulk lifetime
Front SRV	Sample front surface recombination velocity
Rear SRV	Sample rear surface recombination velocity
Sample thickness	Sample thickness
Laser repetition frequency	Excitation laser pulse repetition frequency
Laser pulse width	Excitation laser pulse width in one period
Photon flux	Excitation laser photon flux
Mesh quality	Time span and sample dimension mesh quality (The finer the mesh is, the longer it takes for simulations.)
Excitation wavelength	Excitation laser wavelength
Detection wavelength	Detection wavelength range
Starting wavelength	Detection wavelength range lower limit
Ending wavelength	Detection wavelength range upper limit
Step wavelength	Detection wavelength step (The smaller the step is, the longer it takes for simulations.)
Wavelength for time-resolved PL	User specified detection wavelength for time-resolved PL simulations
Time for spectrally-resolved PL	User specified time for spectrally-resolved PL simulations

Bonus feature: User could always hover over the parameter names to get parameter explanations in the graphical user interface.

Bonus applications

Set “Laser pulse width” to be equal to the inverse of “Laser pulse frequency” to simulate steady-state PL intensity

Set both “Laser pulse width” and “Laser pulse frequency” to relatively long time to simulate simple “light on” and “light off” conditions [8]

Set “Sample thickness” to several centimetre thick to simulation silicon bricks

Physical models

Temperature dependent absorption coefficient of crystalline silicon is calculated using Green's model

$$\alpha(T) = \alpha(T_0)\left(\frac{T}{T_0}\right)^{C_p(T_0)T_0}$$

where $T_0 = 300$ K, C_p and $\alpha(T_0)$ denote the temperature and absorption coefficient at 300 K with values obtained from Ref. [7].

PL intensity is calculated using Eqs. (1) and (8) of Ref. [3][†]

$$PL(t) = BB\left[1 - R_f\right]\frac{N_A}{n_i^2}\alpha\int_0^W n(z,t)\frac{e^{-\alpha z} + R_{bn}e^{-2\alpha W}e^{\alpha z}}{1 - R_{fn}R_{bn}e^{-2\alpha W}}dz$$

where BB is given in Eq. (5) of Ref. [9] as

$$BB = \frac{2c}{\lambda^4}\exp\left(-\frac{hc}{\lambda kT}\right)$$

where c is the speed of light, λ is the detection wavelength, h is the Planck constant, k is the Boltzmann constant, N_A is the background doping density, n_i is the intrinsic carrier density, α is the absorption coefficient of the detection wavelength. R_f, R_{fn} and R_{bn} are the external front, internal front and rear reflection of the detection wavelength[‡].

n_i itself is dependent on temperature, which is given by [6]

$$n_i = 5.29 \times 10^{19}\left(\frac{T}{300}\right)^{2.54}\exp\left(-\frac{6726}{T}\right)$$

Temperature dependent electron and hole mobility are calculated as [6]

$$\mu_e = 160(T/300)^{-0.57} + \frac{(1417 - 160)(T/300)^{-2.33}}{1 + \left[\frac{N_A}{5.6 \times 10^{16}(T/300)^{2.4}}\right]^{0.647(T/300)^{-0.146}}}$$

$$\mu_h = 155(T/300)^{-0.57} + \frac{(470 - 155)(T/300)^{-2.23}}{1 + \left[\frac{N_D}{10^{17}(T/300)^{2.4}}\right]^{0.9(T/300)^{-0.146}}}$$

[†] This equation takes p-type background doping as an example. For n-type background doping, replace N_A with N_D and Δn with Δp.

[‡] In Version 2.1, R_f, R_{fn} and R_{bn} are all set to 0 to simplify calculation. Custom settings of R_f, R_{fn} and R_{bn} will be enabled in the following versions.

References

[1] Mathworks, Creating Apps with Graphical User Interfaces in MATLAB, http://www.mathworks.com.au/discovery/matlab-gui.html (2014)

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[4] T. Trupke, M. A. Green, P. Würfel, P. P. Altermatt, A. Wang, J. Zhao, R. Corkish, Temperature dependence of the radiative recombination coefficient of intrinsic crystalline silicon, Journal of Applied Physics 94, 4930 (2003)

[5] P. Würfel, The chemical potential of radiation, Journal of Physics C 15, 3967 (1982)

[6] D. Clugston, P. Basore, PC1D version 5: 32 bit solar cell modelling on personal computers, in Proceedings of the 26th IEEE PVSC, 207-201 (1997)

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[8] K. Wang, M. A. Green, H. Kampwerth, Transient photoconductance and photoluminescence from thick silicon wafers and bricks: Analytical solutions, Solar Energy Materials and Solar Cells 111, 189-192 (2013)

[9] C. Schinke, D. Hinken, J. Schmidt, K. Bothe and R. Brendel, Modeling the spectral luminescence emission of silicon solar cells and wafers, IEEE Journal of Photovoltaics 3 (3), 1038-1052, 2013.

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