Influence of illumination spectrum on dissociation kinetic of iron-boron pairs in silicon

Oleg Olikh, Oleksandr Datsenko, Serhiy Kondratenko

Taras Shevchenko National University of Kyiv, 64/13, Volodymyrska Street, Kyiv, 01601, Ukraine

olegolikh@knu.ua

Estimation of minority carrier diffusion length

In conditions of homogeneous carrier generation in the solar cell's base, which is several minority carrier diffusion lengths L_n, the short circuit current can be described as follows [1,2]:

$$I_{SC} = qN_{ph}\frac{\alpha_{bb}L_n}{1+\alpha_{bb}L_n}, \tag{S1}$$

where N_{ph} is the number of photons absorbed in the solar cell per second; α_{bb} is the coefficient of light absorption. L_n depends on minority carrier lifetime τ:

$$L_n = \sqrt{\mu_n \tau kT / q}, \tag{S2}$$

where μ_n is the electron mobility in the case of p-type base.

In the assumption that it is the iron-related defects that play a predominant role in the recombination, the following expression can be used to estimate τ:

$$\frac{1}{\tau} = \frac{1}{\tau_i} + \frac{1}{\tau_{Fe_i}} + \frac{1}{\tau_{FeB}}, \tag{S3}$$

where τ_i is the lifetime associated with intrinsic recombination; τ_{Fei} and τ_{FeB} are related to the recombination at interstitial iron atoms and at FeB pairs, accordingly. We used Shockley-Read-Hall model to calculate τ_{Fei} and τ_{FeB} and, then, minority carrier diffusion lengths for p-type silicon with different acceptor concentration – see Fig.S1. In our calculation, we took μ_n from Klaassen [3], the defect parameters from Rougieux et al. [4], and the ratio between the concentrations of interstitial iron atoms and at FeB pairs from Wijaranakula [5]. In calculating τ_i, band-to-band radiation recombination and Auger recombination were taken into account, and the temperature dependence of the corresponding coefficients was calculated according to Niewelt et al. [6] and Black & Macdonald [7].

We took temperature dependence L_n from Fig.S1 and α_{bb} (T) from Green [8]. We fitted by using Equation (S1) the experimental dependance I_{SC}(T), which was established by illuminating the solar cell with monochromatic light of 940 nm wavelength using an LED – see Fig.S2. As fitting parameter, L_n at 340 K was taken. The fitting was performed by using the metaheuristic method EBLSHADE [8].

The correlation coefficient between the experimental and calculated data was strong (R = 0.998) and observed for L_n (340 K) = 83 μm.

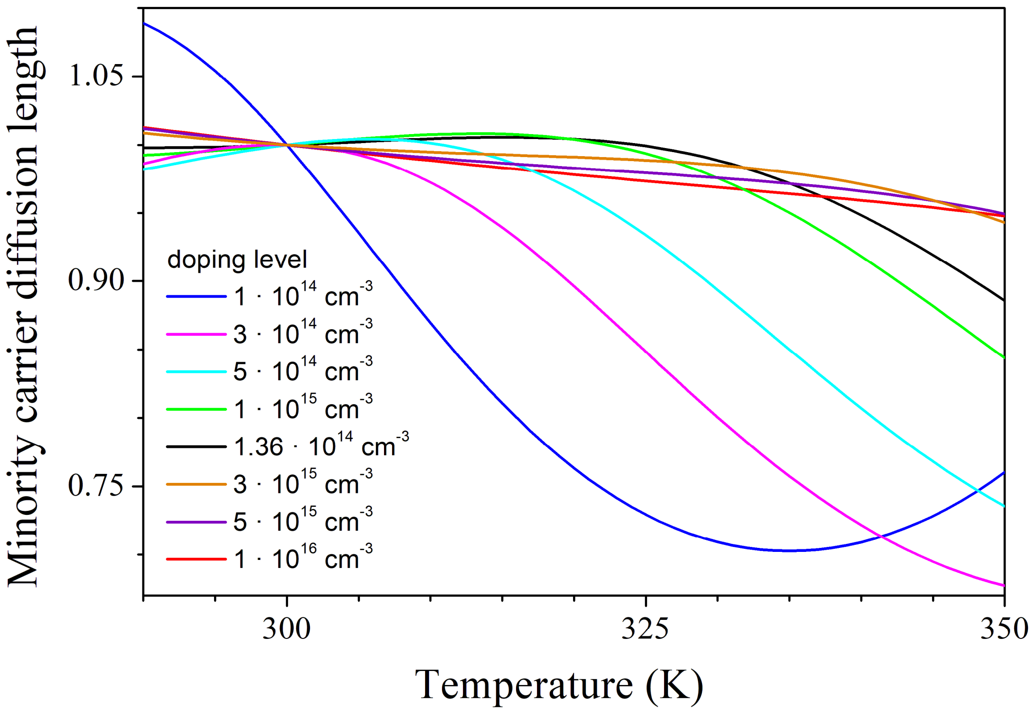

Fig.S1. The temperature dependence of the minority carrier diffusion length in p-Si with predominant recombination at Fe-related defects with total iron concentration in range 10^{12}-10^{13} cm^{-3}. The values of diffusion length are normalized to the magnitude L_n at $T = 300$ K.

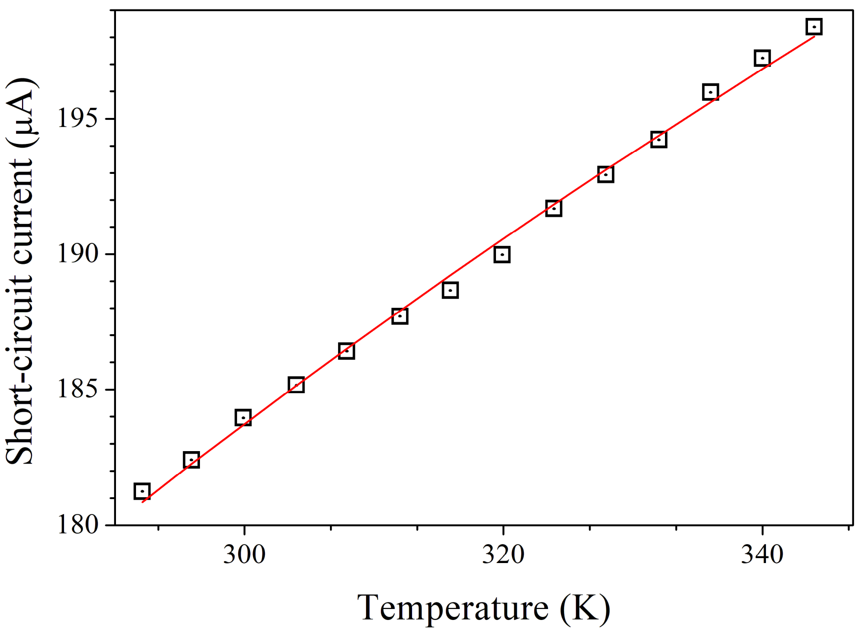

Fig.S2. The temperature dependence of the short-circuit current of investigated solar cell. The marks are the experimental results and the line is the curve fitted by using Equation (S1).

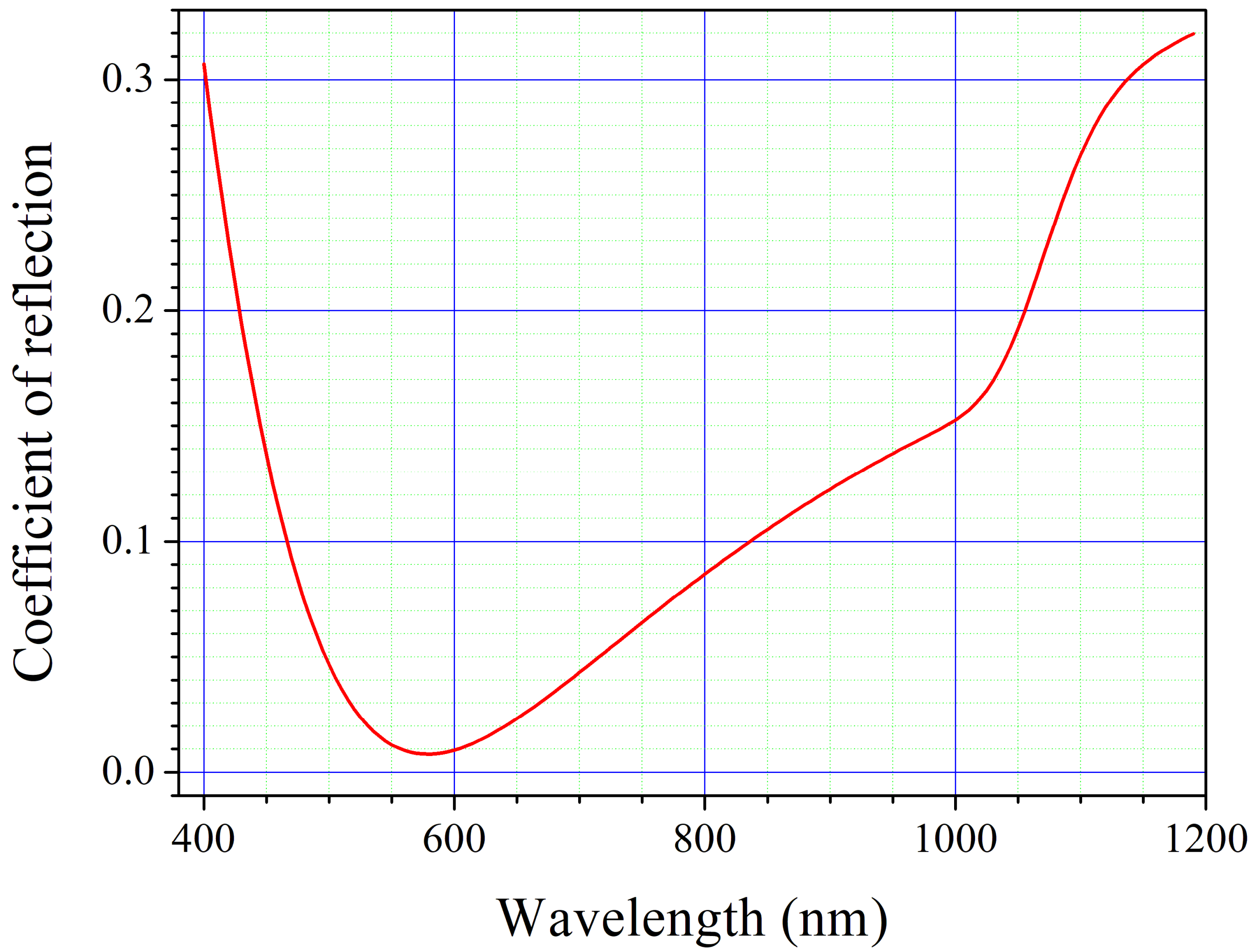

Fig.S3. The spectral dependence of the reflectance for silicon solar cell with antireflective and passivating SiO_2 (30 nm) and Si_3N_4 (40 nm) layers on the front surface. The calculations take into account multiple reflections. The calculations were made in accordance with [10].

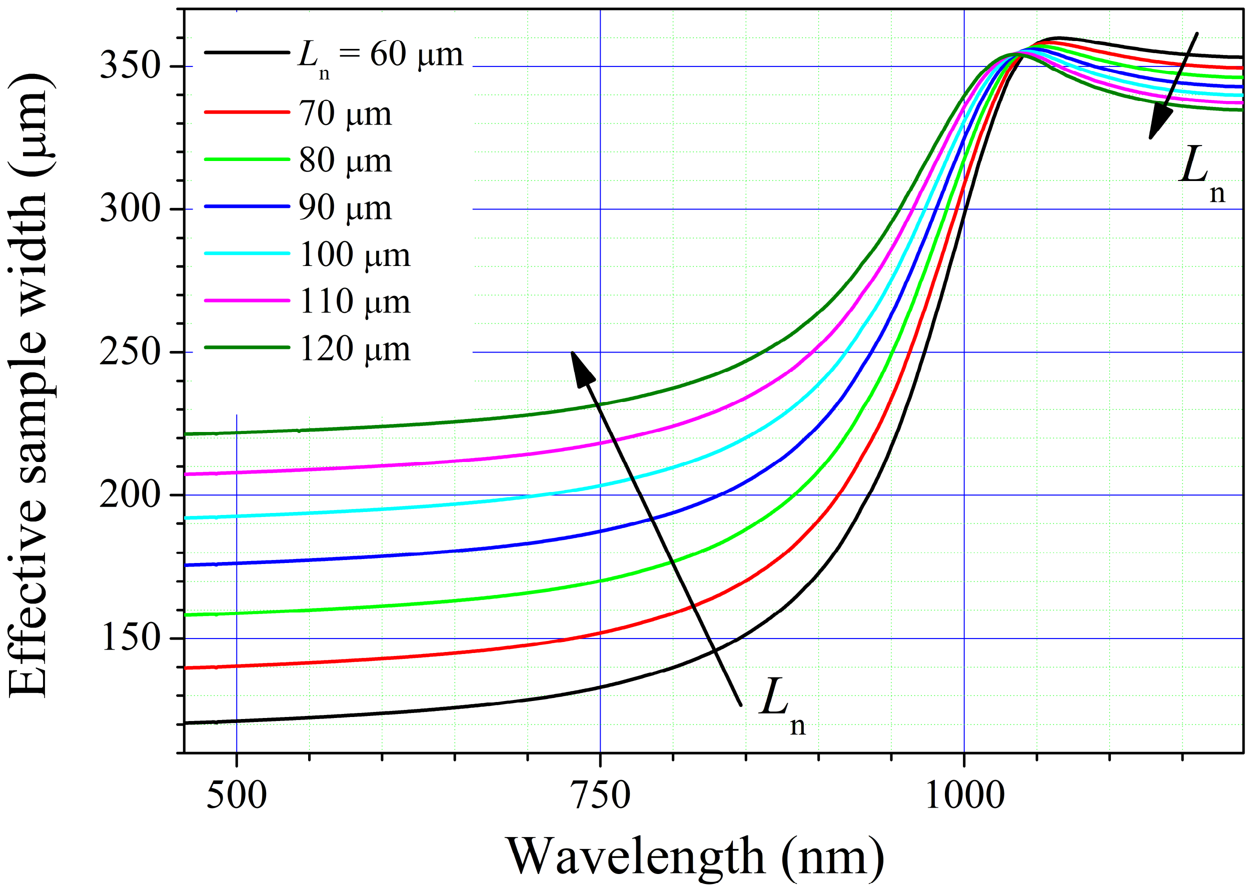

Fig.S4. The spectral dependence of effective width, calculated by using weighted average carrier concentration [11] for the case $T = 340$ K and silicon sample with thick 380 μm, doping level $1.36 \cdot 10^{15}$ cm^{-3}, and minority-carrier diffusion length L_n in the range 60-120 μm.

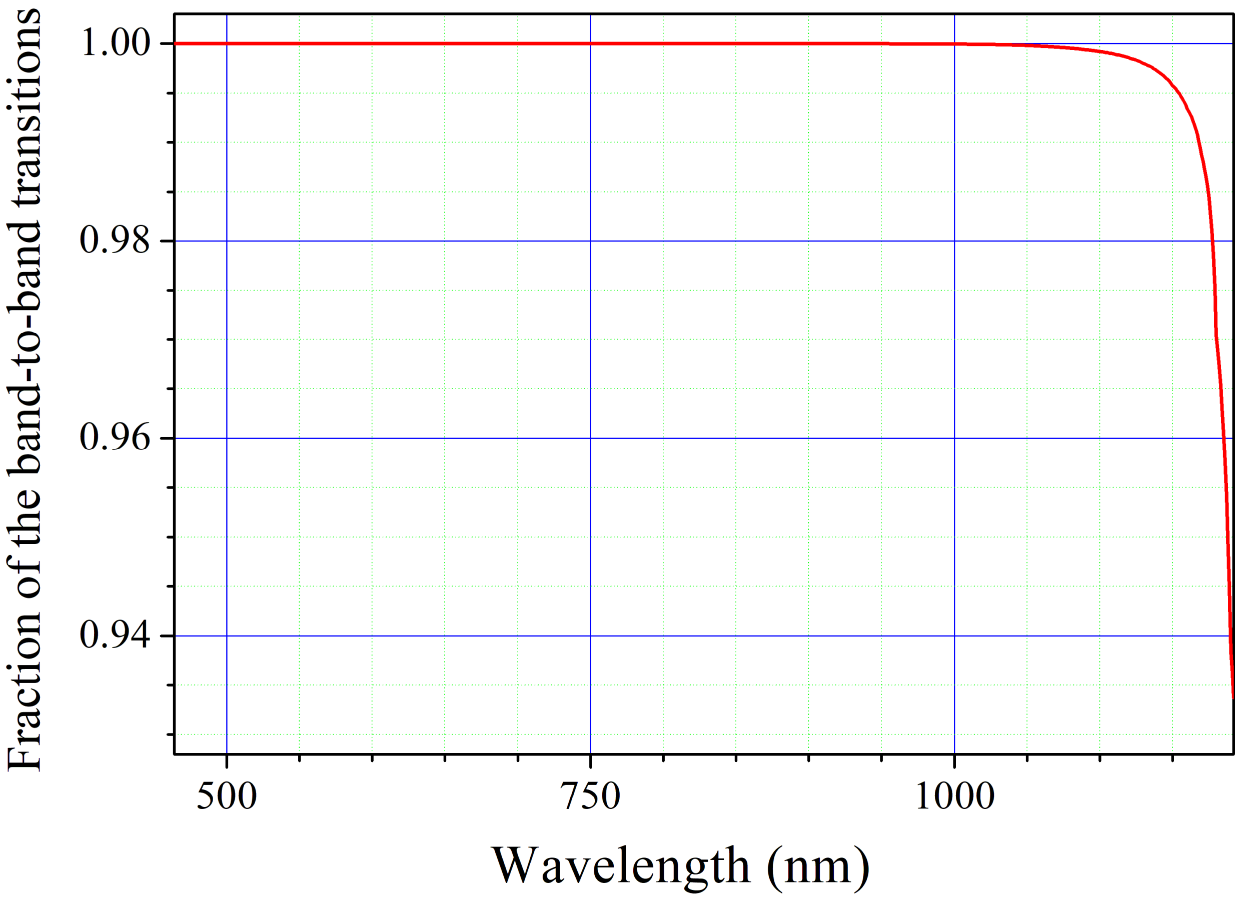

Fig.S5. The spectral dependence of fraction of the band-band transitions, calculated according to [12] for the case T = 340 K and silicon sample with thick 380 μm and doping level $1.36 \cdot 10^{15}$ cm^{-3}.

References

[1] A. Fahrenbruch, R. Bube, *Fundamentals of Solar Cells: Photovoltaic Solar Energy Conversion*, Academic Press, NY, London, Paris, **1983**.

[2] M. Razeghi, A. Rogalski, *J. Appl. Phys.* **1996**, *79*, 10 7433.

[3] D. Klaassen, *Solid-State Electron.* **1992**, *35*, 7 953.

[4] F. E. Rougieux, C. Sun, D. Macdonald, *Sol. Energy Mater. Sol. Cells* **2018**, *187* 263.

[5] W. Wijaranakula, *J. Electrochem. Soc.* **1993**, *140*, 1 275.

[6] T. Niewelt, B. Steinhauser, A. Richter, B. Veith-Wolf, A. Fell, B. Hammann, N. Grant, L. Black, J. Tan, A. Youssef, J. Murphy, J. Schmidt, M. Schubert, S. Glunz, *Sol. Energ. Mat. Sol.* **2022**, *235* 111467.

[7] L. E. Black, D. H. Macdonald, *Sol. Energ. Mat. Sol.* **2022**, *234* 111428.

[8] M. A. Green, *Prog. Photovoltaics Res. Appl.* **2022**, *30*, 2 164.

[9] A. W. Mohamed, A. A. Hadi, K. M. Jambi, *Swarm Evol. Comput.* **2019**, *50* 100455.

[10] N. Klyui, V. Kostylyov, A. Rozhin, V. Gorbulik, V. Litovchenko, M. Voronkin, N. Zaika, *OptoElectr. Rev.* **2000**, *8*, 4 402.

[11] S. Bowden, R. A. Sinton, *J. Appl. Phys.* **2007**, *102*, 12 124501.

[12] S. Schafer, R. Brendel, *IEEE J. Photovolt.* **2018**, *8*, 4 1156.