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

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Please insert your abstract here

1 Introduction

Defects significantly impact semiconductor properties. Although minimizing device dimensions to nanometers shifts some focus from extensive to point defects, physical properties still rely heavily on the presence and distribution of these irregularities. Hence, many strategies for enhancing semiconductor structures, including radiation and temperature treatments or certain fabrication conditions, strive to decrease the defect concentration or neutralize its effects [1, 2, 3]. For instance, in the case of photovoltaic devices, we must understand and optimize the carrier properties tied to defects and impurities [1]. Such controlled alteration methods of the defective subsystem have been generalized under the term "defect engineering" and are extremely important from a practical standpoint.

Successful defect engineering hinges on an in-depth understanding of defect properties. Key factors are defect formation energy, transition energy levels, self-compensating effects, nonradiative recombination caused by defects, and the mechanism of reconstruction and diffusion [1]. Considering the extraordinary diversity of possible intrinsic and impurity defects, complete information on all of them is lacking even for silicon, which is the most studied semiconductor. Nevertheless, it must be noted that considerable data have been amassed on silicon, and have a solid understanding of some defects [4].

For instance, such defects are iron impurity, a common, detrimental, and often unavoidable contaminant in photovoltaic silicon [3, 5], and iron-boron pair. Specifically, iron atoms are known to be at the interstitial sites, and Fe_i^+ are highly efficient recombination centers [6]. In p-type Si at room temperature, iron atoms are almost predominantly bound in complexes with dopants (B, Ga, Al, In). This defect demonstrates bistable behavior: the stable state is defined by the configuration in which the Fe occupies the first nearest tetrahedral interstitial site closest to the substituent atom, whereas, in the metastable configuration, Fe is at the second T_d interstitial site [7]. The energy levels associated with iron and its complexes, as well as the respective carriers capture cross-sections, are well-established [4, 8]. Among the acceptor-iron pairs, the complex FeB is the most thoroughly investigated, primarily due to the widespread use of Si:B in the fabrication of various devices, such as solar cells. However, it is worth mentioning that gallium is gaining increasing attention as an acceptor dopant whose incorporation, for instance, can help mitigate the light and elevated temperature-induced degradation [9].

It is known that FeB pairs can be dissociated by illumination, minority carrier injection and thermal treatment at 200 ° [10].

Reassessing iron–gallium recombination activity in silicon [11]

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Effect of Dopant Compensation on the Behavior of Dissolved Iron and Iron-Boron Related Complexes in Silicon InterJPhotoener 2015 154574 [13]

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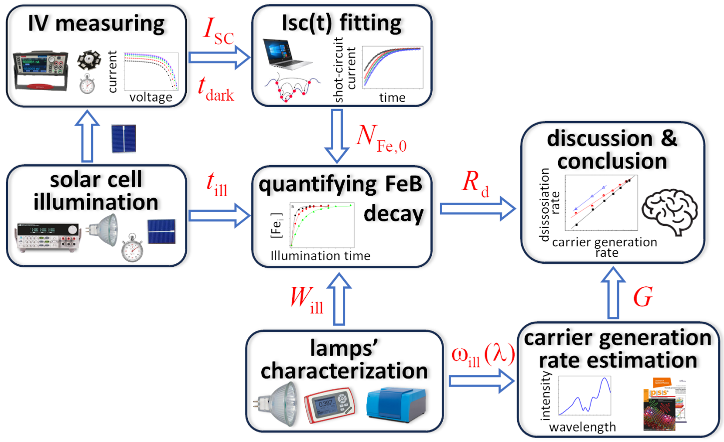

Figure 1: Investigation framework

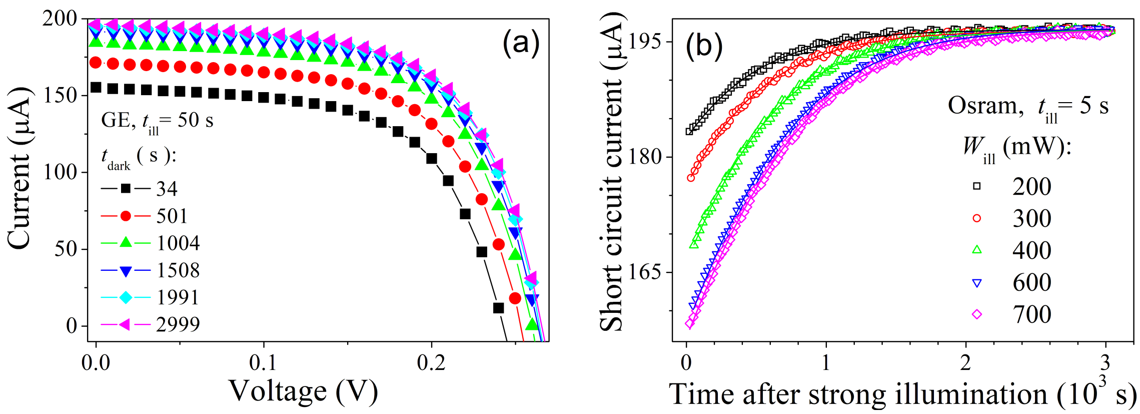

Figure 2: Typical current-voltage characteristics measured under low-intensive (LED) illumination across different periods following exposure to strong light (halogen lamp) (panel a) and short circuit current plotted as a function of the time after high-intensive illumination (panel b). The marks are the experimental results and the lines on panel b are the curves fitted according to [20, 21]. Light sources: GE (a), Osram (b). $t_{\rm ill}$, s: 50 (a), 5(b). $W_{\rm ill} = 50$ mW (b). $T = 340$ K.

PR JApplPhys 98 083509 [16]
SolStPhenom 242 p230 [17]
JApplPhys 95 p1021 [18]
PR PhysStSolRRL 6 p1 [19]

2 Results and Discussion

2.1 First Subsection

2.2 Second Subsection

A part of the radiation especially in the near infrared region of the spectrum is modified by infrared transparency of the reflector and by absorption in the plexiglass window. [22]
$d_{\rm eff}$ [23]
$A_{\rm bb}$ [24]
$\alpha_{\rm bb}$, refractive index n [25]
$\alpha_{\rm fca}$ [26]

3 Conclusion

[27, 8, 28],[29, 30, 31],

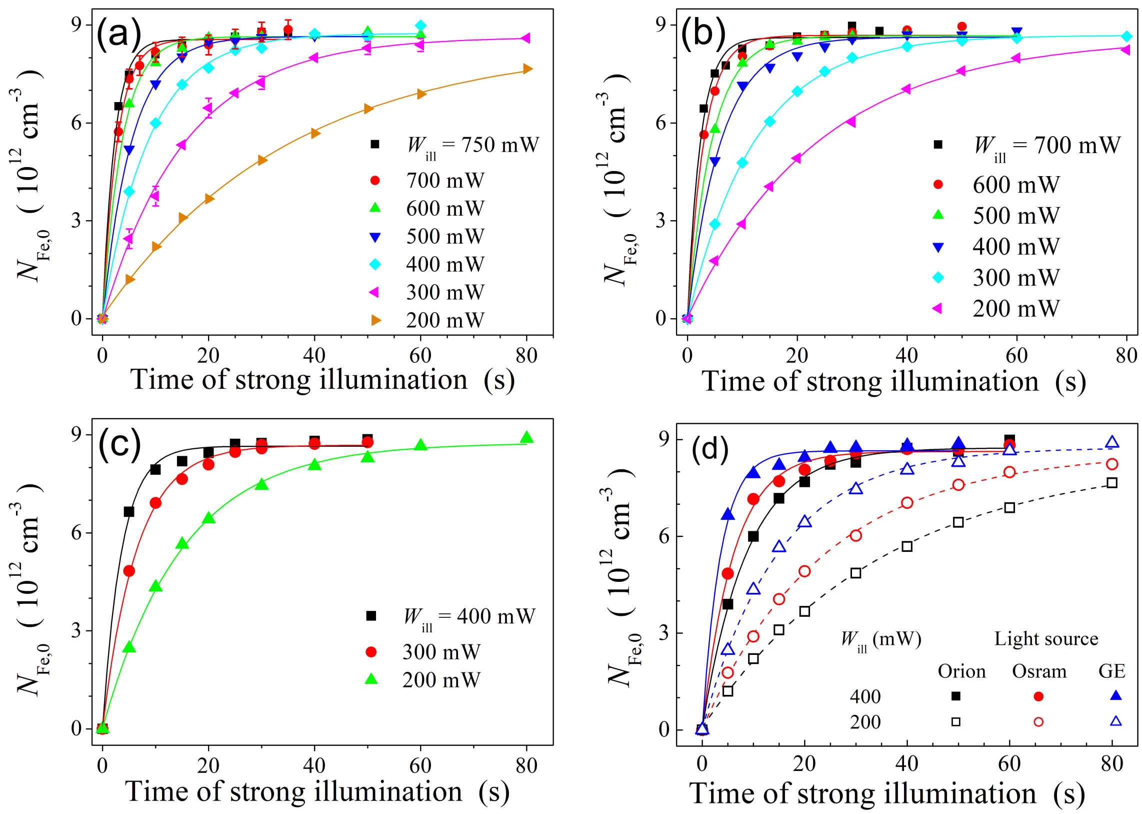

Figure 3: The relationships between the concentration of FeB pairs following intense illuminations of varying intensities and the illumination duration. Light source: Orion (a), Osram (b), GE (c). Panel d highlights variations in the dissociation of pairs induced by different light sources. The marks are the experimental results, the lines are the fitted curves using Equation (**??**). $T = 340$ K.

Table 1: The value of maximum concentrations of iron atoms after illumination and characteristic dissociation time obtained by approximating experimental dependencies by Equation (**??**). Coefficient of determination is listed as well.

$W_{\rm ill}$ [mW]	Light source	$\tau_{\rm dis}$ [s]	$N_{\rm Fe,fit}$ [10^{12} cm^2]	R^2
750	Orion	2.2 ± 0.2	8.6 ± 0.1	0.993
700	Orion	2.7 ± 0.2	8.6 ± 0.1	0.995
	Osram	2.4 ± 0.2	8.6 ± 0.1	0.992
600	Orion	3.7 ± 0.2	8.65 ± 0.06	0.998
	Osram	3.0 ± 0.2	8.69 ± 0.08	0.995
500	Orion	5.5 ± 0.2	8.65 ± 0.04	0.999
	Osram	4.5 ± 0.1	8.7 ± 0.1	0.998
400	Orion	8.8 ± 0.3	8.74 ± 0.06	0.998
	Osram	6.1 ± 0.2	8.63 ± 0.08	0.997
	GE	3.6 ± 0.3	8.7 ± 0.1	0.996
300	Orion	15.7 ± 0.6	8.6 ± 0.1	0.998
	Osram	12.4 ± 0.1	8.69 ± 0.02	0.999
	GE	6.5 ± 0.2	8.69 ± 0.05	0.998
200	Orion	35 ± 3	8.5 ± 0.3	0.998
	Osram	24 ± 1	8.6 ± 0.1	0.999
	GE	15.1 ± 0.5	8.7 ± 0.1	0.999

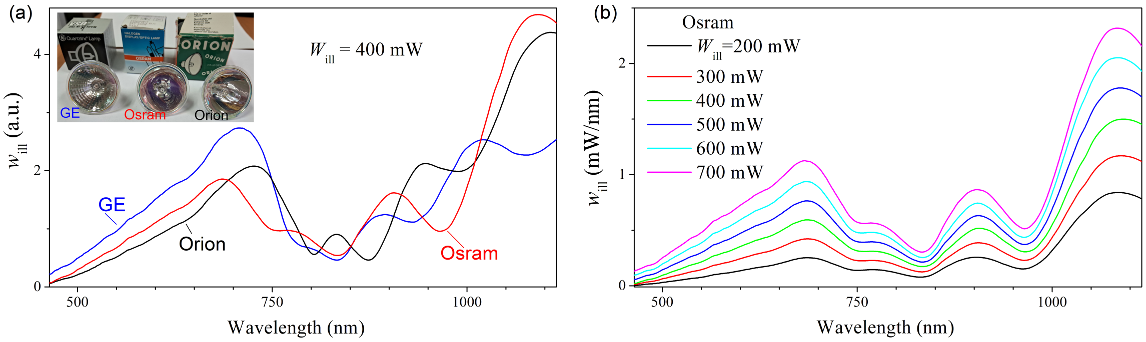

Figure 4: The spectra of sample illumination in the case of using different light sources with the same integrated intensity $W_{\text{ill}} = 400$ mW (panel a) and a single source (Osram) at various W_{ill} values (panel b). The inset shows photos of light sources.

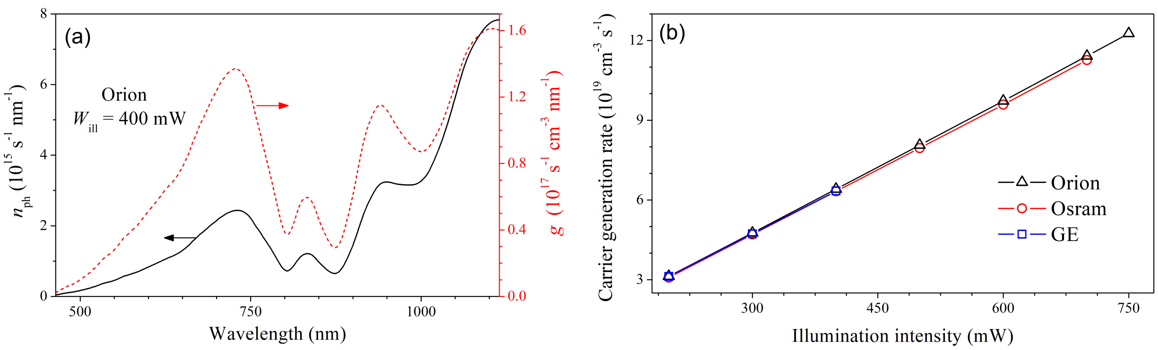

Figure 5: (a) Photon flux spectral density (left axis, solid line) and carrier generate rate spectral density (right axis, dashed line). Orion light source, $W_{\text{ill}} = 400$ mW. (b) Dependencies of carrier generation rate on illumination intensity for different light sources.

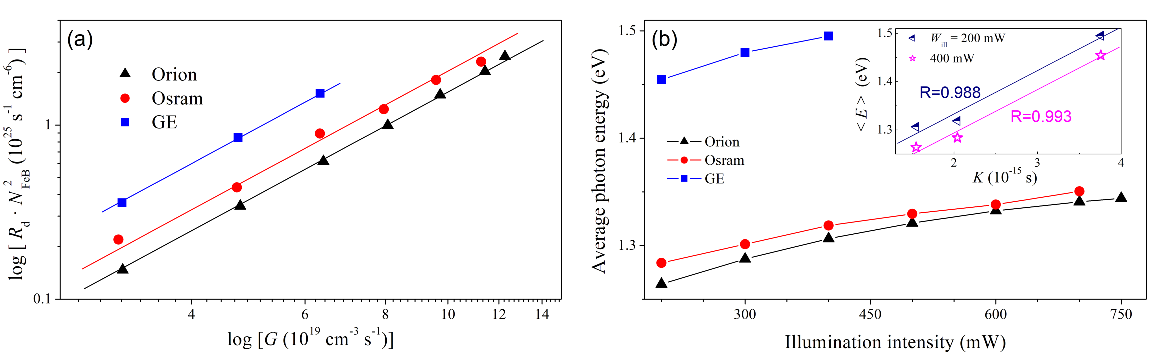

Figure 6: (a) FeB pair dissociation rate plotted as $R_d \cdot N_{\text{FeB}}^2$ over the light induced generation rate. The solid lines show the quadratic dependence according to Equation (**??**). (b) Dependencies of average photon energy on illumination intensity for different light sources. The inset shows prefactor K vs average photon energy for the different light sources and illumination intensities. The lines are linear fitted curves. Coefficients of correlation are shown as well.

Klyui *et al.*[32])

4 Experimental Section

The temperature was maintained constant using a PID (proportional-integral-derivative controller) algorithm which is implemented in the software which serves the system.

First part of experimental section:

Second part of experimental section:

Supporting Information
Supporting Information is available from the Wiley Online Library or from the author.

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Conflict of Interest The authors declare no conflict of interest.

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