Recombination Processes in Diamond

Steps towards a description of long-time trapping

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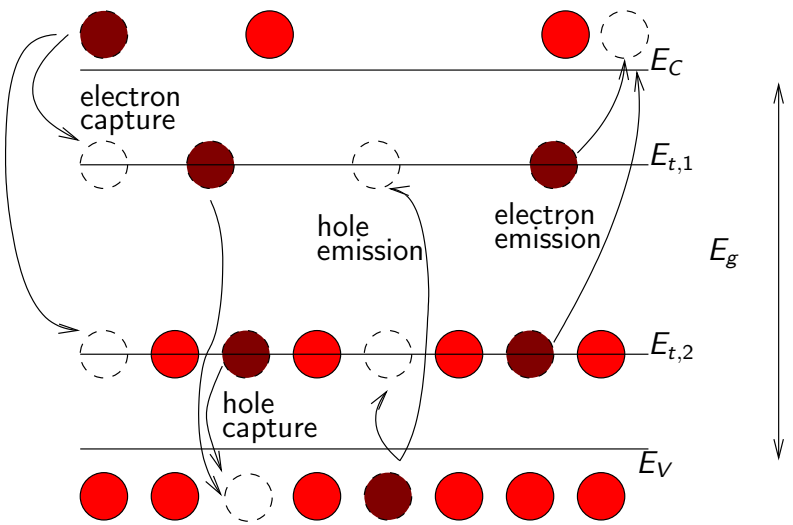
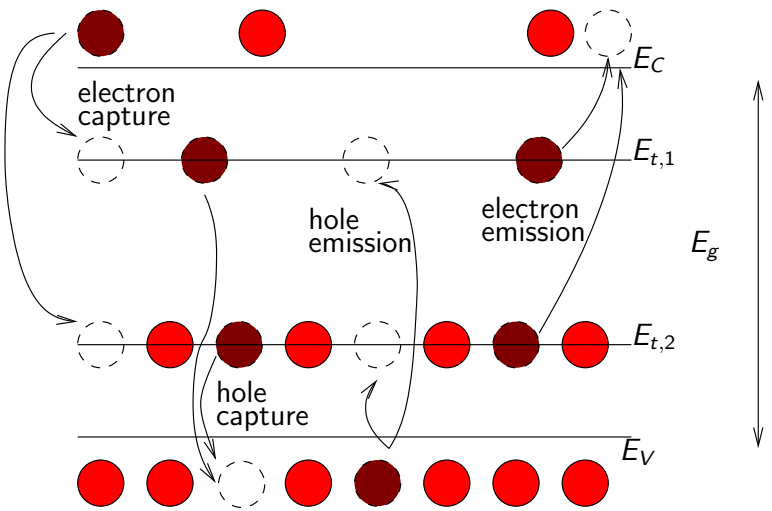
Introduction
Motivation to look at recombination

- Need long time space charge for build up of electric field $\Rightarrow$ Traps
- Statistics of filled traps usally described by Shockley-Read-Hall statistics
- Much depends on energy level of trap within bandgap



Recombination mechanisms
Shockley-Read-Hall (Phonon)



Note:

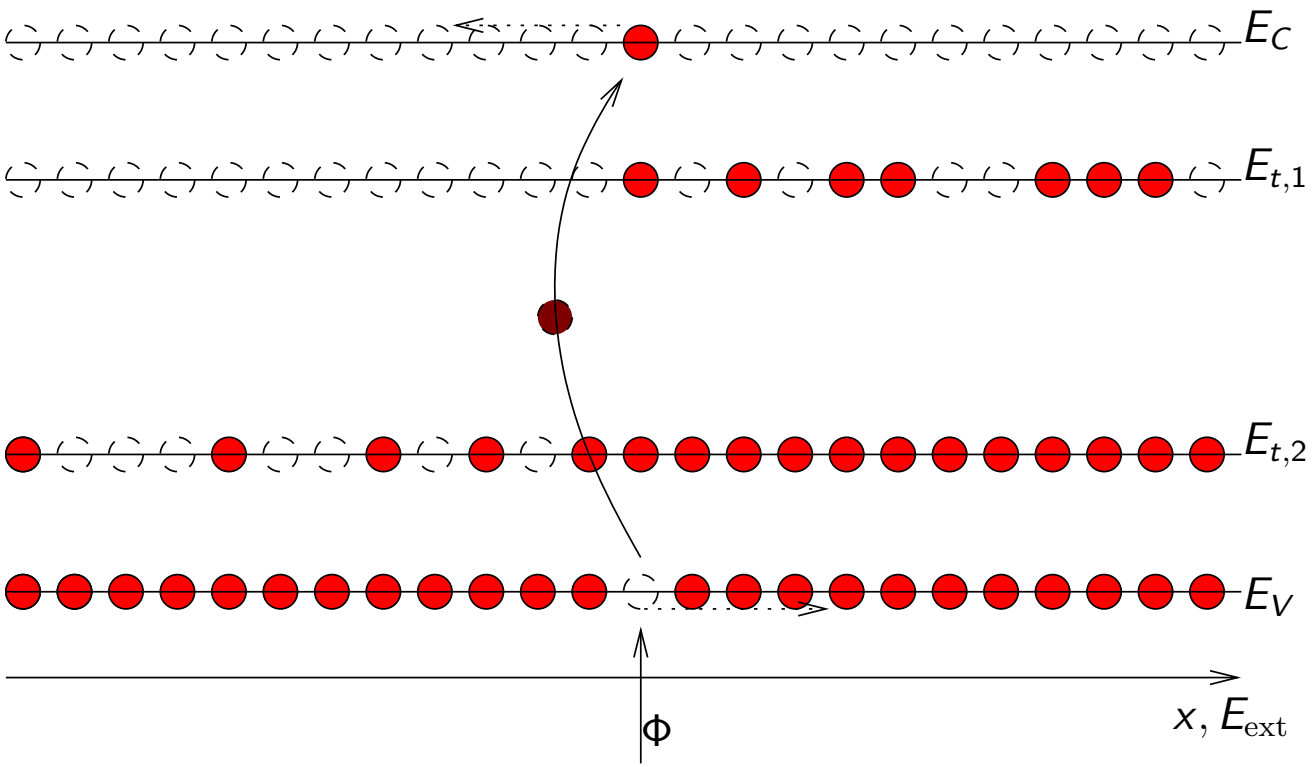
- Levels below E_F are filled with electrons in the neutral crystal
- Position in bandgap determines which carrier type is trapped
- Recombination most probable at mid-bandgap
- Else: trapping of charges
- Depth of trap determines lifetime of trapped carriers: Carriers in shallow traps can easily be thermally rexcited.

Recombination mechanisms

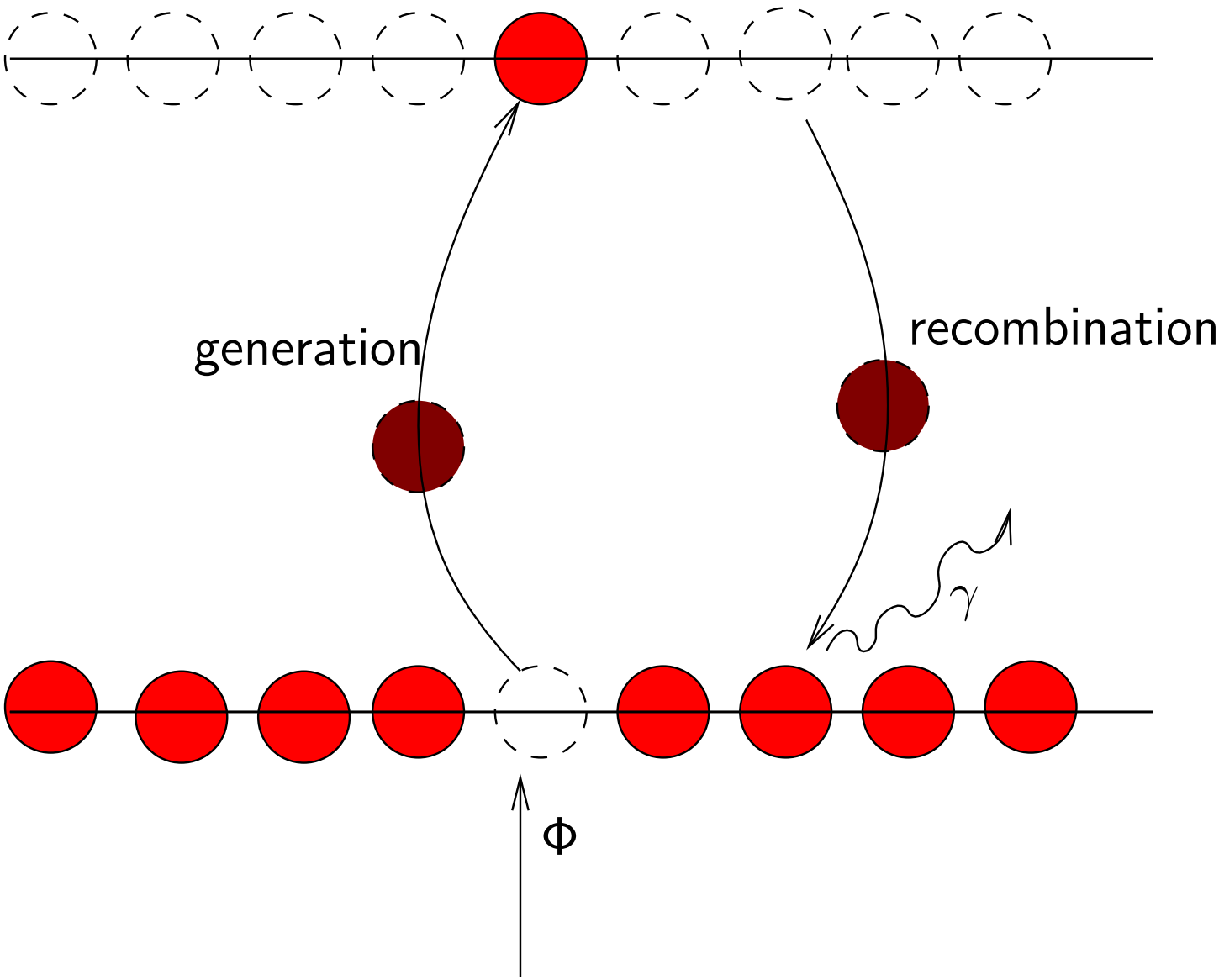
Shockley-Read-Hall: Polarization

Hypothesis

Polarization is a result from filled deep traps. Deep means around $E_V + \frac{1}{4}E_g$ *or* $E_C - \frac{1}{4}E_g$*. Carriers trapped in mid-bandgap will most likely recombine. Carriers trapped closer to* E_C *or* E_V *will be thermally released in short time.*



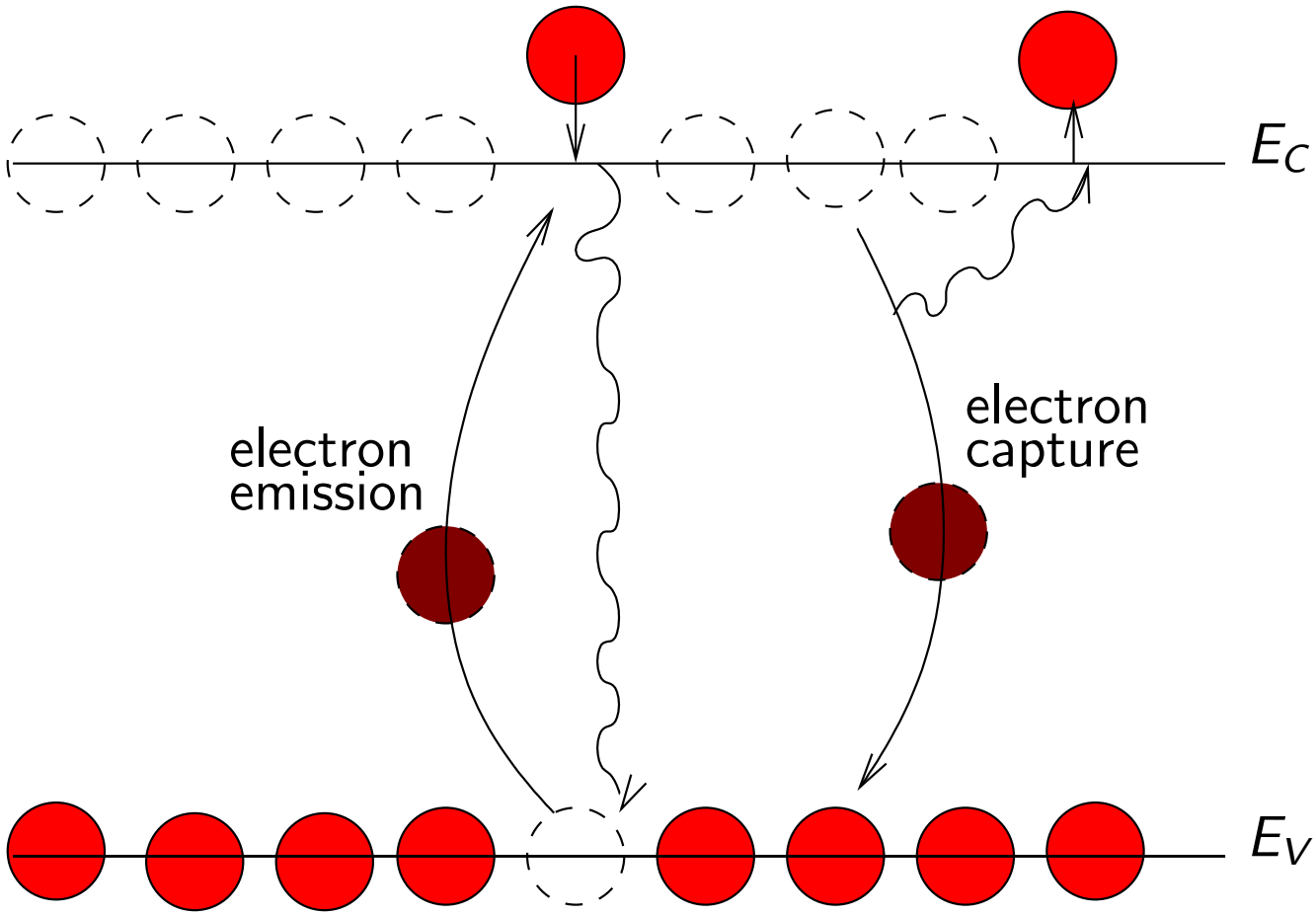
Recombination mechanisms
Direct Recombination (Photon)



Recombination mechanisms

Three particle (Auger) generation/recombination

Energy/momentum is transferred to third particle (also possible for holes)

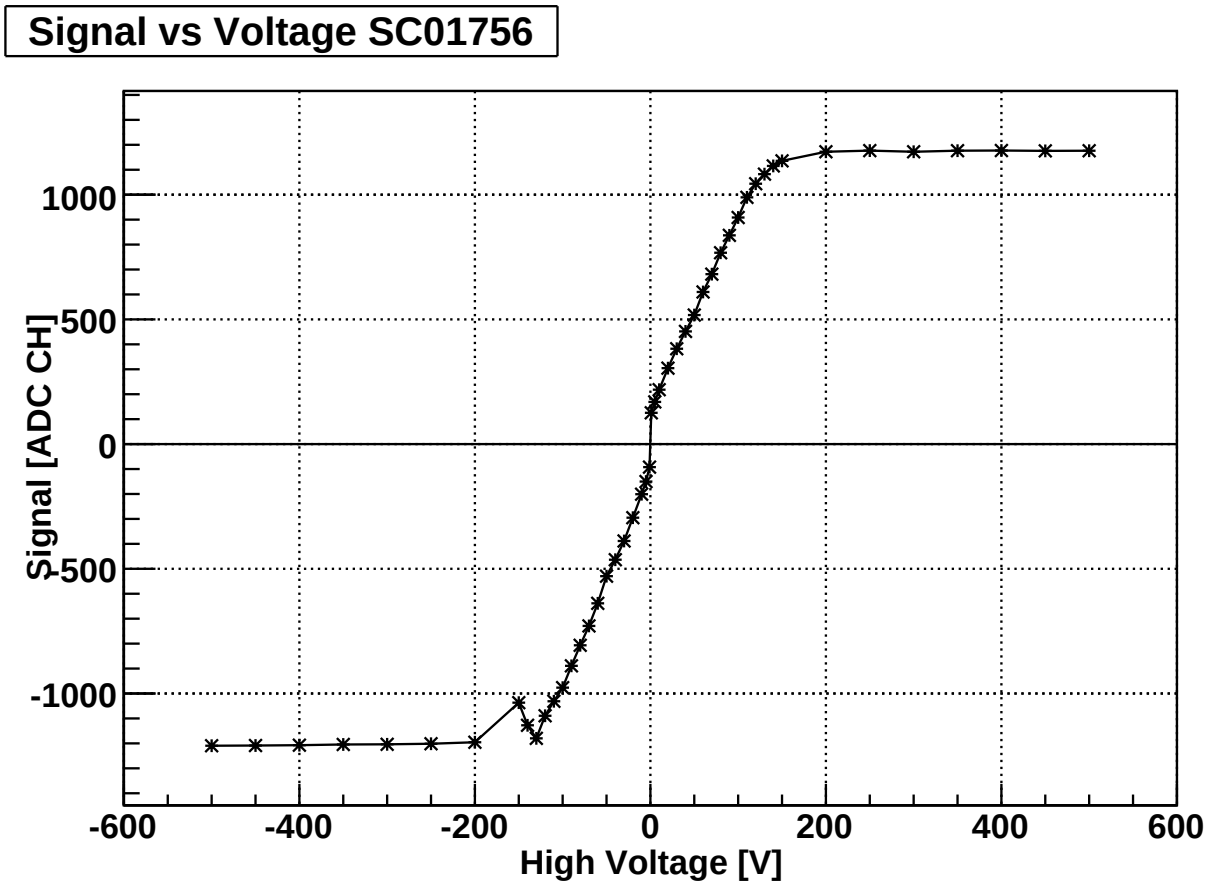


Recombination mechanisms
Rates

	R_n	R_p	G_n	G_p
Direct	$C_c^{\gamma} \cdot n \cdot p$		C_e^{γ}	
SRH	$C_{cn}^{\mathrm{SRH}} \cdot n \cdot (1 - f_t)$	$C_{cp}^{\mathrm{SRH}} \cdot p \cdot f_t$	C_{en}^{SRH}	C_{cp}^{SRH}
Auger	$C_{cn}^{\mathrm{AU}} \cdot n^2 \cdot p$	$C_{cp}^{\mathrm{AU}} \cdot n \cdot p^2$	$C_{en}^{\mathrm{AU}} \cdot n$	$C_{cp}^{\mathrm{AU}} \cdot p$

- Wide-bandgap (diamond): n, p usually small
- Thus, SRH should dominate

Recombination
Unirradiated Diamond



- What happens before saturation? $\longrightarrow$ recombination
- But it's undamaged...still SRH? $\longrightarrow$ traps in undamaged crystal?

Recombination
Unirradiated Diamond

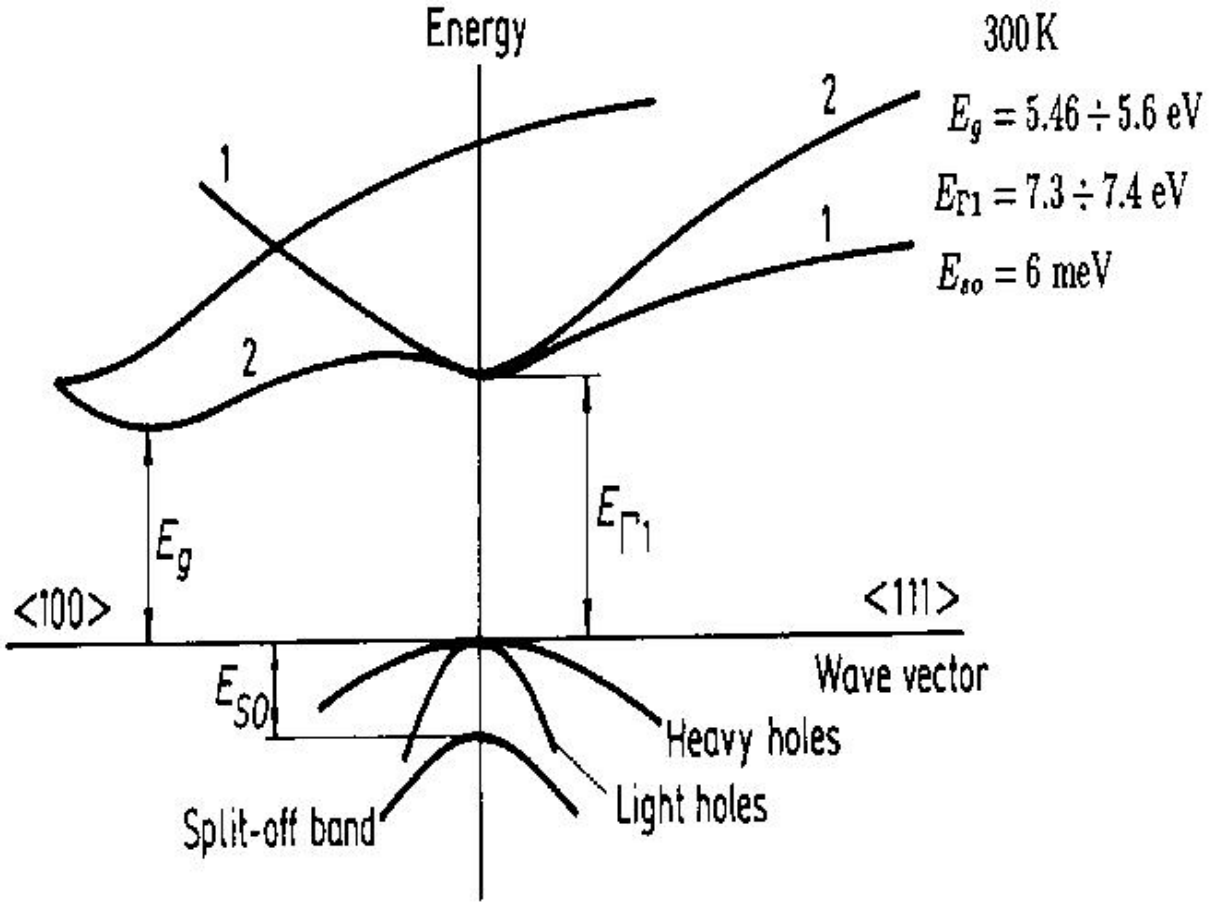


Figure: from: New Semiconductor Materials. Characteristics and Properties, http://www.ioffe.ru/SVA/NSM/

Recombination
Unirradiated Diamond

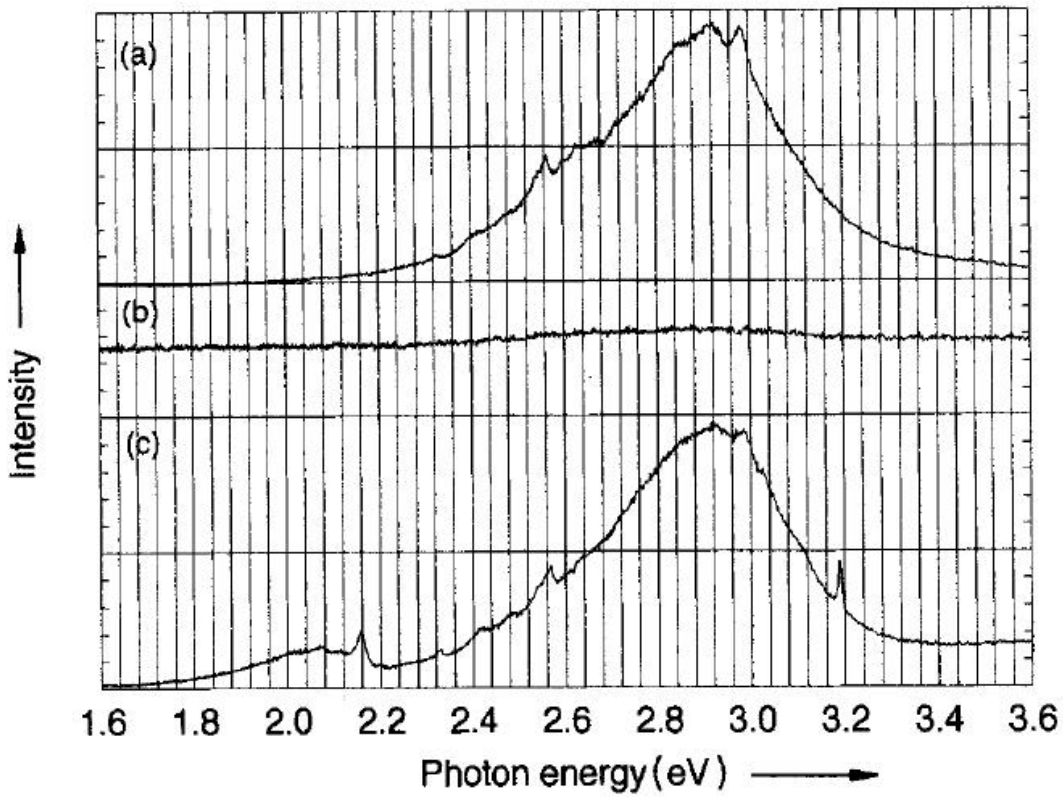


Fig. 12. CL spectra of (a) as-deposited sample, (b) as-implanted sample, (c) as-H_2 plasma annealed sample

Figure: H. Yagzu, phys. stat. sol. (a) 154, 305 (1996)

Recombination
Unirradiated Diamond

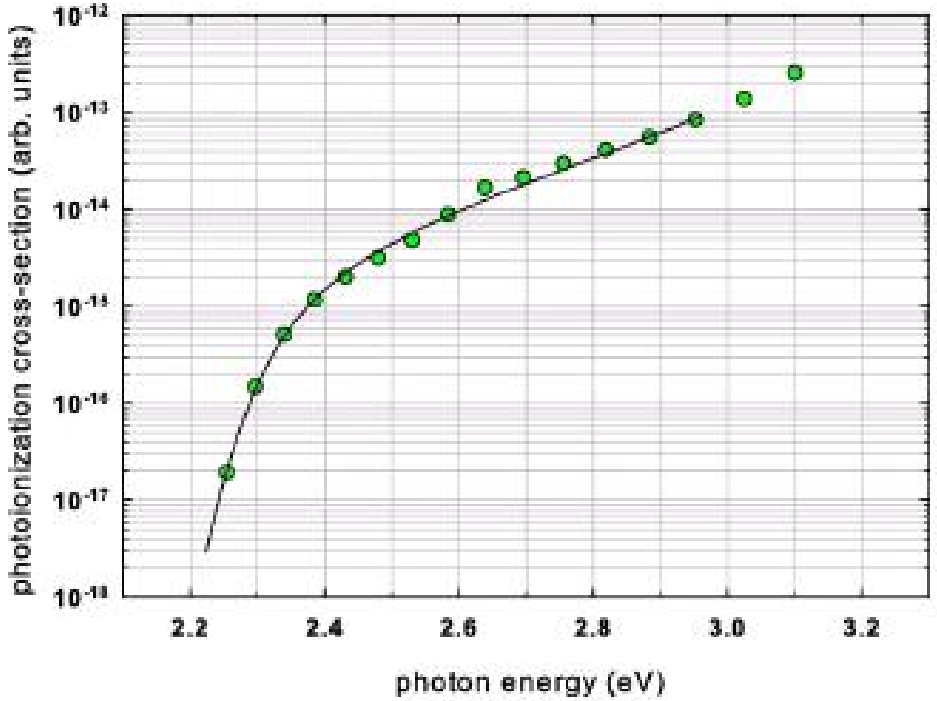


FIG. 5. (Color online) Photoionization cross-section by the dominant deep defect measured using the method described in the text.

Figure: Isberg, J. and Tajani, A. and Twitchen, D. J., Phys. Rev. B 73, 245207 (2006)

Recombination
What now?

- Which recombination mechanism to implement?
- What measurements possible?
- SRH: nice because describes trapping $\longrightarrow$ polarization. If not, what else?
- Optical, Auger recombination negligible?