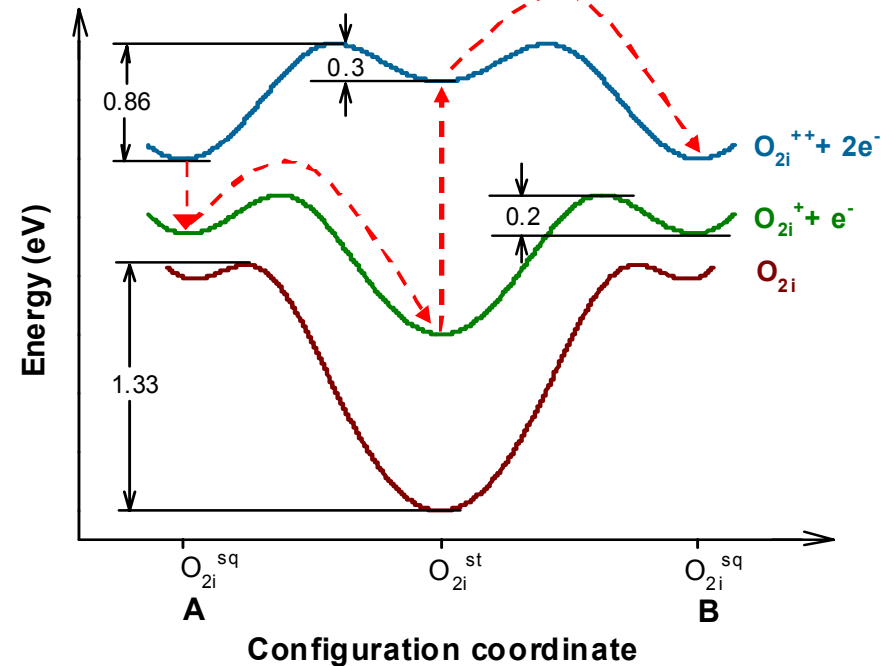
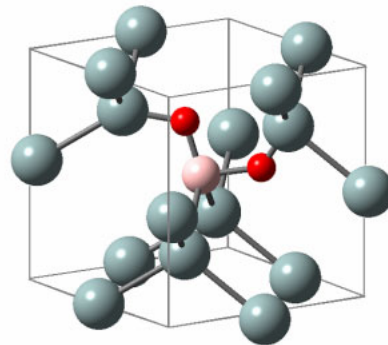
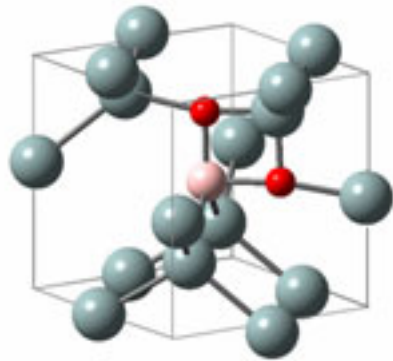
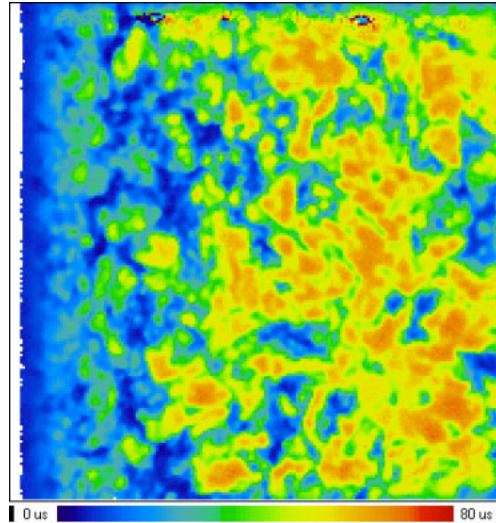
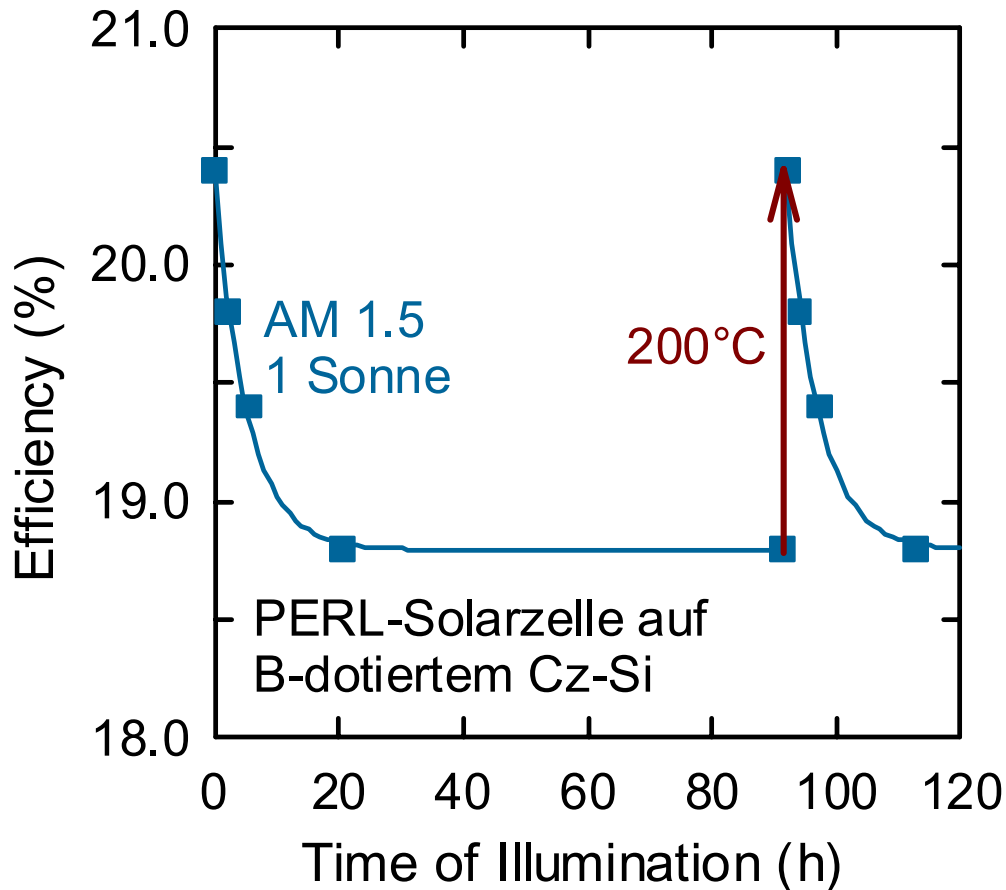


Efficiency-limiting defects in silicon for solar cells

J. Schmidt, K. Bothe, P. Pohl

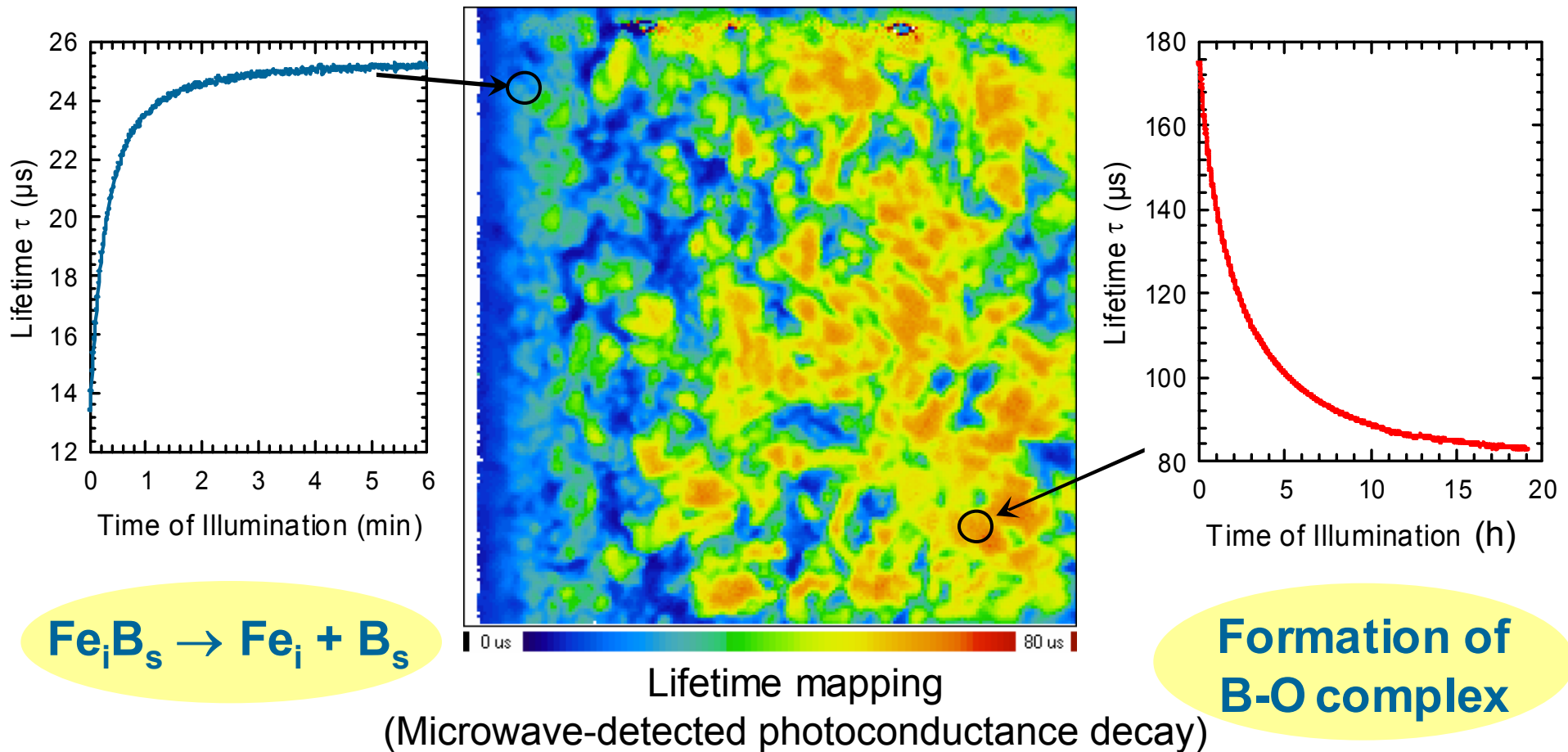


Degradation of Cz-Si solar cells

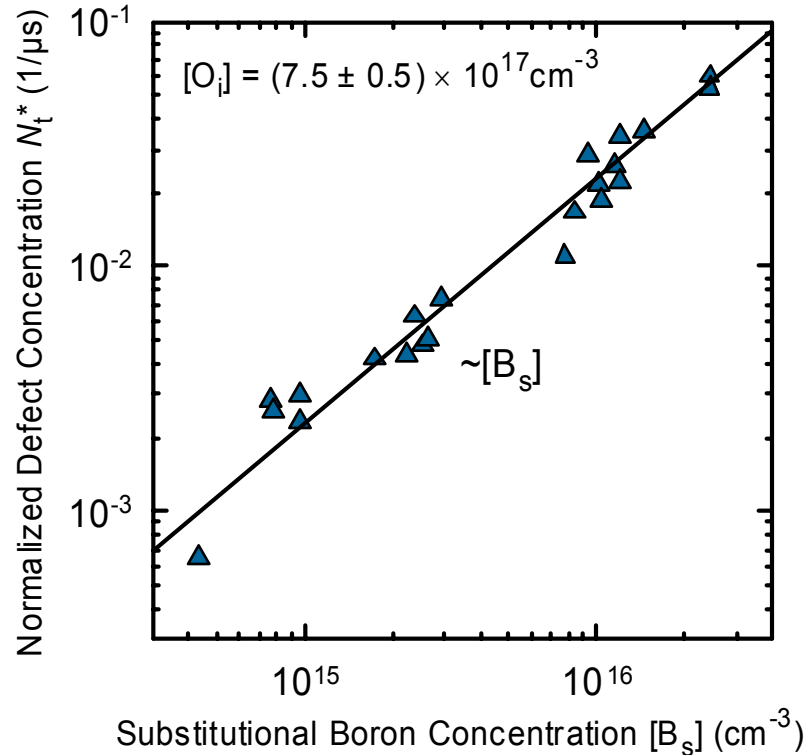


- η degrades up to 10% (relative) during illumination
- Full recovery at $\sim 200^\circ\text{C}$
- Light-induced defect in Cz-Si reduces lifetime
- Defect related to **boron and oxygen**

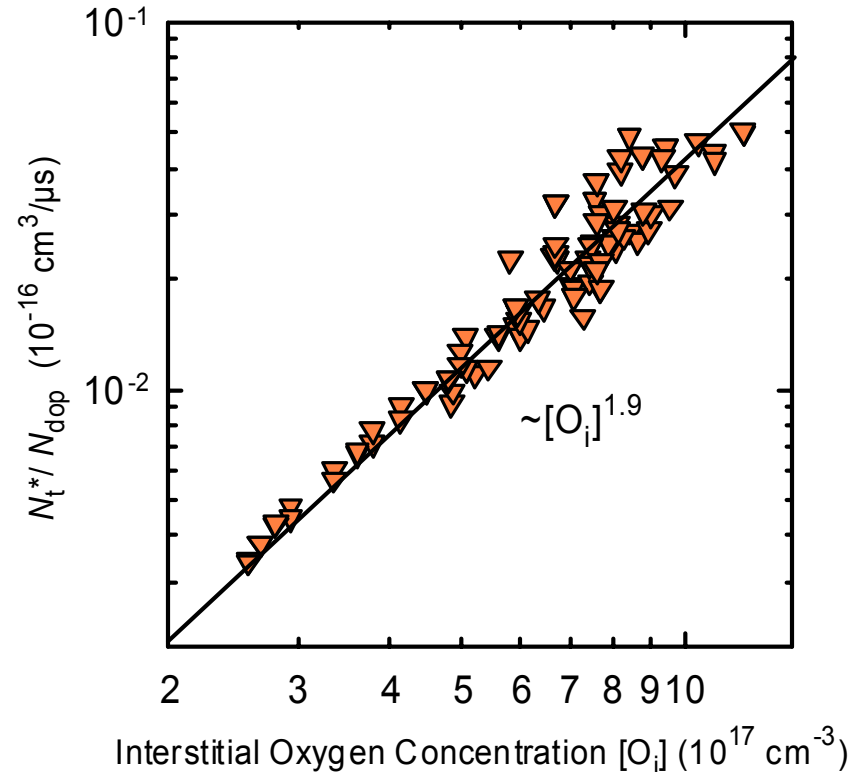
Different light-induced instabilities in mc-Si



Boron and oxygen dependence



Linear increase with $[B_s]$



Quadratic increase with $[O_i]$

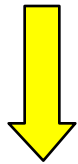
⇒ Defect composed of 1 B_s + 2 O_i atoms

J. Schmidt and K. Bothe, *Phys. Rev. B* 69, 024107 (2004)

Degradation by electron injection



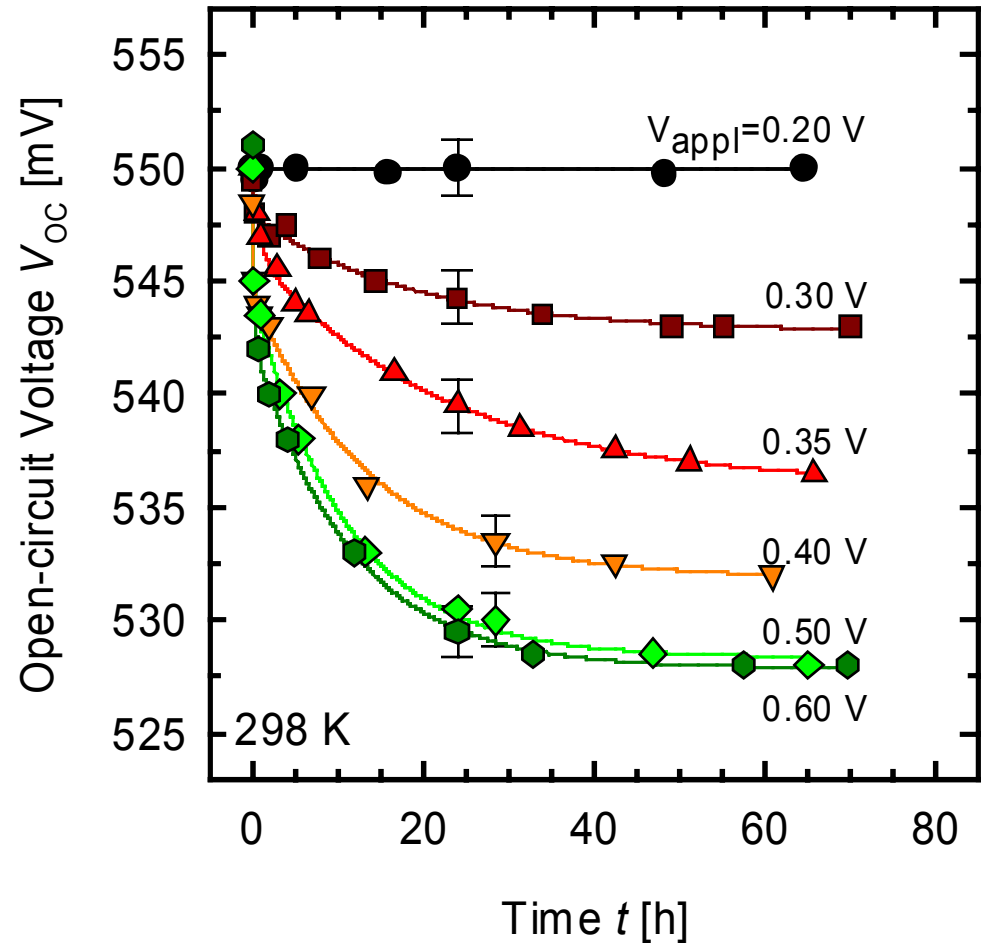
Degradation by applying a forward-bias in the dark



Degradation is electronically stimulated



Recombination-enhanced defect reaction

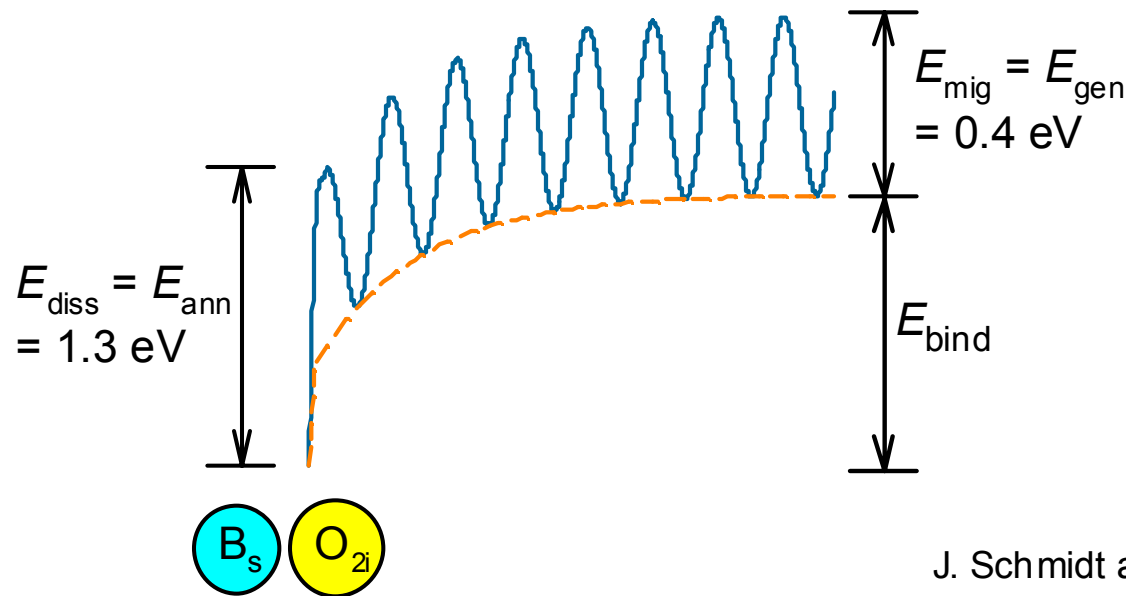


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Two-step defect formation:

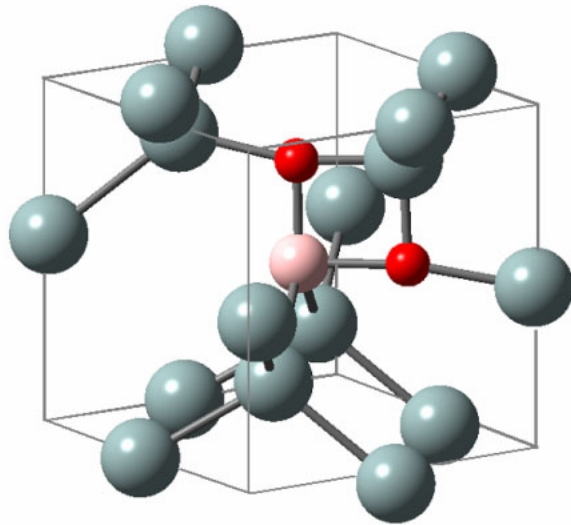
- (i) Configurational change of O_{2i} due to recombination event
 O_{2i} (low diffusivity) \rightarrow O_{2i}^* (high diffusivity)
- (ii) Fast-diffusing O_{2i}^* captured by $B_s \rightarrow B_s-O_{2i}$



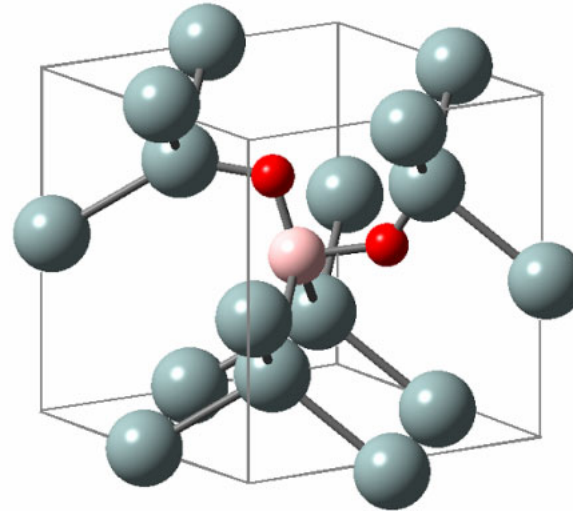
Recombination-enhanced diffusion of oxygen dimer O_{2i}

J. Schmidt and K. Bothe, *Phys. Rev. B* **69**, 024107 (2004)

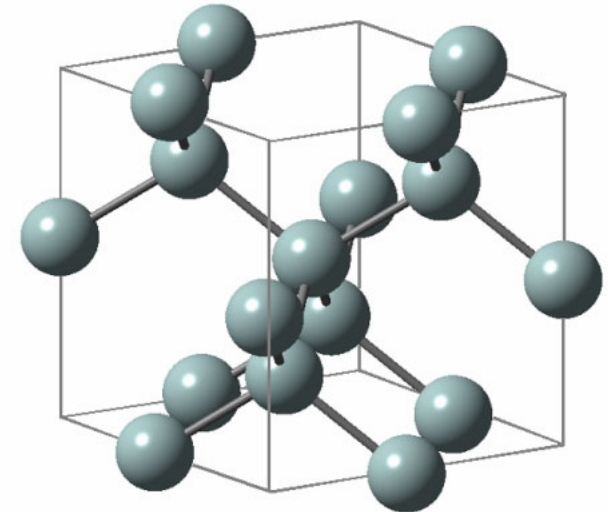
Ab-initio calculations (AIMPRO)



'square' form



'staggered' form



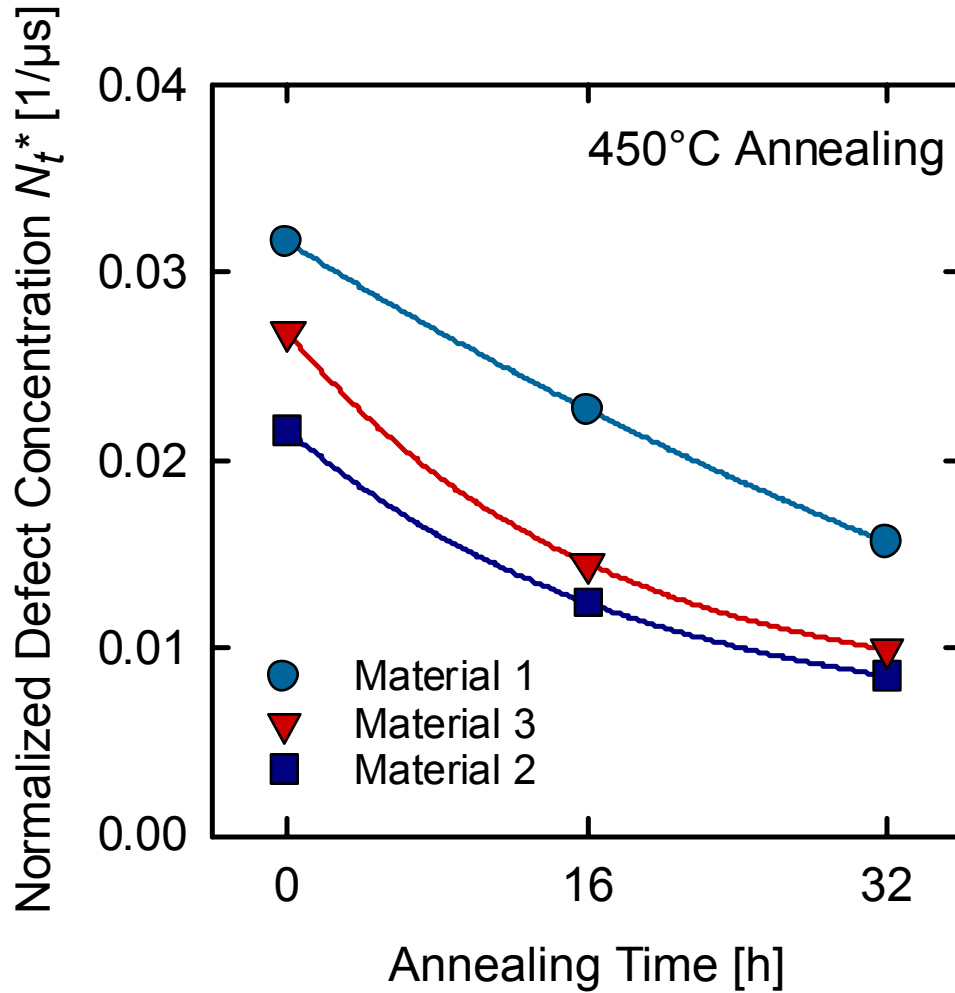
Si host lattice

- More stable in + charge state
- $E(0/+) = E_C - 0.3 \text{ eV}$
- More stable when neutral
- No energy level in silicon band gap

Institut für Solarenergieforschung Hameln/Emmerthal

Cooperation with R. Jones,
School of Physics, University of Exeter

Reducing the degradation by defect engineering



- Formation of thermal donors ($\sim 0.25 \times 10^{16} \text{ cm}^{-3}$ TDs in 16h)
- TD formation reduces $[O_{2i}]$

↓

**Reduction of degradation
by a factor of ~2-3**

- Today's Si solar cells suffer from **boron-oxygen-related degradation**
- Recombination-enhanced defect reaction: $B_s + O_{2i} \rightarrow B_sO_{2i}$
- Defect model confirmed by **ab-initio calculations**
- **Remedies** for light-induced degradation:
 - use of **alternative dopants** (gallium, phosphorus)
 - **reduced oxygen concentration** (magnetically confined Cz growth)
 - **defect engineering** (during process, deliberate contamination)
 - adaptation of **solar cell structure** (e.g., RISE-EWT)