Silicon solar cell efficiency limited by boron-oxygen defect centers

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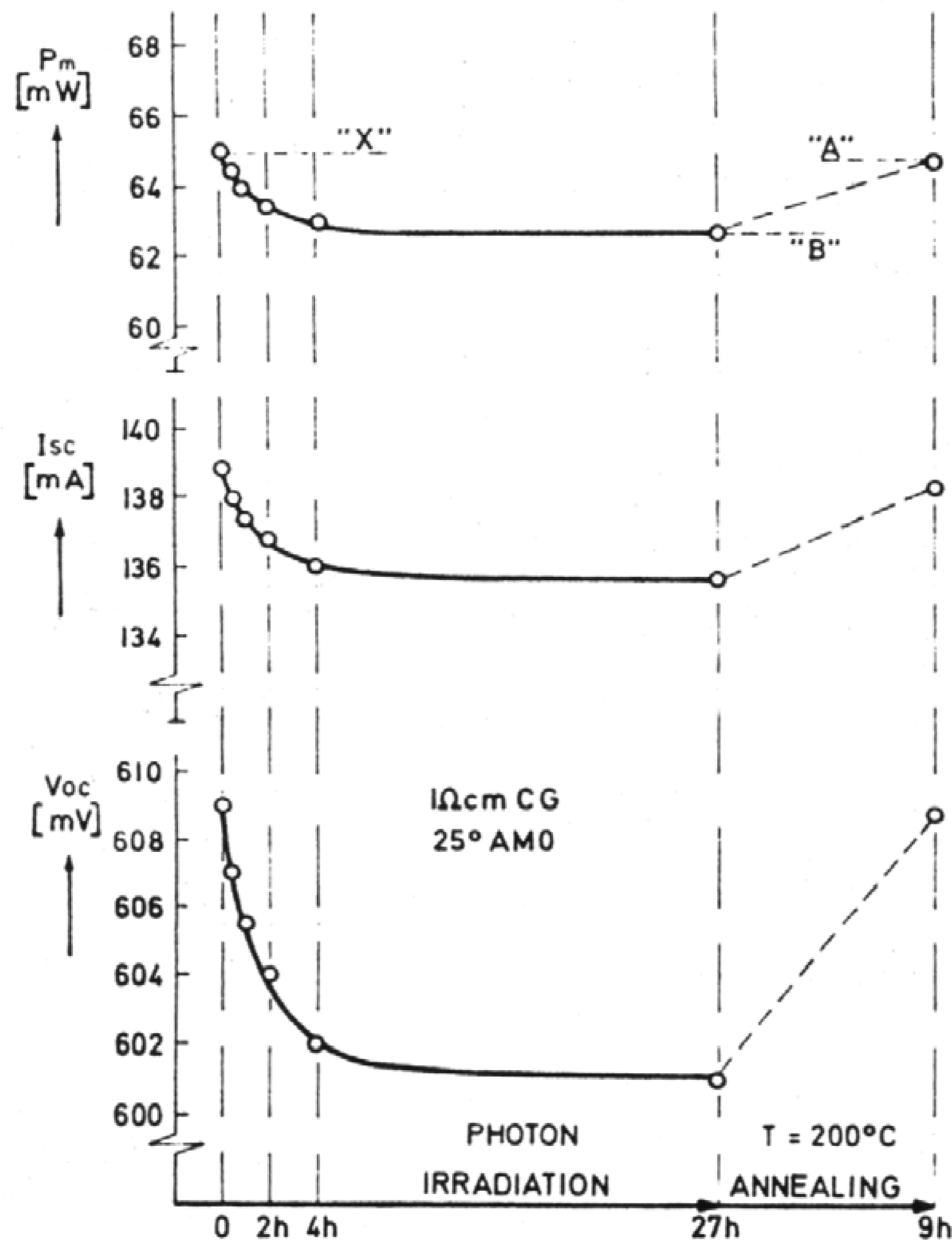
Motivation

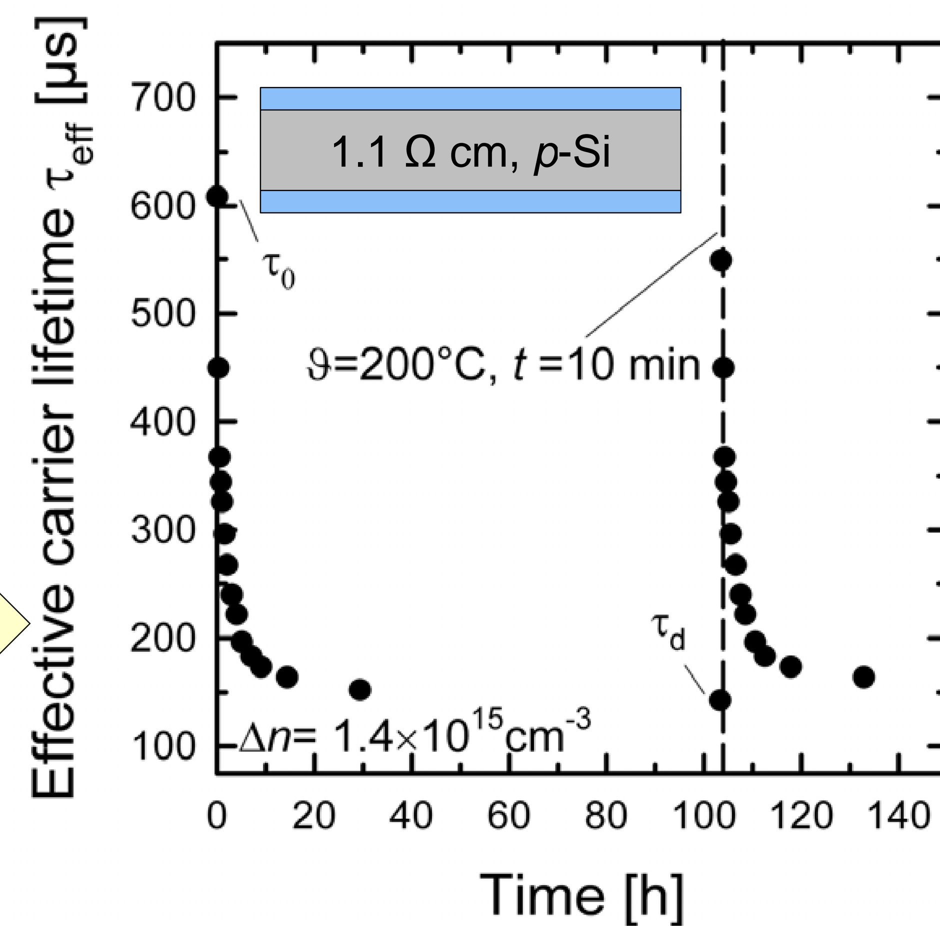


Fischer and Pschunder, *Proc. 10th IEEE PVSC*, **1973**, p. 404

- Degradation of boron-doped oxygen-rich crystalline silicon
- Market share of ~30% of total PV production in 2011

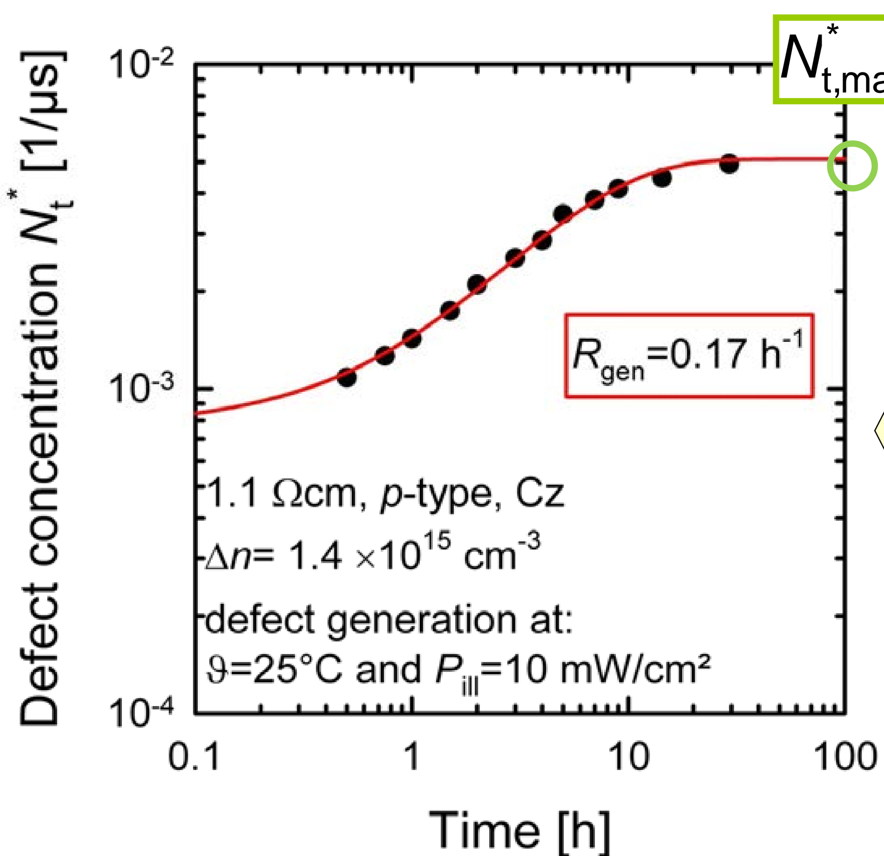
- Degradation of solar cell parameters under illumination at 25°C
- Complete recovery to the initial values after annealing at 200°C
- Recovered state degrades under subsequent illumination

- Degradation of the effective carrier lifetime under illumination at 25°C
- Complete recovery of the initial values after annealing at 200°C
- Solar cell degradation due to reduction of bulk lifetime



Defect generation

- Effective defect concentration N_t^*

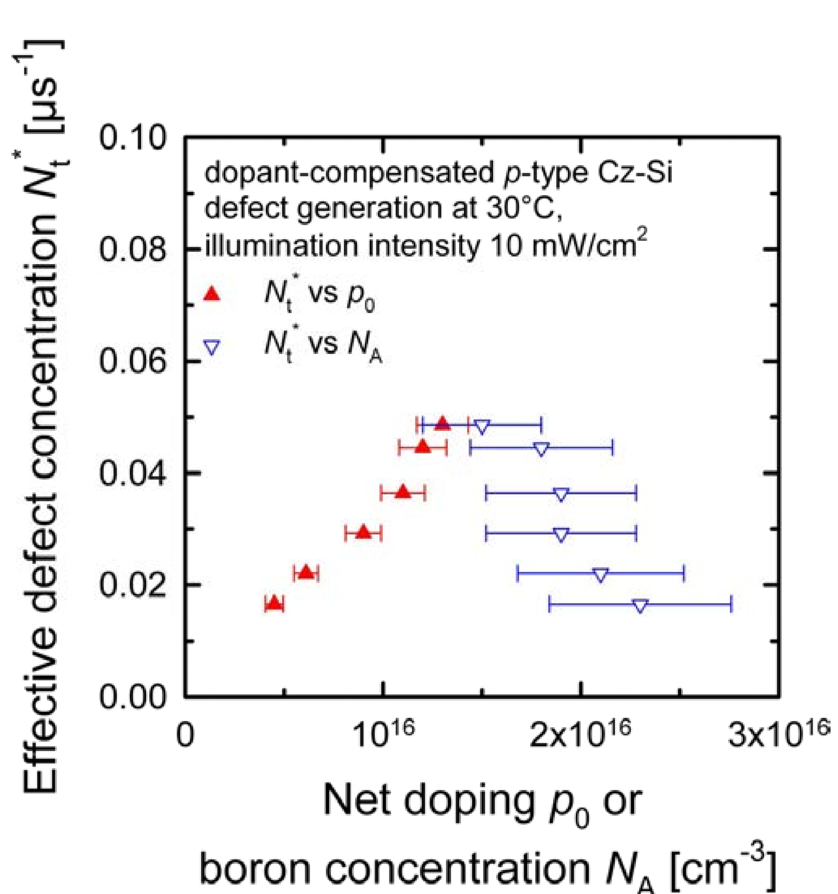


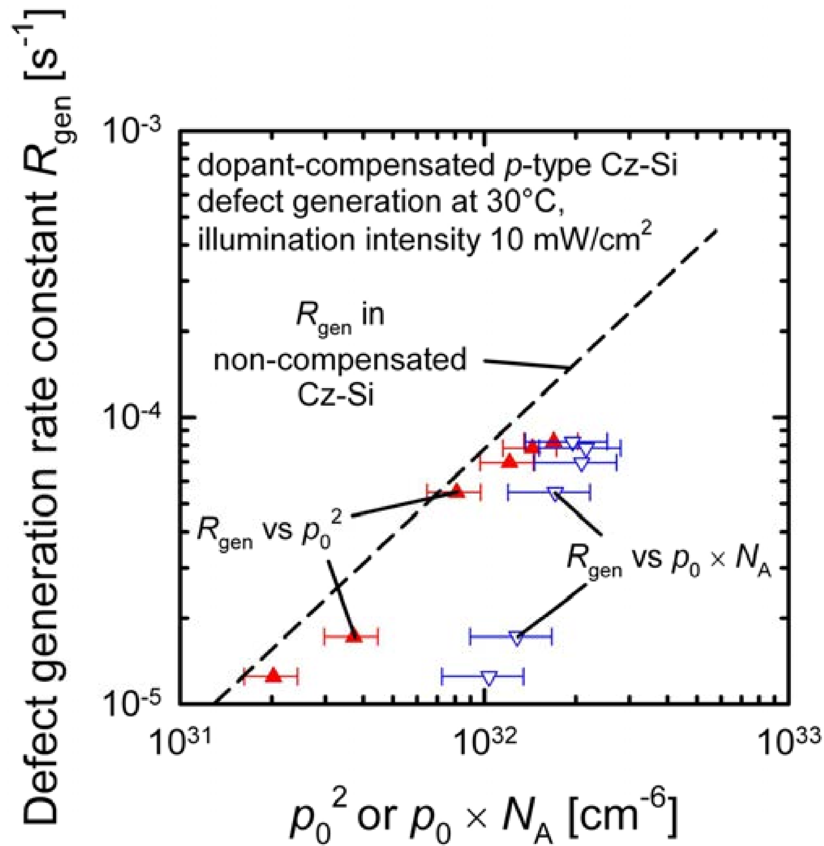
$$N_t^* = \tau_{eff}^{-1} - \tau_0^{-1}$$

exponential increase of the defect concentration during illumination

$$N_t^* = N_1 + a \times (1 - e^{-R_{gen} \times t})$$

- Investigation of dopant-compensated material





$N^*_{t,max} \propto p_0$

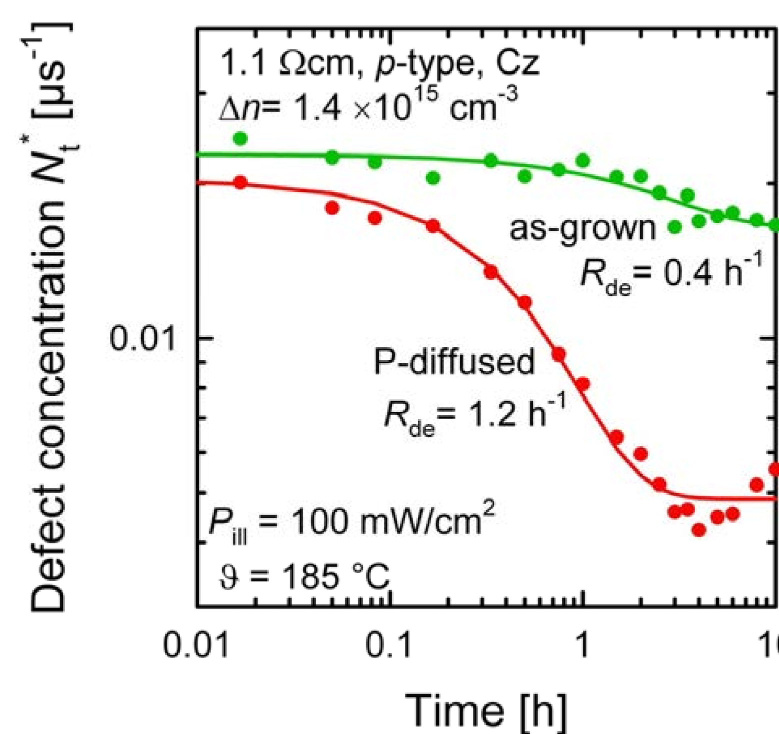
$N^*_{t,max} \not\propto N_A$

$R_{gen} \propto p_0^2$

$R_{gen} \not\propto p_0 \times N_A$

B. Lim, F. Rougieux, D. Macdonald, K. Bothe, and J. Schmidt, *J. Appl. Phys.* **108** 013706 (2010)

Permanent recovery by illumination at elevated temperatures



Illumination at temperatures between 140°C and 200°C

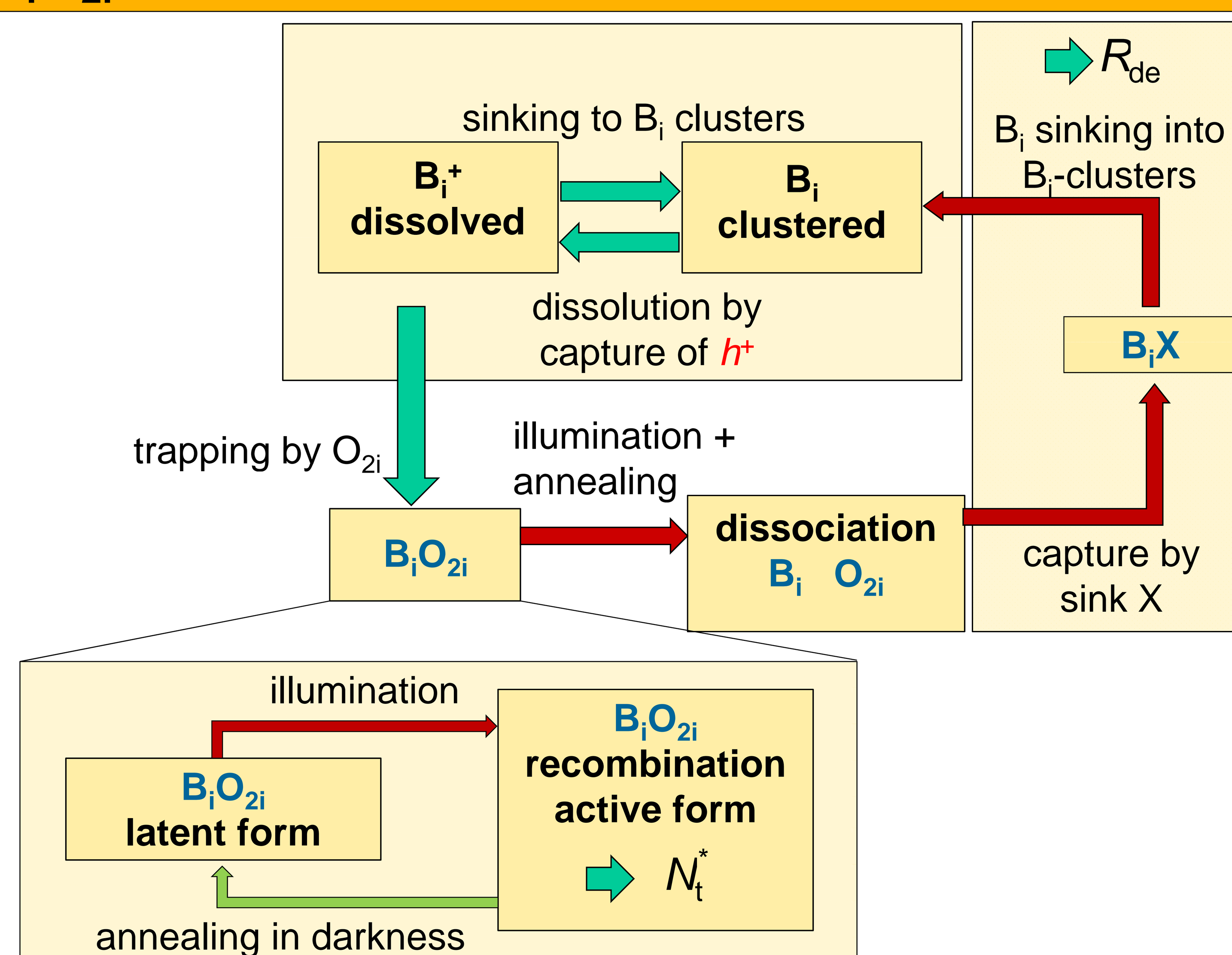
exponential decrease of the defect concentration

$$N_t^*(t) = N_2 + b \times e^{-R_{de} \times t}$$

Defect concentration stable under subsequent illumination

A. Herguth, G. Schubert, M. Kaes, and G. Hahn, *Proc. 21st EUPVSEC*, p. 530 (2006)
B. Lim, K. Bothe, and J. Schmidt, *Phys. Stat. Sol. RRL* **2** 93 (2008)

B_iO_{2i} defect model



V.V. Voronkov and R. Falster, *J. Appl. Phys.* **107**, 053509 (2010)
V.V. Voronkov, R. Falster, B. Lim and J. Schmidt, *J. Appl. Phys.* **112**, 113717 (2012)

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