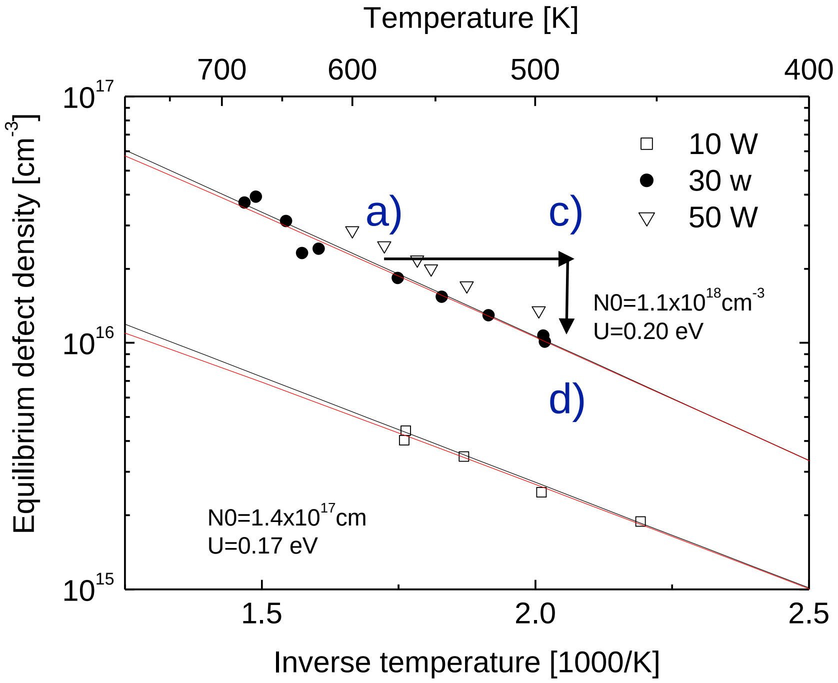
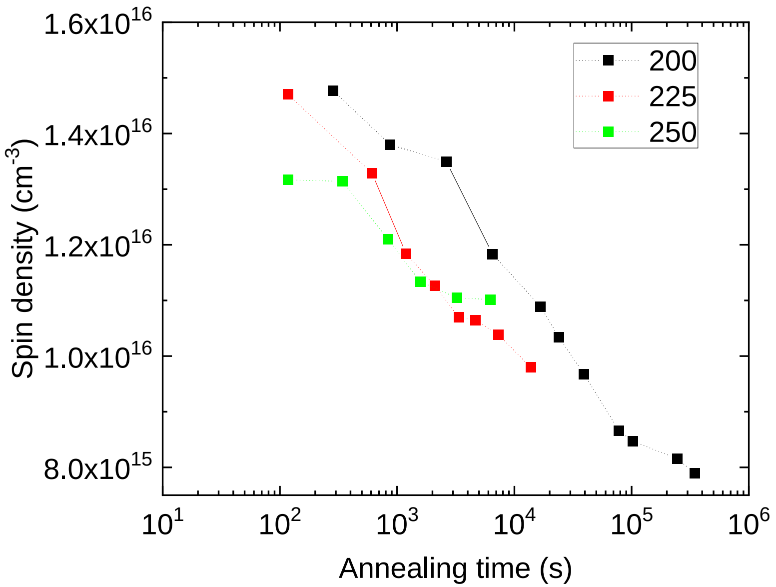
Defect kinetics in a-Si:H

Annealing of intrinsic defects (undoped films)

Experiment:
a) establish equilibrium defect density at high temperature
b) quench status at T_Q by rapid cooling (high defect density)
c) establish annealing temperature $T_{ann} < T_Q$
d) observe relaxation towards equilibrium $N_D(T_{ann})$





Street, PRL 40(9) p6236 (1989)

Kinetics with saturation

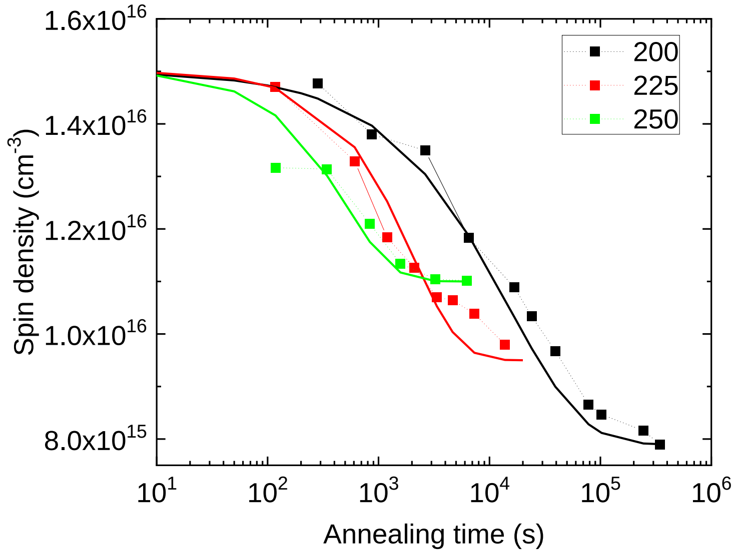
Exponential decay
(radioactivity, (beer-)foam)

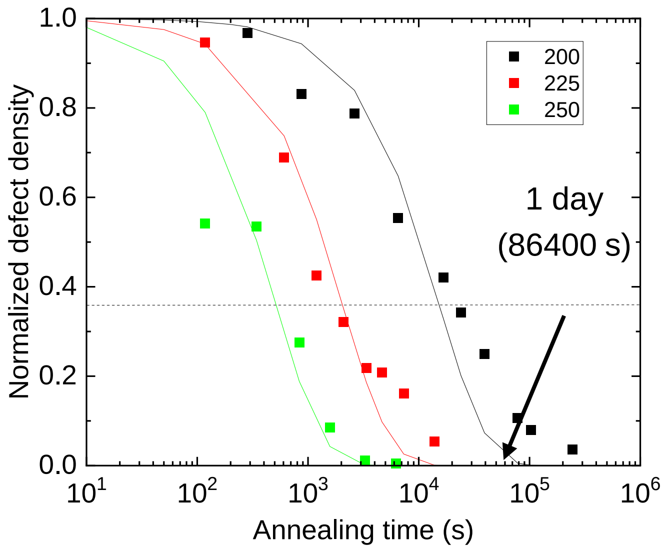
$$\frac{dN}{dt} = -c \cdot (N - N_{sat})$$

$$N(t) = N_{sat} - (N_{sat} - N_0)e^{-t/\tau}$$

Time constant: τ
(decay to $1/e \approx 37\%$)

Exponential decay
- starts too slow
- saturates too fast





Stretched exponential kinetics

Exponential decay
(radioactivity, (beer-)foam)

$$\frac{dN}{dt} = -c \cdot (N - N_{sat})$$

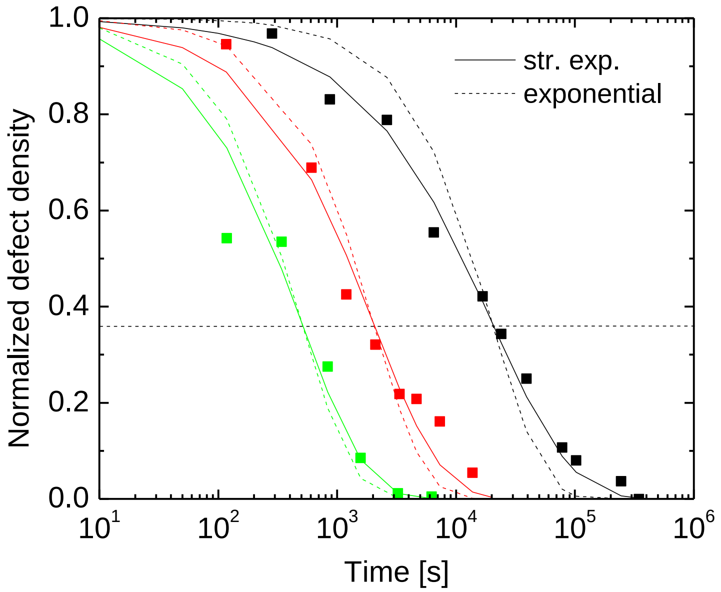
$$N(t) = N_{sat} - (N_{sat} - N_0)e^{-t/\tau}$$

Stretched exponential decay
(phenomena with a variety
of decay times)

$$\frac{dN}{dt} = -(\nu t)^{-\alpha} \cdot c \cdot (N - N_{sat})$$

$$N(t) = N_{sat} - (N_{sat} - N_0)e^{-\left(\frac{t}{\tau}\right)^{\beta}}$$

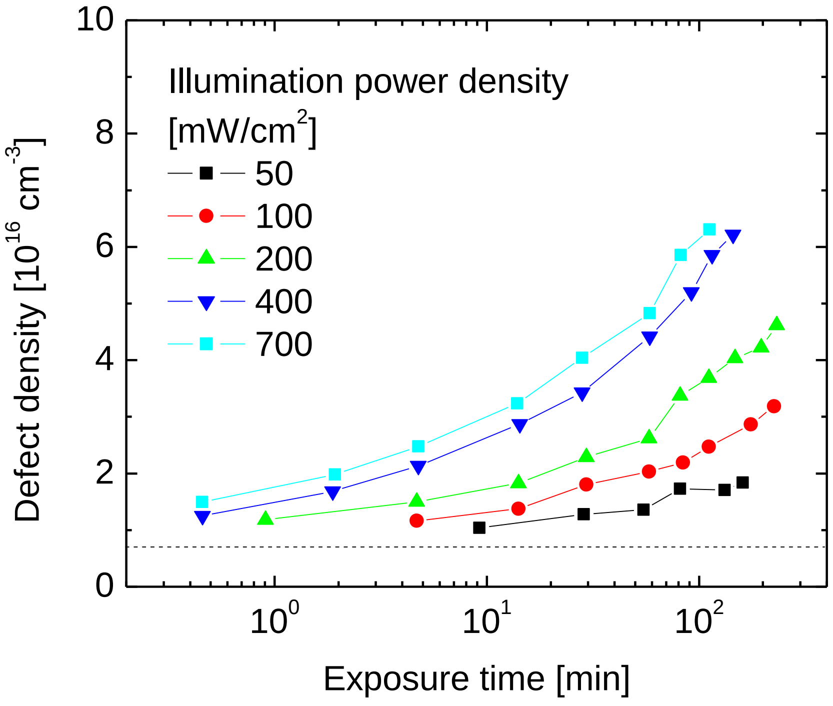
$$\beta = (1 - \alpha)$$



str. exp. first mentioned: Kohlrausch, Ann. Phys. Chem, p56-82 & 179-213 (1854)

Kinetics of light induced defects

Defect creation with continuous illumination:
weakly absorbed light (1.83 eV, uniform profile across sample),
measure defect density by electron spin resonance (ESR)



Saturation at $1x10^{17}$ cm^{-3}, reached upon longer illumination

Initial defect density 7...8 $x10^{15}$ cm^{-3}

Stutzmann, PRB 32(1), p23 (1985)

Initial kinetics of light induced defects

Idea: defects are created by recombination of charge carriers at the existing defects.

Carrier densities p and n are:

- proportional to generation rate G
- inversely proportional to existing defect density N_D

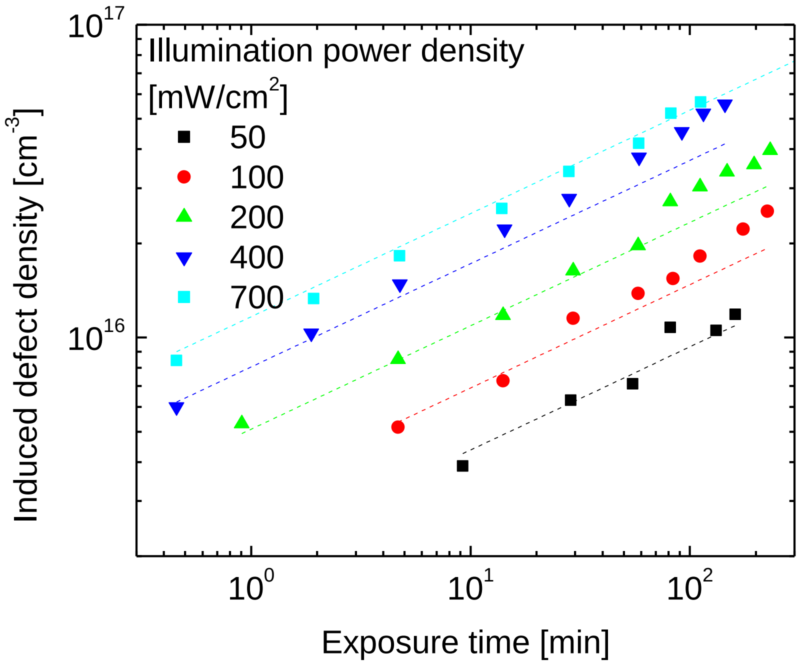
$$p \sim G / N_D$$

$$n \sim G / N_D$$

$$\frac{dN_D}{dt} = const \cdot G^2 N_D^{-2}$$

New defects: subtract $N_D(0)$

$$N_D - N_0 \sim G^{2/3} \cdot t^{1/3}$$



initial increase well described by $t^{1/3}$ relation, but no saturation!

Stutzmann, RPB 32(1), p23 (1985)

Unified idea on defect kinetics

Starting point:

Stretched exponential kinetics

Assumption:

Defect creation **and** defect annealing

are related to the same microscopic process

Build a model that contains:

- Light (and thermally) induced defect creation
- Light induced healing (saturation occurs also at low temperatures, even at 77 K)
- Saturation

Redfield, APL 54(11), p1037 (1989)
and later papers of Redfield and Bube

Model

thermally induced changes

$$\frac{dN_D}{dt} = (\upsilon t)^{-\alpha}\left[\underbrace{(c_1 G + \nu_1)\cdot(N_T - N_D)}_{\text{creation term}} - \underbrace{(c_2 G + \nu_2)\cdot N_D}_{\text{healing term}}\right]$$

light induced changes

β=(1-α): dispersion parameter

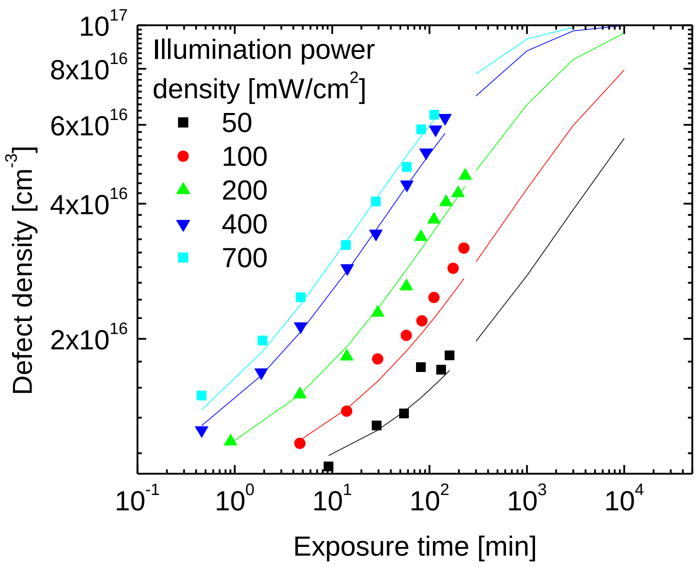
Solution: stretched exponential

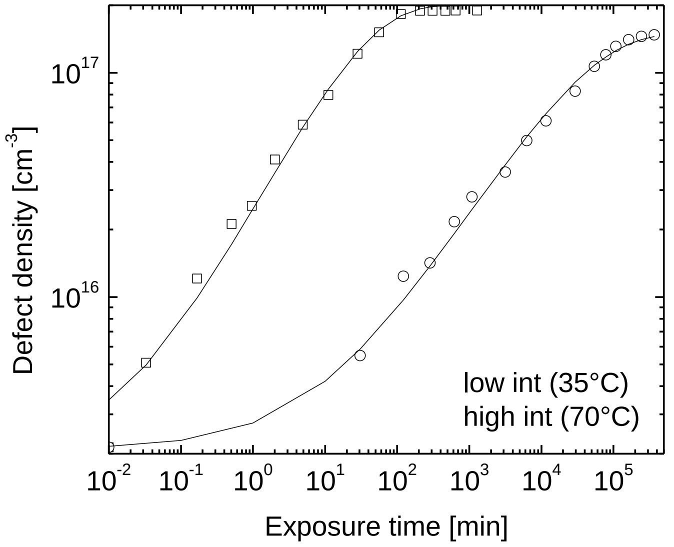
$$N_D = N_{sat} - (N_{sat} - N_0)e^{-(t/\tau)^\beta}$$

Problem: purely descriptive

Redfield, APL 54(11), p1037 (1989)
and later papers of Redfield and Bube

Light induced defect creation





$$N_D = N_{sat} - (N_{sat} - N_0)e^{-(t/\tau)^\beta}$$

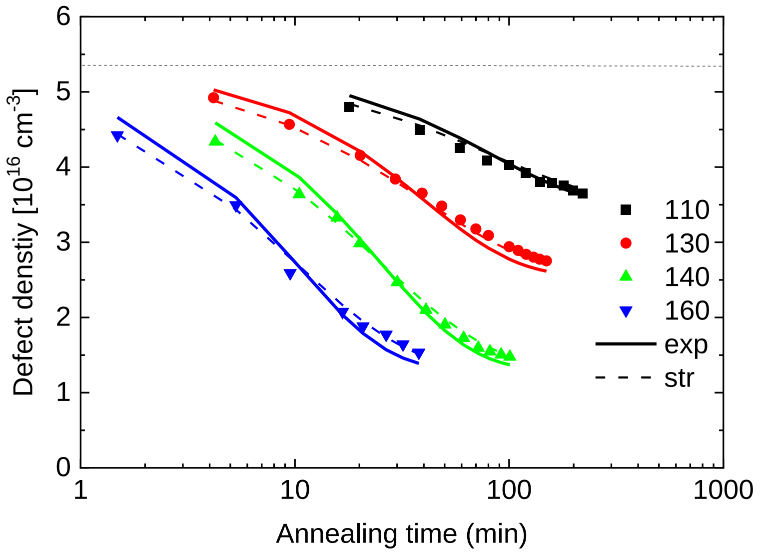
Data: Stutzmann, RPB 32(1), p23 (1985)
Park, APL 55(25), p2658, (1989)

- equivalently valid description of data
- Stutzmann's $t^{1/3}$ dependence is interpreted to be a coincidence (because β varies with temperature)

Redfield, APL 54(11), p1037 (1989)
and later papers of Redfield and Bube

Annealing of light induced defects

- Create starting level of defects with continuous illumination (at RT)
- Expose to annealing temperature and measure defect density by electron spin resonance (ESR)



Exponential decay starts too slow, and decays too fast

Stretched exponential slightly better match

Stutzmann, RPB 32(1), p23 (1985)

Variation of stretching parameters

F.-J. Haug

beta depends linearly on temperature

$\beta = T/T_0\,,\ T_0 \approx 600\ \mathrm{K}$

the relaxation time is thermally activated and varies with doping