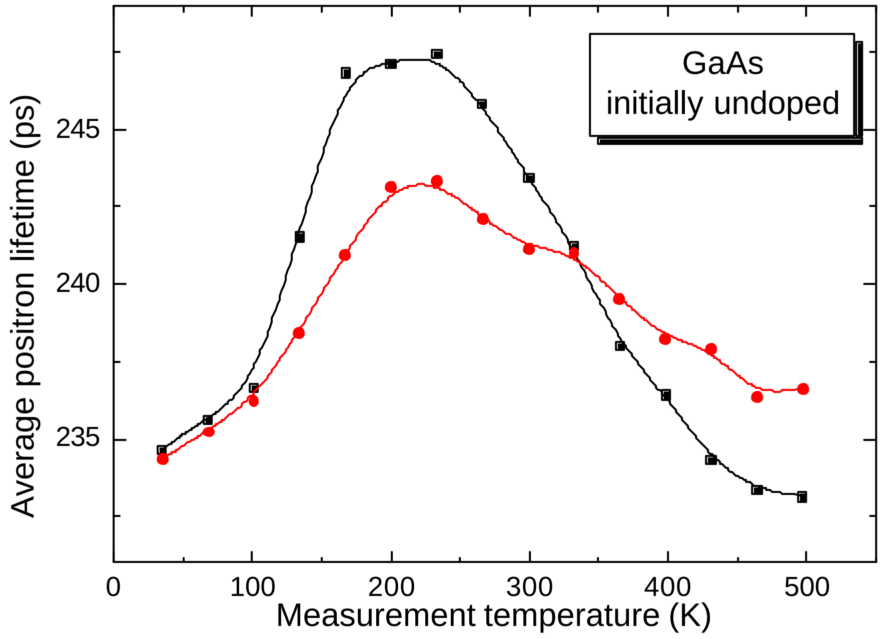
On the temperature dependence of positron trapping in semiconductors

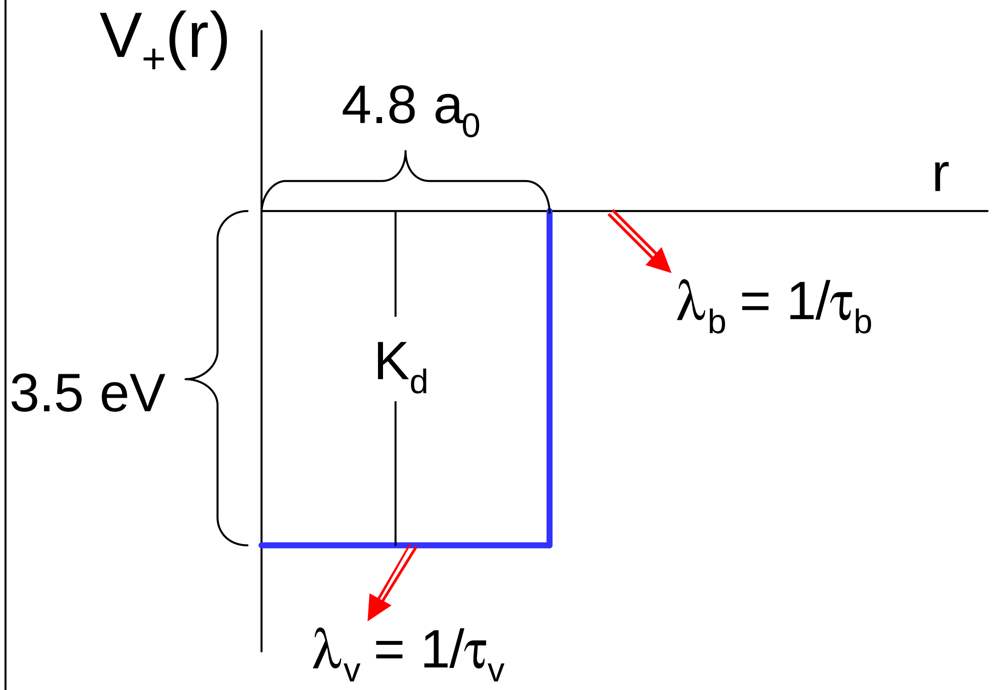
V. Bondarenko

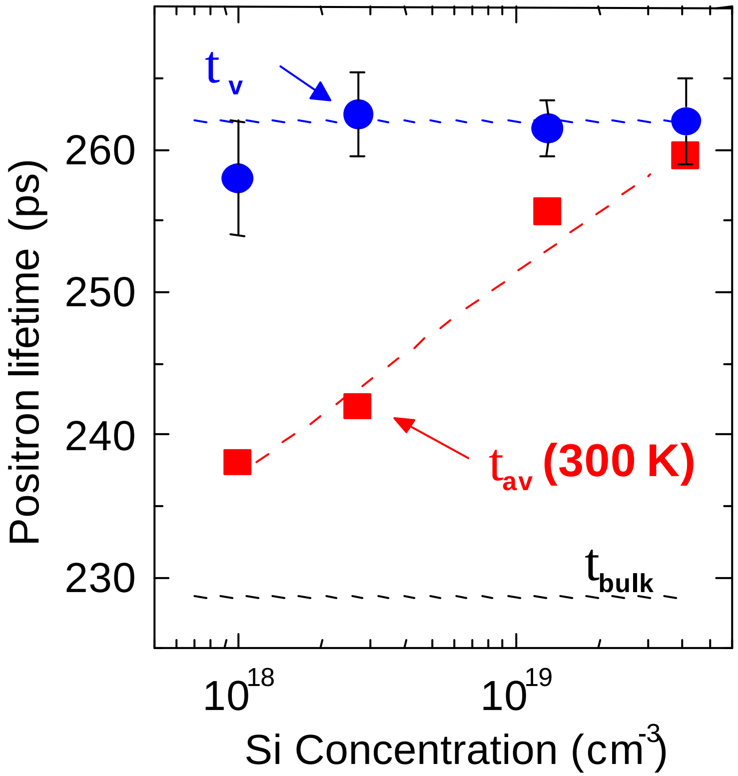
Outlook:

- Why T-dependent?
- Model
- Problems and discussion



Trapping into a vacancy

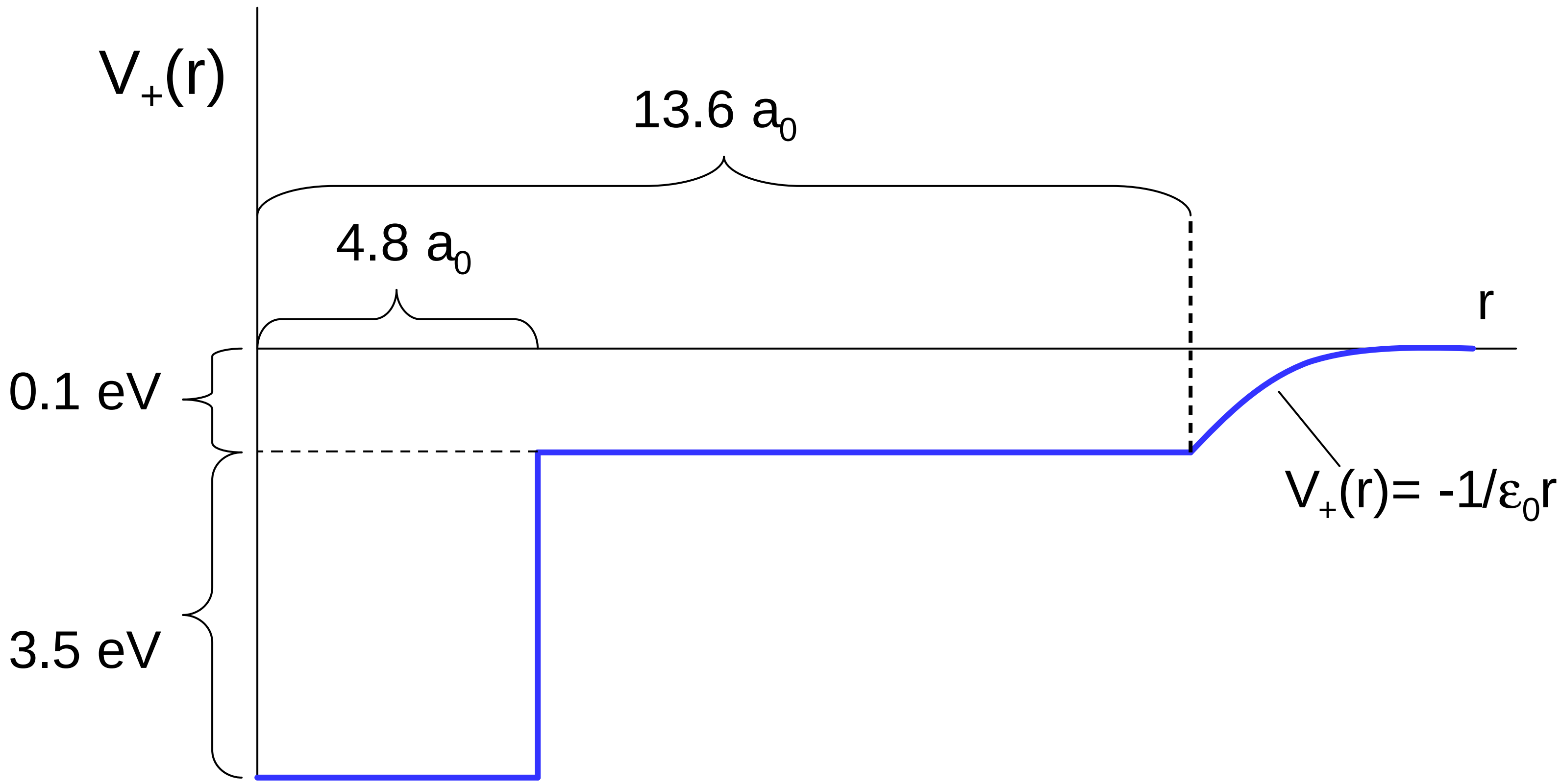




(J. Gebauer et al. 1997)

$$K_d = m_d C_d = \frac{1}{t_b} \frac{(t_{av} - t_b)}{(t_d - t_{av})}$$

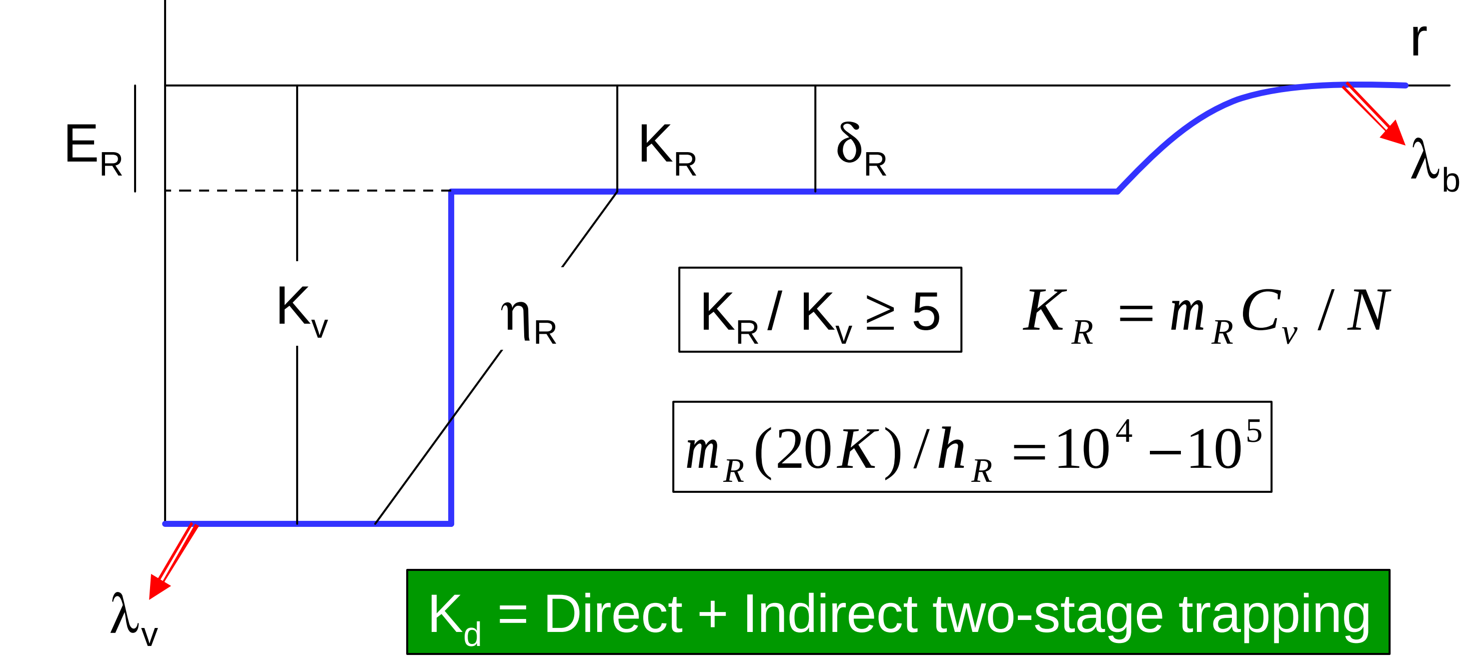
Negative vacancy



Two-stage trapping model

$$\frac{d_R}{K_R} = \frac{1}{C_v}\left[\frac{m_+ k_b T}{2p\hbar^2}\right]^{3/2} \exp\left[-\frac{E_R}{k_b T}\right]$$

Density of positron states per unit volume



$\boxed{K_R / K_v \geq 5}$ $\quad K_R = m_R C_v / N$

$$\boxed{m_R(20K)/h_R = 10^4 - 10^5}$$

K_d = Direct + Indirect two-stage trapping

Temperature dependence

$$K_d = K_v + \frac{K_R}{1 + \frac{m_R}{Nh_R}\left[\frac{m_+ k_b T}{2p\hbar^2}\right]\exp\left[-\frac{E_R}{k_b T}\right]}$$

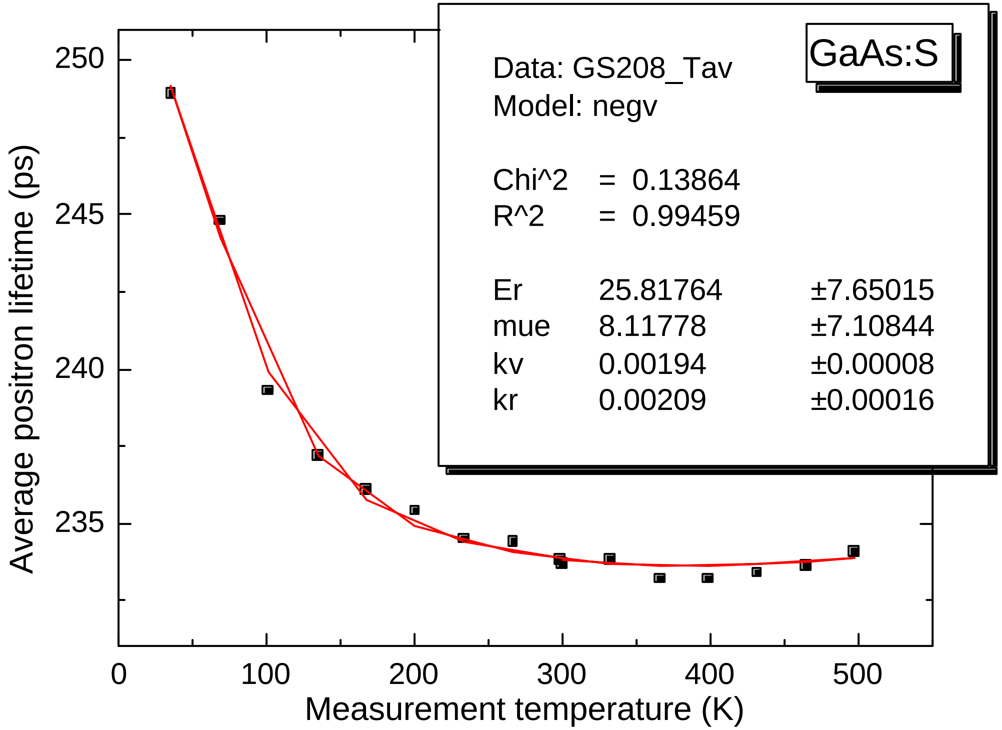
$$K_R = m_R C_v / N$$

$$K_d = K_v(20K)\left[\frac{T}{20\,K}\right]^{-1/2} + \frac{K_R\left[\frac{T}{20\,K}\right]^{-1/2}}{1 + \frac{m_R}{Nh_R}\left[\frac{T}{20\,K}\right]^{-1/2}\left[\frac{m_+ k_b T}{2p\hbar^2}\right]\exp\left[-\frac{E_R}{k_b T}\right]}$$

Temperature dependence – negative vacancy

$$K_d = m_d C_d = \frac{1}{t_b}\frac{(t_{av} - t_b)}{(t_d - t_{av})}$$

$$t_{av} = t_b \frac{1 + K_d t_v}{1 + K_d t_b}$$

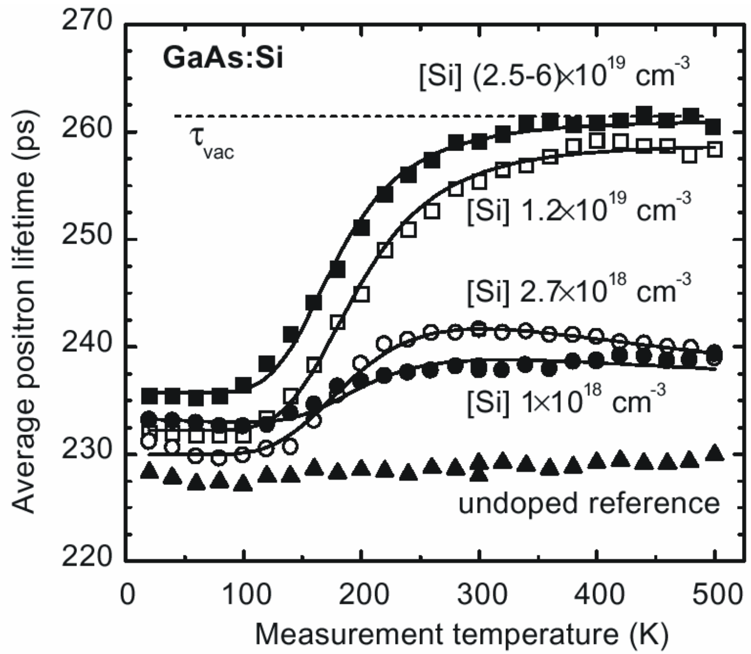


$$m_v(20\,K) = 1.5 \times 10^{16}\, s^{-1}$$

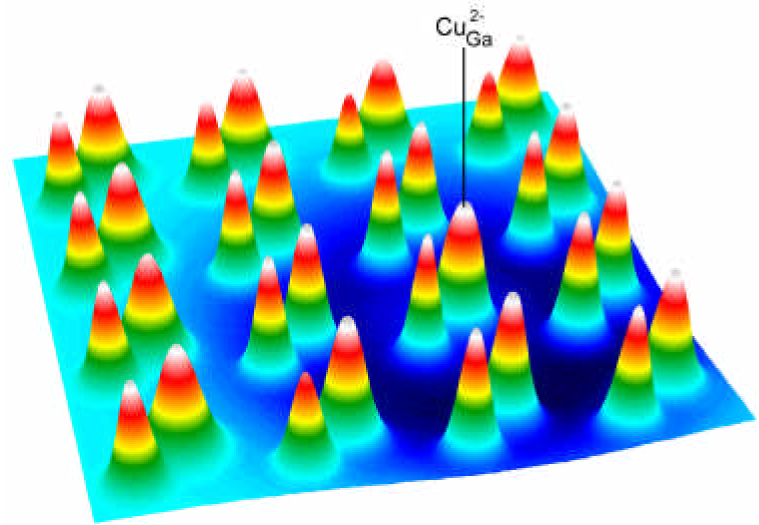
$$C_v = 5.7 \times 10^{15}\, cm^{-3}$$

Positron trapping – shallow traps

- negative ions are also positron trapping centers due to small negative Coulomb potential



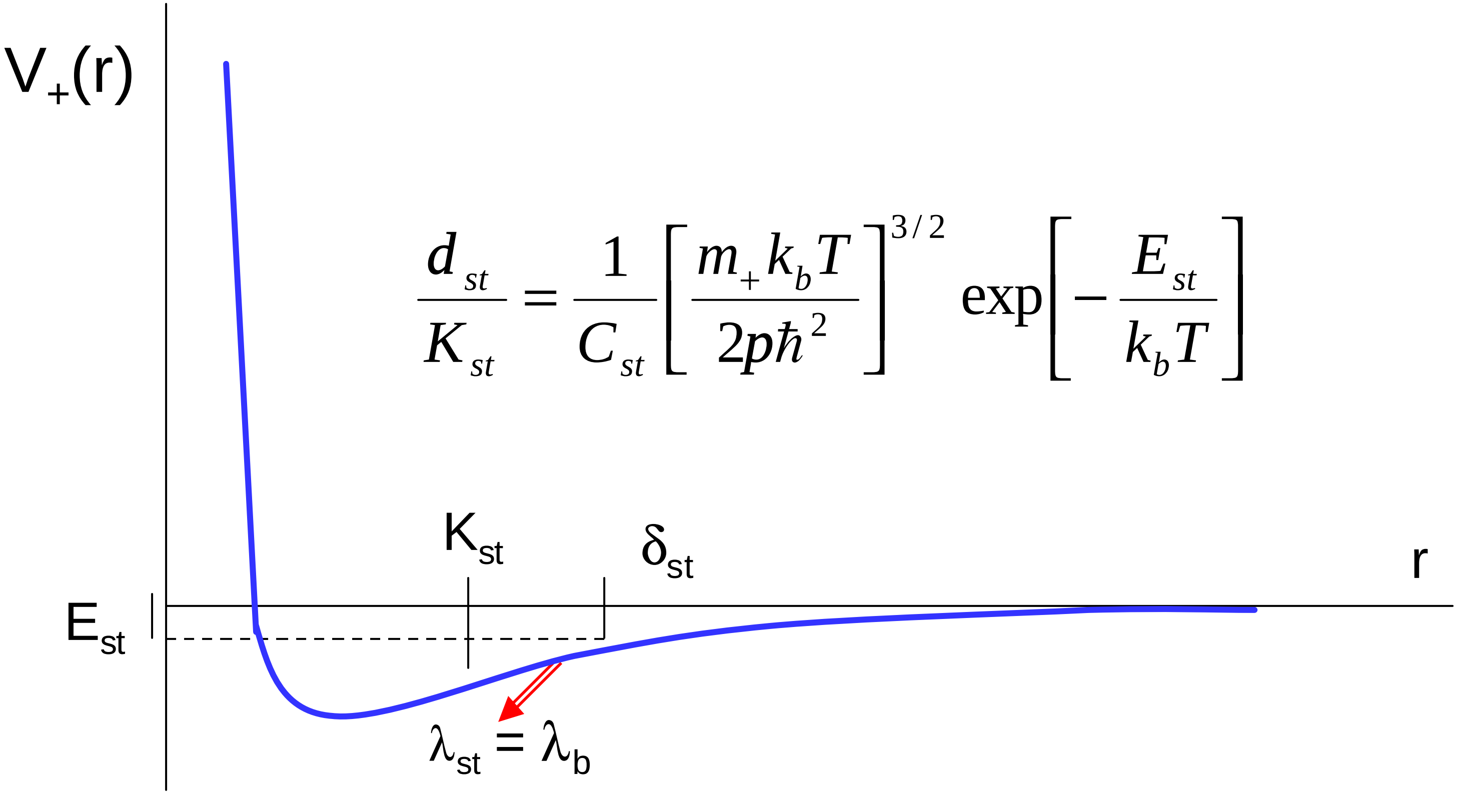
(J. Gebauer et al. 1997)



- term shallow relates to the positron binding energy (few meV). Therefore the trapping is significant at low temperatures only
- the electron density is not reduced:

$$t_{st} = t_b$$

Positron shallow traps



$$\frac{d_{st}}{K_{st}} = \frac{1}{C_{st}}\left[\frac{m_{+}k_{b}T}{2p\hbar^{2}}\right]^{3/2}\exp\left[-\frac{E_{st}}{k_{b}T}\right]$$

Trapping model: negative vacancy + shallow trap

$$t_{av} = t_d \frac{(l_d + K_d)\left[\frac{l_{st}}{K_{st}} + \frac{d_{st}}{K_{st}}\right] + l_d}{(l_b + K_d)\left[\frac{l_{st}}{K_{st}} + \frac{d_{st}}{K_{st}}\right] + l_{st}}$$

7 Parameters

(enough to fit a Chinese font):

E_r

E_{st}

$K_v(20K)$

$K_r(20K)$

$K_{st}(20K)$

$m_R(20K)/h_R$

C_{st}

But there are some constraints:

$$K_v(20K) = m_v(20K)C_v / N$$

$$K_{st}(20K) = m_{st}(20K)C_{st} / N$$

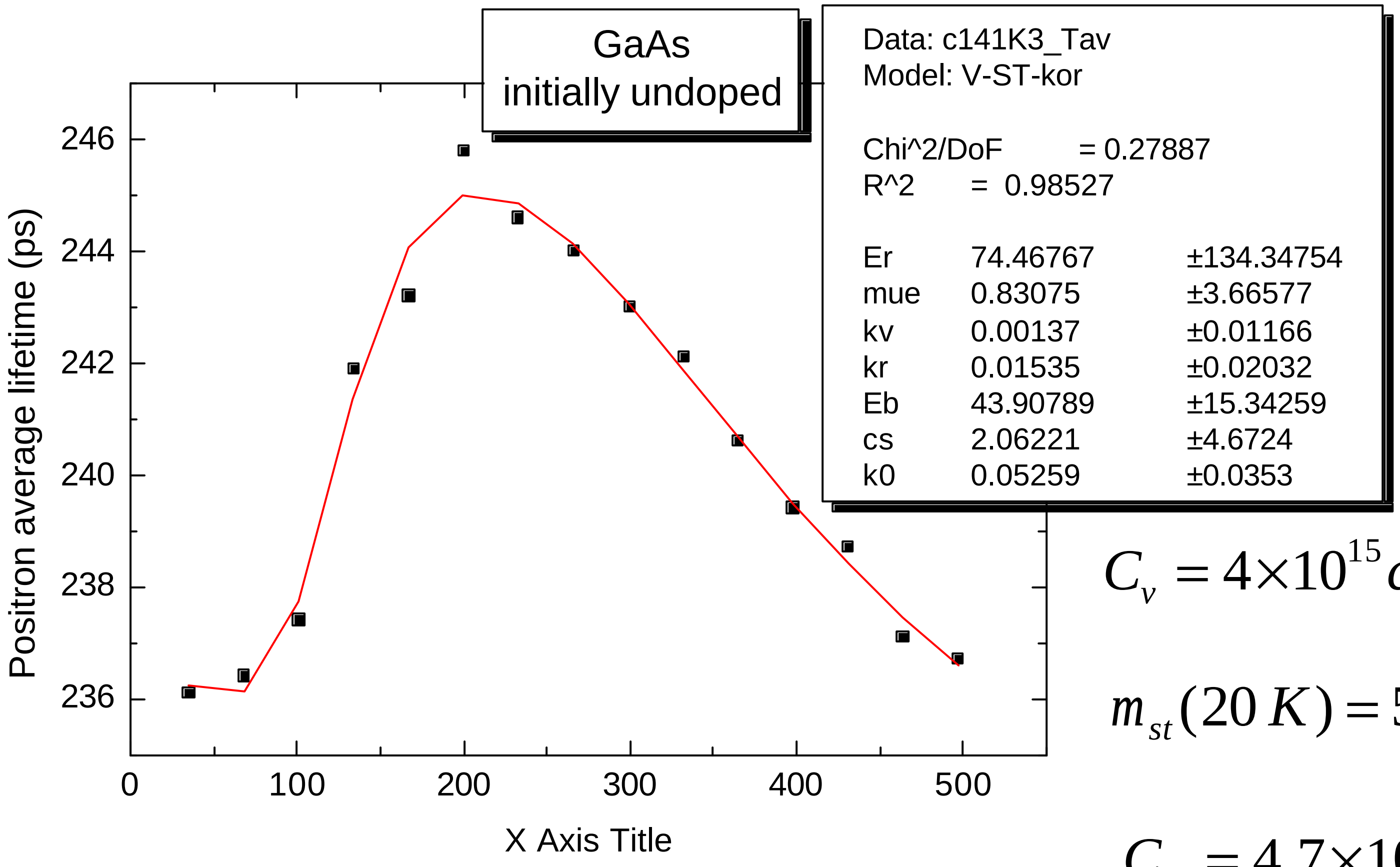
$$m_R(20K)/h_R = 10^4 - 10^5$$

$$m_v(20\,K) = 1.5\times10^{16}\,s^{-1}$$

$$m_{st}(20\,K) = 5\times10^{16}\,s^{-1}$$

(J. Gebauer et al. 1997)

Undoped GaAs – negative vacancy + shallow traps

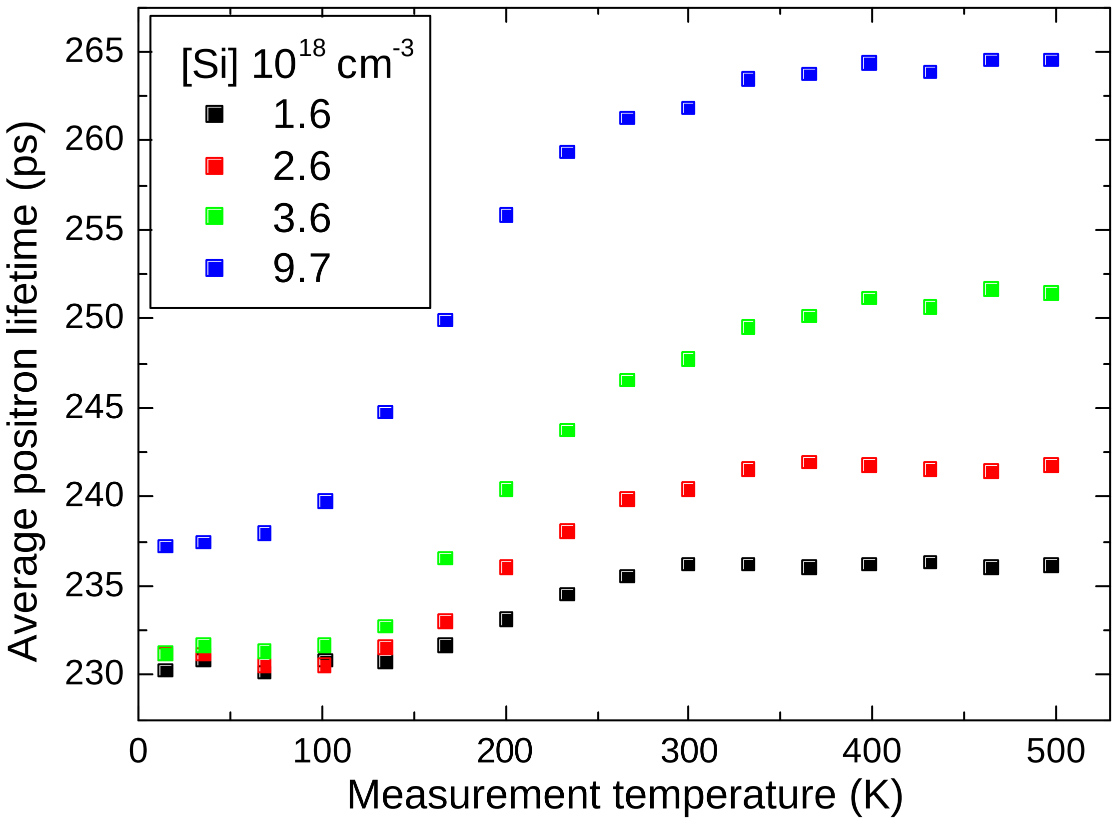


$$C_v = 4\times10^{15}\,cm^{-3}$$

$$m_{st}(20\,K) = 5\times10^{16}\,s^{-1}$$

$$C_{st} = 4.7\times10^{16}\,cm^{-3}$$

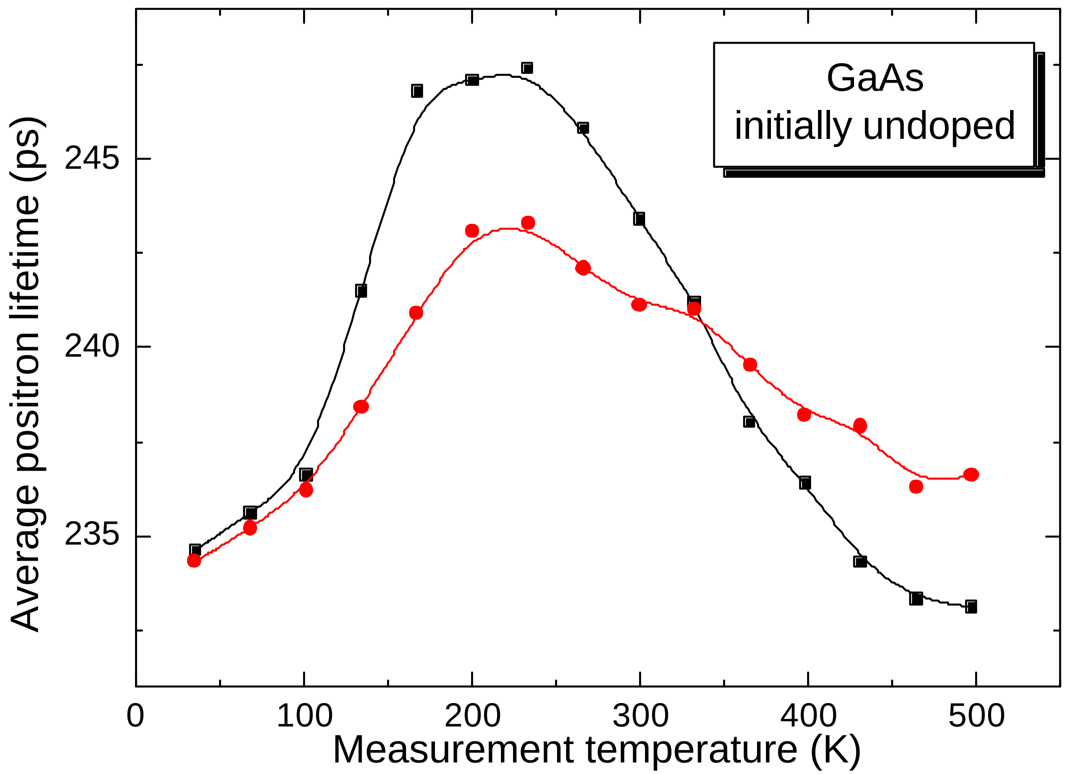
GaAs:Si - problematic fitting



$(Si_{Ga}V_{Ga})^{2-}$ complex
but:
no decrease of τ_{av}
characteristic for
negative vacancy

Fit gives unreasonably high concentrations of shallow traps

Sensitivity to the defects charge state?



Presented model does not differentiate between -e, -2e or -3e charge states

further developments are needed