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Determining Compensation of Implanted Aluminum Dopants by Simultaneous Fitting of Charge Carrier Concentration and Mobility

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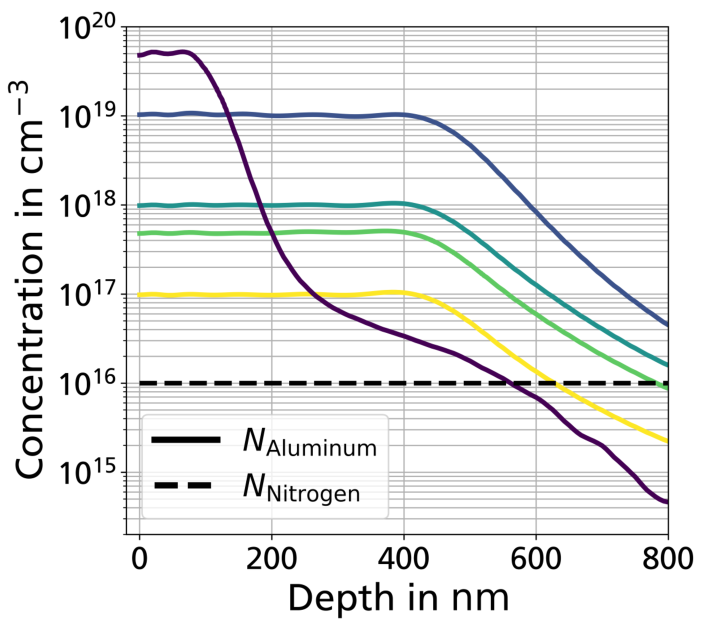
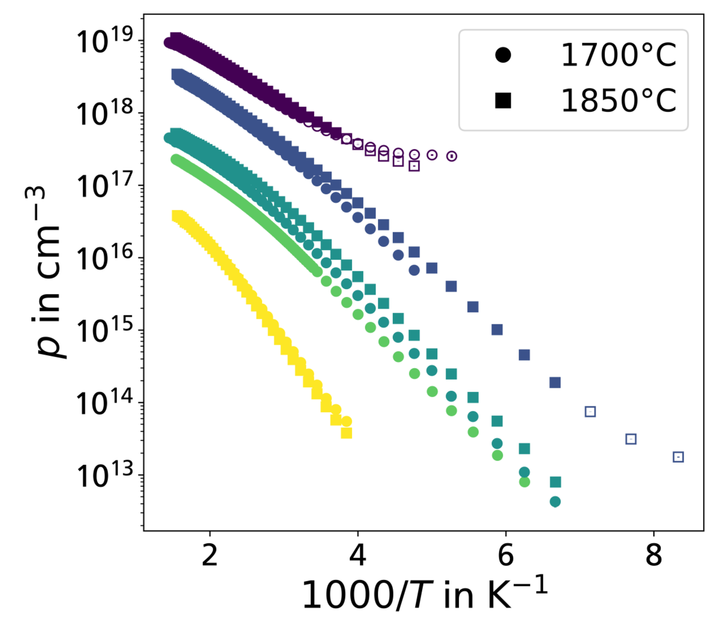
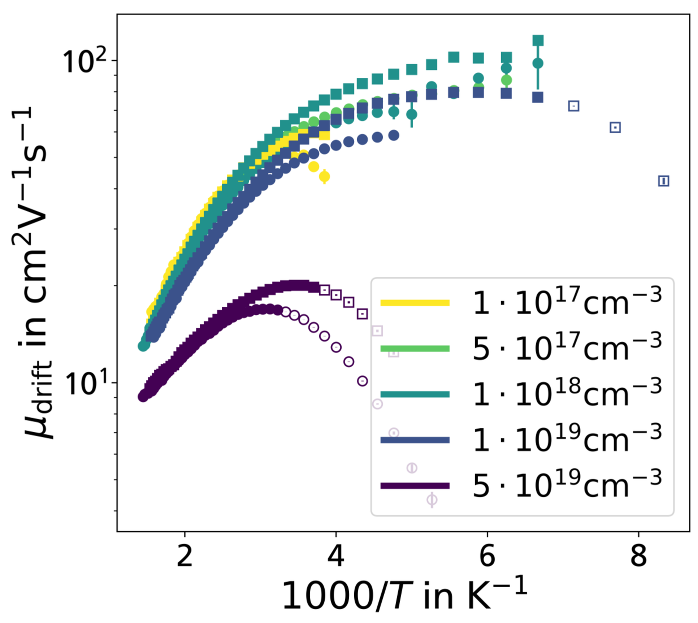
Sample Preparation and Characterization

- Square van der Pauw test structures
- In n-type epitaxial layers with a nitrogen concentration of $1 \cdot 10^{16}$ cm^{-3}
- Implanted aluminum concentrations from $1 \cdot 10^{17}$ cm^{-3} to $5 \cdot 10^{19}$ cm^{-3}
- Annealed at 1700°C or 1850°C for 30 min
- Graphs show target implantation profile and Hall measurement results
- Empty symbols → impurity band conduction → excluded from fit







Common Data Analysis

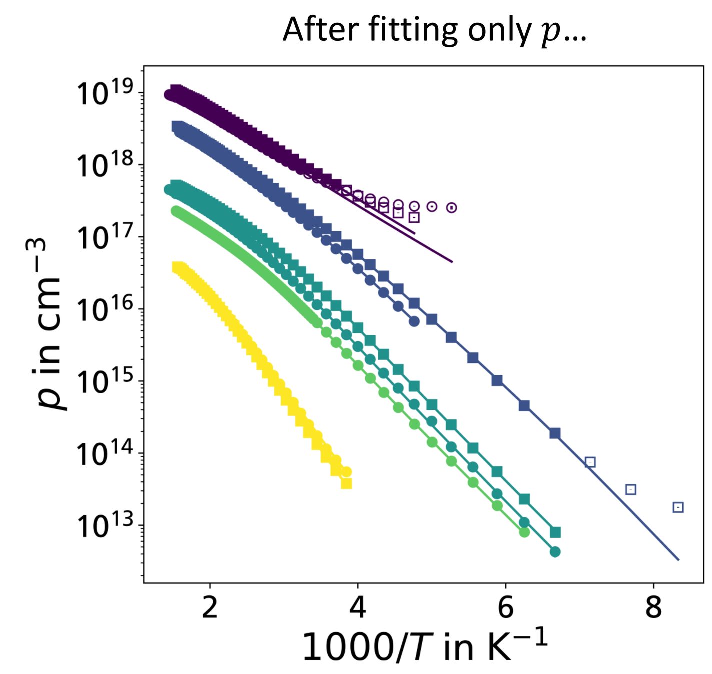
Commonly the neutrality equation is fit to the charge carrier concentration data [3]:

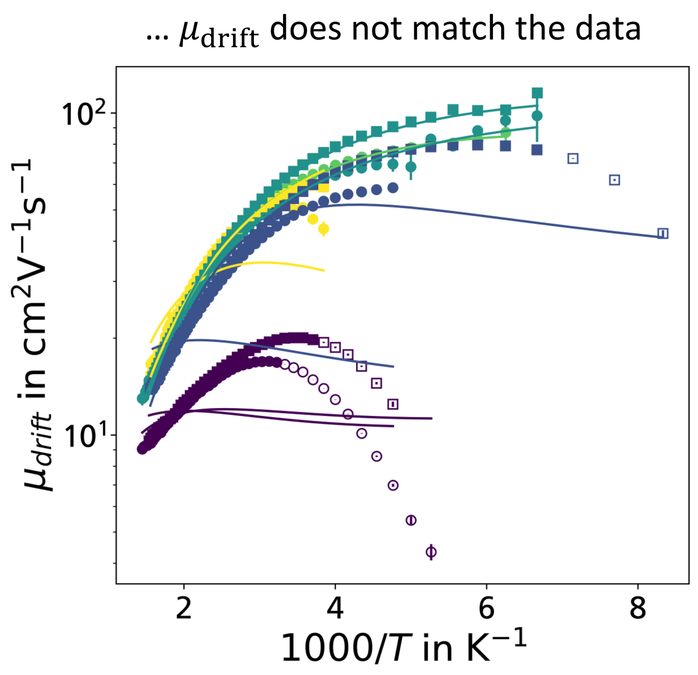
$$p + N_{\mathrm{Comp}} = n + N_{\mathrm{Acc,1}}^{-} + N_{\mathrm{Acc,2}}^{-}$$

$$N_{\mathrm{Acc}}^{-} = \frac{N_{\mathrm{Acc}}}{1 + 4 \cdot \exp\left(\frac{E_{\mathrm{Acc}} - E_{\mathrm{F}}}{\mathrm{k_B} T}\right)}$$

- Resulting parameters: ionization energies, acceptor and compensation concentrations
- Optional: total acceptor concentration limited to nominal implanted concentration

But: After fitting neutrality equation, the mobility model does not match the data





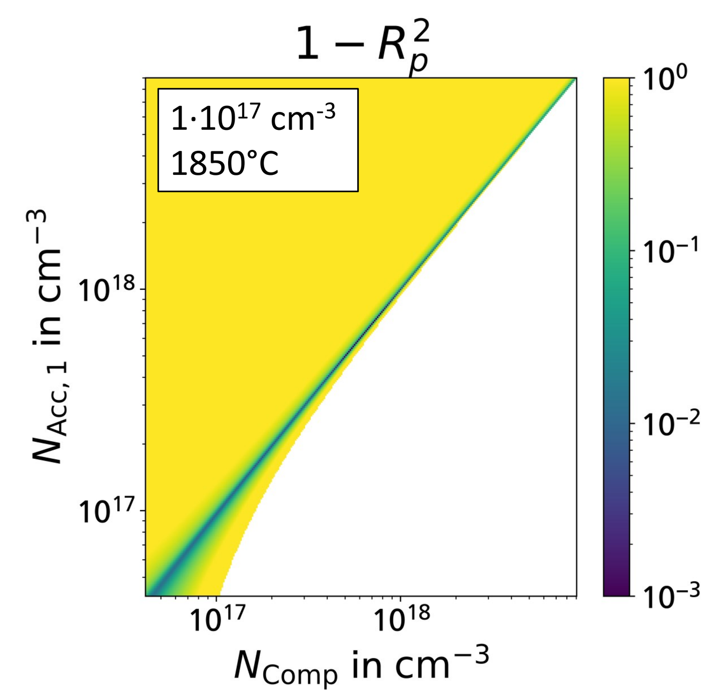
Fitting Without Limits

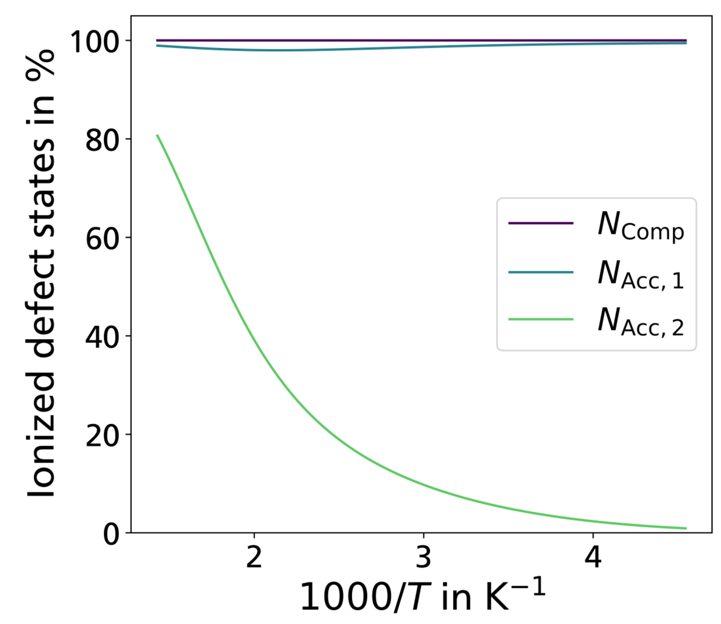
- Fits to measurement results of highly doped samples ($N_{\mathrm{Implanted}} > 1 \cdot 10^{18}\mathrm{cm}^{-3}$) show only small changes when removing the limit

But when fitting data from lowly doped samples ($N_{\mathrm{Implanted}} < 1 \cdot 10^{18}\mathrm{cm}^{-3}$) without limit:

- $N_{\mathrm{Acc,1}}$ and N_{Comp} reach unreasonably high values
- $N_{\mathrm{Acc,1}}$ and N_{Comp} are linked together - a fit is equally as good with low $N_{\mathrm{Acc,1}}$ and low N_{Comp} as it is with high $N_{\mathrm{Acc,1}}$ and high N_{Comp}
- Due to the position of the Fermi level, $N_{\mathrm{Acc,1}}^{-}$ depends only weakly on temperature, just like the concentration of ionized compensating defects.

→ High degrees of freedom → poorly defined fit → results may be unphysical





Analysis Incorporating the Mobility

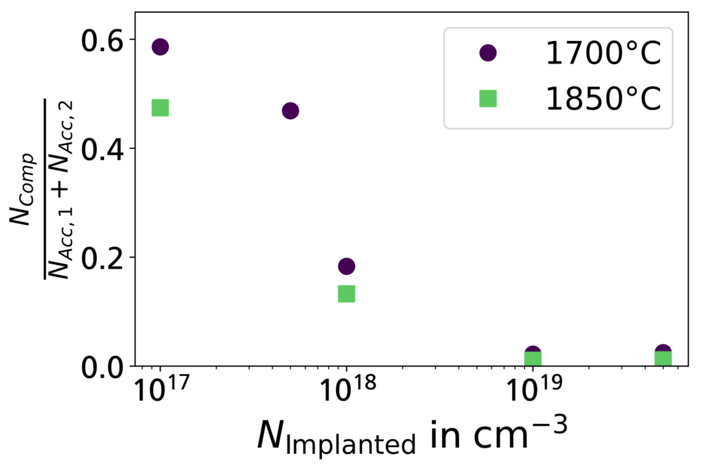
In addition to the charge carrier concentration the mobility can also be used in the fit [2]. The mobility is calculated by accounting for different scattering mechanisms [1,4]:

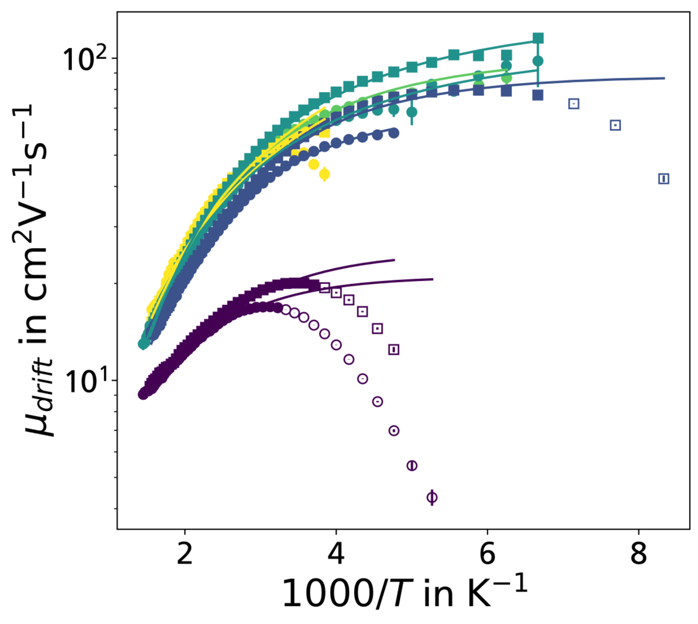
$$\mu_{\mathrm{drift}} = \frac{\mathrm{e}\langle\tau\rangle}{\mathrm{m_h}} \qquad \frac{1}{\tau} = \frac{1}{\tau_{\mathrm{ii}}(N_{\mathrm{Acc/Comp}})} + \frac{1}{\tau_{\mathrm{ni}}(N_{\mathrm{Acc/Comp}})} + \frac{1}{\tau_{\mathrm{po}}} + \frac{1}{\tau_{\mathrm{nop}}(D_{\mathrm{nop}})} + \frac{1}{\tau_{\mathrm{ac}}(D_{\mathrm{ac}})}$$

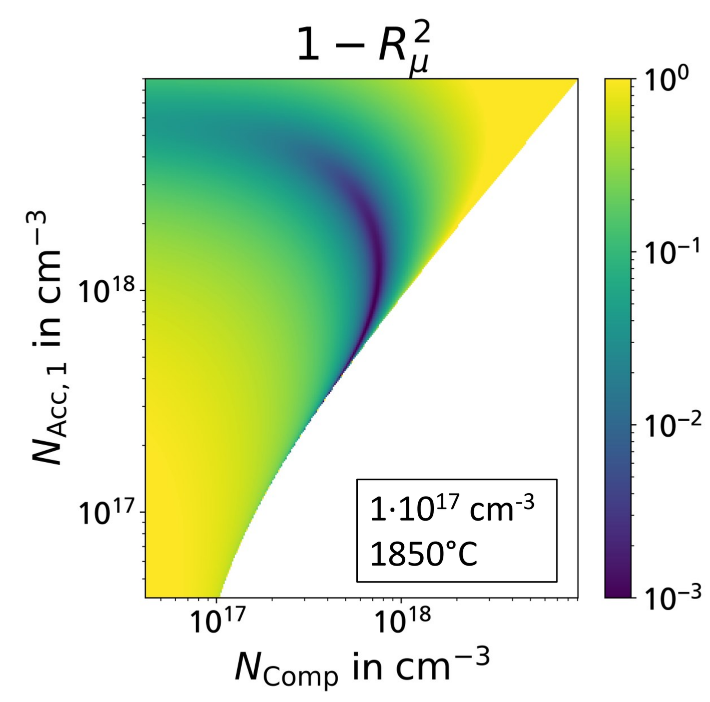
- $N_{\mathrm{Acc,1}}$ and N_{Comp} show a different dependence when looking at the fit to μ_{drift} vs the fit to p and thus are naturally more restricted

Abbreviations are for scattering due to:

- τ_{ii}: ionized impurities
- τ_{ni}: neutral impurities
- τ_{po}: polar optical phonons
- τ_{nop}: non-polar optical phonons
- τ_{ac}: acoustic phonon







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Conclusion:

- Fitting Hall measurement results of lowly Al-doped 4H-SiC with two acceptors is difficult, as the problem is ill-defined
- Simultaneously fitting p and μ_{drift}, a clear trend of the compensation concentration with implanted Al-concentration and annealing temperature emerges