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Determination of compensation ratios of Al-implanted 4H-SiC by TCAD modelling of TLM measurements

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Introduction

- Implantation and high temperature annealing can create compensation centers which reduce the free hole concentration in the implanted region
- The ratio of these donor type impurities $N_{comp,D}$ to the activated acceptor concentration N_A is defined as compensation ratio [1, 2]
- Increasing compensation increases the
  - contact resistance
  - resistance of the implanted region (sheet resistance R_{sh})
  - power losses
- Commonly the compensation ratio is determined by the rather complex Hall effect measurements
- In this work, the compensation ratio is approximated by evaluating and simulating transfer length method (TLM) structure measurements
- TLM structures are commonly used to determine i.a. R_{sh} of implanted regions [3]

Samples

- TLM structures with different Al box profiles
- Al surface concentration ranging from $3.3 \cdot 10^{18}$ cm^{-3} to $5.0 \cdot 10^{19}$ cm^{-3} (see Table 1)
- Implantation annealing: 30 min at 1700 °C in Ar atmosphere with carbon capping
- The total fabrication process sequence has been previously described [4]

Simulation model

- Numerical simulation model (Sentaurus TCAD) of a TLM structure (see Fig. 1)
- Simulated TLM structure consists of
  - two ideal ohmic contacts
  - the Monte-Carlo-simulated Al implantation profile
  - an additional virtual nitrogen doping profile for local charge compensation
- The virtual N profile
  - is assumed to have the same shape as the implanted Al profile
  - is scaled linearly by using the scaling factor f_{comp} (definition see Eq. (1))
  - adds donor atoms with low ionization energy in the Al implanted region to reduce the free hole density through recombination
  - allows to estimate an average compensation ratio by fitting the simulated sheet resistance with the measured values
- The numerical model
  - assumes full activation
  - includes carrier recombination (Shockley-Read-Hall and Auger)
  - considers the doping dependence of the carrier mobility
  - takes incomplete ionization into account

$$N_{comp,D} = f_{comp} N_A + N_D \tag{1}$$

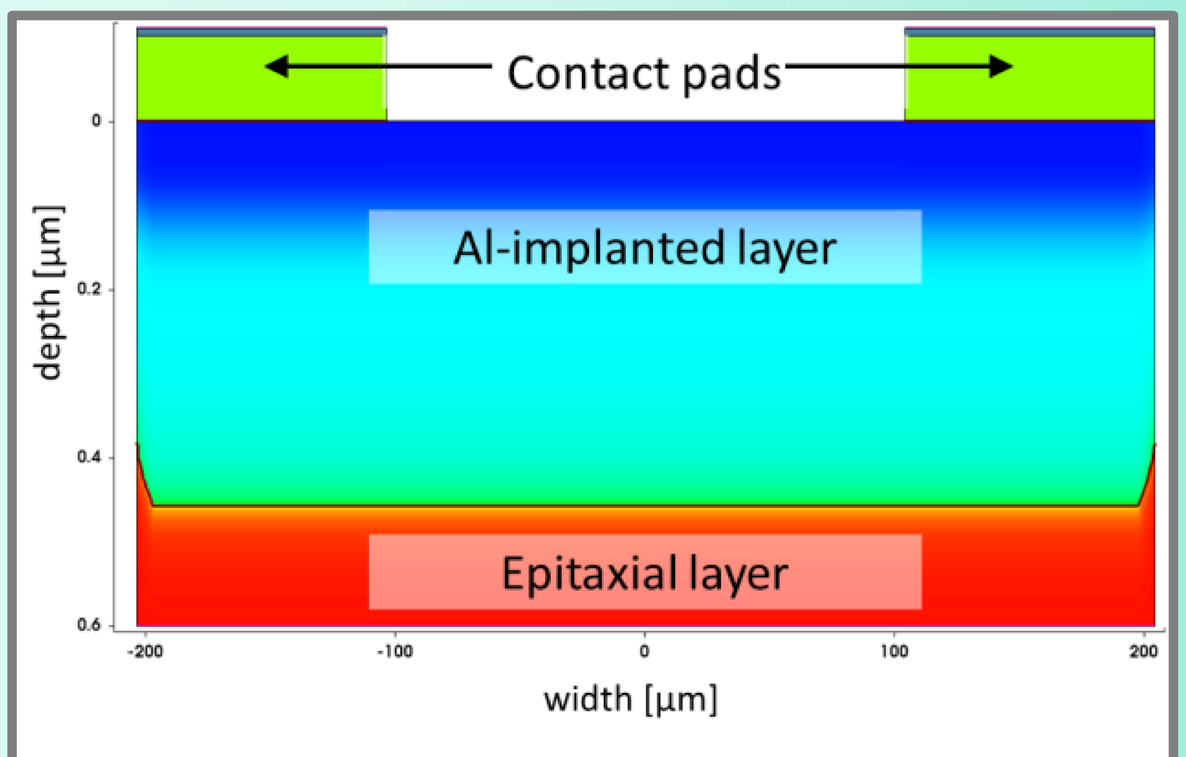

Fig. 1: Scheme of the simulated TLM structure

Table 1: Al box profile concentration, determined compensation ratio and deviation between measured and simulated sheet resistance for each shown sample

sample	Al concentration [10^{19}cm^{-3}]	compensation ratio [1]	deviation [%]
01	0.33	0.330	1.34
02	0.67	0.222	1.37
03	1.00	0.211	-1.20
05	1.67	0.205	-1.83
07	2.33	0.230	2.16
08	2.67	0.210	-0.06
11	3.67	0.240	-2.60
13	4.33	0.250	0.08
15	5.00	0.264	-1.81

Table 2: Determined fitting parameters for equation (2)

parameter	unit	value
$f_{comp,A}$	[1]	0.230
$f_{comp,B}$	[1]	0.625
$N_{A,ref}$	[cm^{-3}]	$2.11 \cdot 10^{18}$

Simulation results

- Compensation ratios are determined by adjusting f_{comp} until the deviation between measured and simulated R_{sh} is sufficiently small (see Tab. 1)
- Fig. 2 shows the comparison between determined compensation ratios by using the TLM approximation model (blue squares) and by using Hall effect measurements from literature [5] (red circles)
- Both types of evaluation show a consistent trend of the dependence of the compensation ratio on the Al concentration

Numerical fitting function

- Summarizing the compensation ratios determined by TLM approximation and from literature a numerical fitting function can be derived (see Fig. 2, dashed line)
- Equation (2) shows the determined fitting function, Table 2 the corresponding fitting parameters
- Fitting function allows for estimating the compensation ratio of similarly fabricated Al implanted regions in a wide concentration range

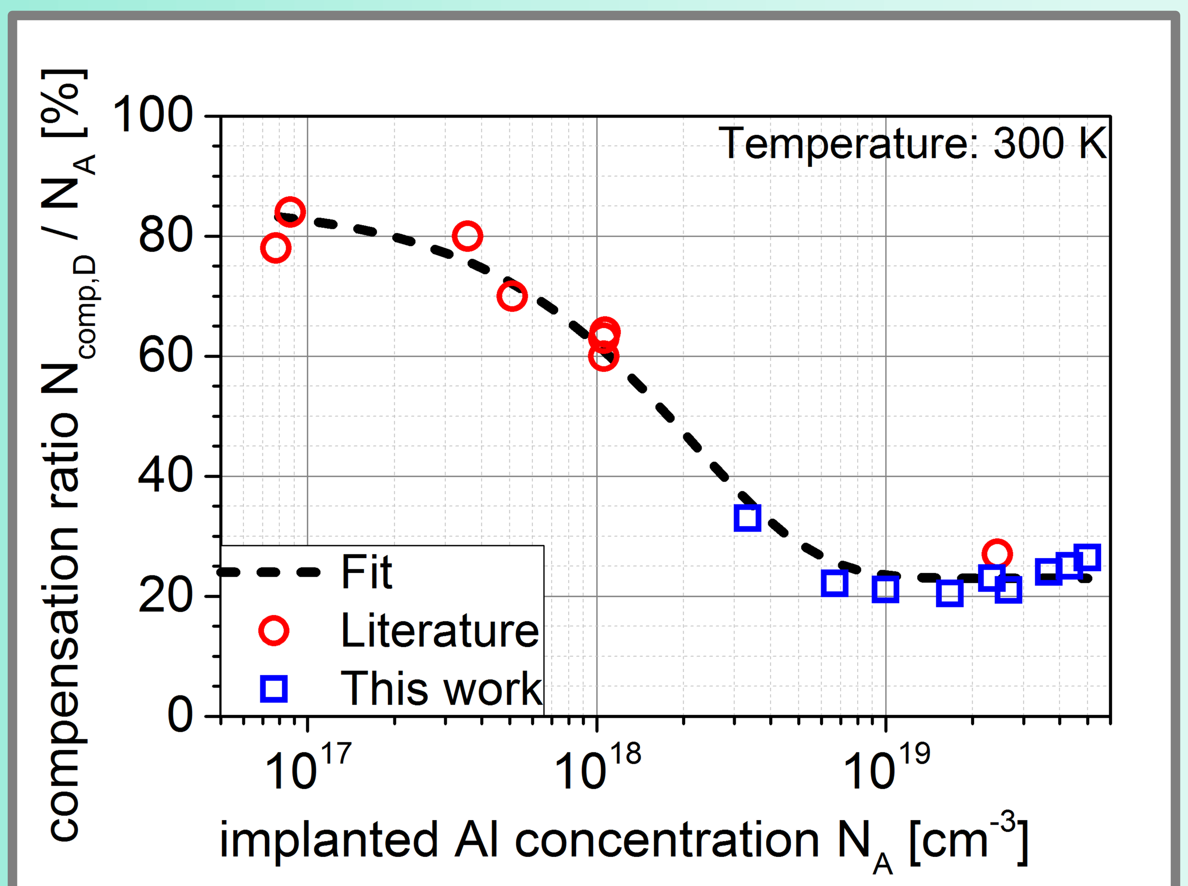

Fig. 2: Modelled compensation ratios of different samples (blue squares) by using our approximation model compared with ratios from Hall effect measurements from literature (red circles) [5]; black dashed line shows the resulting fitting function

$$f_{comp}(N_A) = f_{comp,A} + f_{comp,B} \exp\left(-\frac{N_A}{N_{A,ref}}\right) \tag{2}$$

Conclusion and Outlook

- Compensation ratios determined from TLM measurements seem to be an easy and promising complement to those obtained from to Hall measurements
- The numerical fitting function allows to estimate compensation ratios of Al implanted 4H-SiC samples before actual device processing
- To generalize the TCAD simulation model and the numerical fitting function, further investigations will be necessary
- Especially for low Al concentrations more results are required to cross check the compensation ratios obtained with the newly introduced method to those obtained from Hall measurements

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