FRAUNHOFER INSTITUTE FOR INTEGRATED SYSTEMS AND DEVICE TECHNOLOGY IISB

International Conference on Silicon Carbide and Related Materials, September 17th - 22th 2017, Washington, D.C., USA

Influence of Al doping concentration and annealing parameters on TiAl based ohmic contacts on 4H-SiC

M. Kocher [1, a], M. Rommel [1, b], T. Erlbacher [1, c], A. J. Bauer [1, d]

[1] Fraunhofer Institute for Integrated Systems and Device Technology (IISB), Schottkystrasse 10, 91058 Erlangen, Germany
[a] Matthias.Kocher@iisb.fraunhofer.de, [b] Mathias.Rommel@iisb.fraunhofer.de, [c] Tobias.Erlbacher@iisb.fraunhofer.de,
[d] Anton.Bauer@iisb.fraunhofer.de

Motivation

- TiAl is on of the preferred metal stacks used to form ohmic contacts on p-doped SiC [1] and is known to grow a Ti_3SiC_2 layer directly on the SiC surface [1, 2]
- Ti_3SiC_2 is the key to achieve an ohmic contact behavior [2]
- Ohmic contacts on p-doped SiC are commonly verified on epitaxial layers, but ohmic contacts on Al implanted layers are technologically more relevant
  → Performing a DoE with different TLM structures [3] by varying Al concentrations and annealing conditions to investigate their influence on the ohmic behavior
- Developing a TCAD model in order to get a better understanding of Ti_3SiC_2 based ohmic contacts on Al implanted regions

Sample preparation

- Three 100 mm 4H-SiC wafers with epitaxial layer (6 µm; 10^{16} cm^{-3})
- p^+ front side implantation
  - 15 different Al box profiles with concentration ranging from $3.3\cdot10^{18}$ cm^{-3} to $5.0\cdot10^{19}$ cm^{-3}
- Three different high-temperature anneal plateaus in Ar atmosphere
  - 30 min @ 1700 °C; 30 min @ 1800 °C; 1 min @ 1900 °C
- Depositing 450 nm LPCVD passivation oxide
- Removing oxide in ohmic contact pad area, sputtering TiAl metal stack (60 nm/300 nm) and structuring via a lift-off process
- Forming ohmic contact via RTA (2 min; 980 °C)
- Depositing Al pads (500 nm) by sputtering and structuring via a lift-off process

Electrical characterization

- Measurement setup
  - Four wire (Kelvin) I-V measurement (voltage range: -10 V to 10 V (step: 0.1 V))
  - Measurement temperature: 300 K
- Measured resistance R_{meas} of all TLM structures showed ohmic behavior
- Fig. 1 shows the specific contact resistances ρ_C
  - ρ_C decreases with increasing implanted doping concentration
  - Lowest ρ_C for implantation annealing temperature of 1800 °C
- Fig. 2 shows the corresponding sheet resistance R_{sh} of the implanted region
  - R_{sh} decreases with increasing doping concentration and increasing implantation annealing temperature

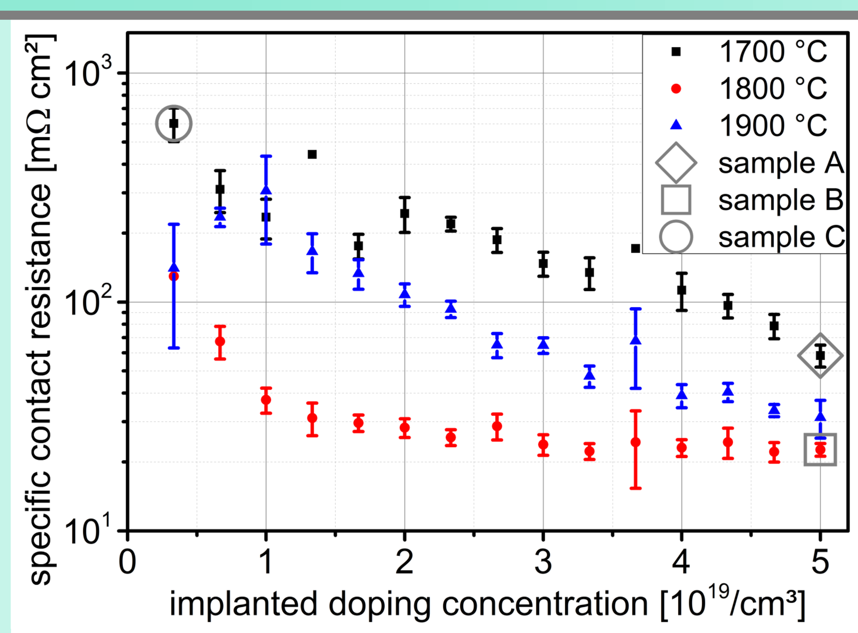


Fig. 1: Average specific contact resistance

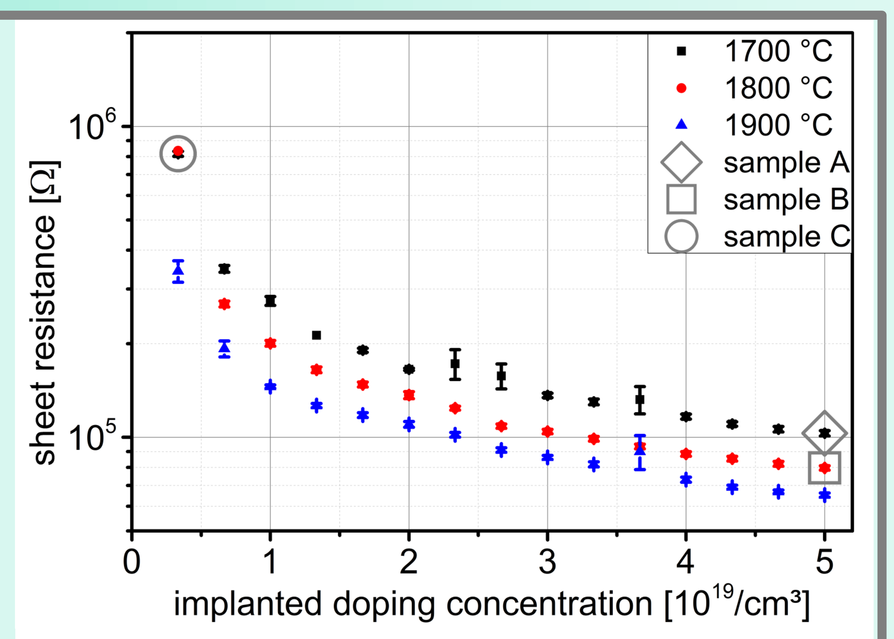
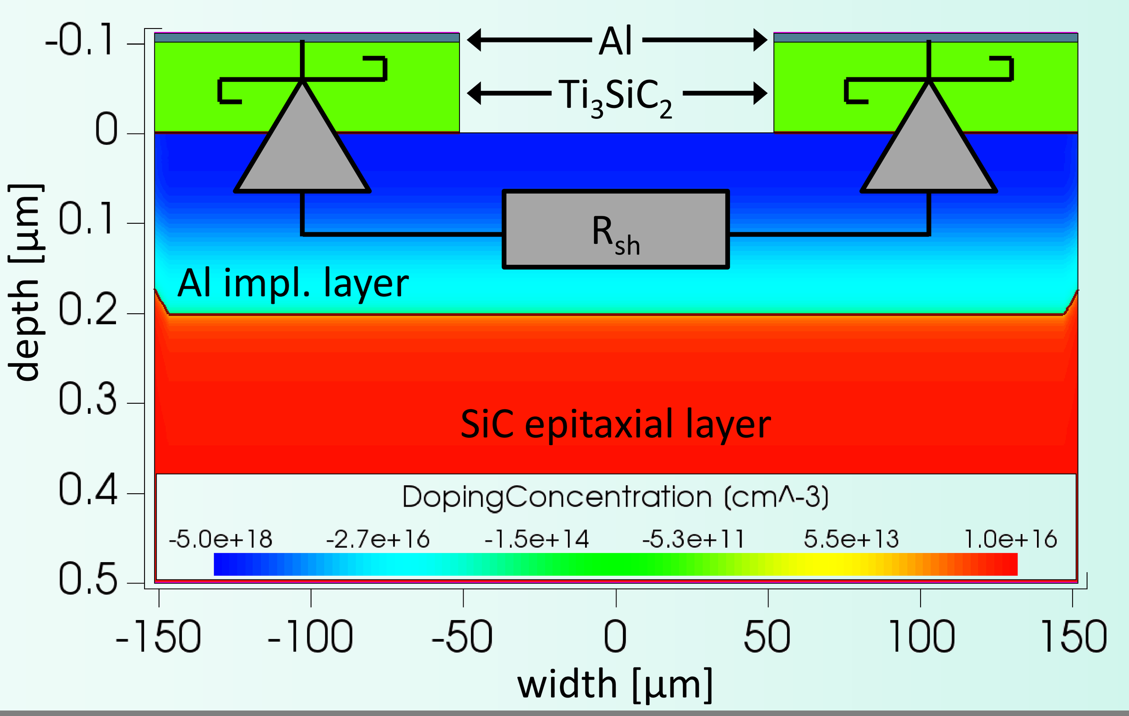


Fig. 2: Average sheet resistance

Simulation model

- TCAD simulation model (Sentaurus)
- Three layer stack (SiC with Al implantation, Ti_3SiC_2, Al)
- Ti_3SiC_2–Al interface is modelled as an ideal ohmic contact
- Ti_3SiC_2-SiC interface is modelled as a Schottky contact
- Ti_3SiC_2 parameters
  - electrical conductivity (300 K): $4.6\cdot10^6$ $(\Omega m)^{-1}$ [4]
  - Bandgap (300 K): 0.12eV [5]
- Introduction of three simulation parameters to take account of:
  - Carrier compensation: Al implantation scaling factor f_{imp}
  - Tunneling parameters: effective density of states for holes N_V (Ti_3SiC_2) and hole tunneling mass $m_{t,h}$ (SiC)



Simulation results

- Simulation results are exemplarily shown for three different samples A-C (highlighted in Fig. 1 and Fig. 2; see Tab. 1 for process parameters; see Tab.2 for simulation parameters)
  - Determination of R_{sim} by using the simulated I-V curves
  - Deviation between R_{sim} and R_{meas} sufficiently low (max. deviation: approx. ±5.5 %; see Tab. 3)
  - Sample C showed that even for a hole concentration as low as $2.6\cdot10^{17}$ cm^{-3} ohmic contact behavior (see Tab. 2)
  - N_V is independent of the carrier concentration, while $m_{t,h}$ strongly depends on the carrier concentration
- Fig. 3a) and Fig. 4a) show the simulated band diagram of samples A and C (magnification to the right of each figure)
  - Both semiconductors (SiC and Ti_3SiC_2) show band bending at the Ti_3SiC_2-SiC interface
  - Ti_3SiC_2 degenerates to a metallic-like behavior and accumulates holes at the Ti_3SiC_2-SiC interface

Table 1: Process parameters

Parameter	unit	sample A	sample B	sample C
Impl. Al conc. N_{imp}	10^{19} cm^{-3}	5.0	5.0	0.33
Impl. annealing	---	30 min @ 1700 °C	30 min @ 1800 °C	30 min @ 1700 °C

Table 2: Determined simulation parameters

parameter	unit	sample A	sample B	sample C
f_{imp}	%	6.2	9.4	7.9
$f_{imp}\cdot N_{imp}$	10^{17} cm^{-3}	31	47	2.6
N_V	10^{18} cm^{-3}	8.5	8.5	8.5
$m_{t,h}$	10^{-34} kg	63.8	63.8	2.46

Table 3: Comparison of measured and simulated resistances

		d1	d2	d3	d4
sample A	R_{meas} [kΩ]	9.70	21.3	44.1	88.7
	R_{sim} [kΩ]	9.69	20.9	43.4	88.4
	deviation [%]	-0.08	-1.98	-1.65	-0.35
sample B	R_{meas} [kΩ]	7.12	15.9	33.5	68.3
	R_{sim} [kΩ]	6.78	15.5	33.0	68.1
	deviation [%]	-4.91	-2.49	-1.26	-0.40
sample C	R_{meas} [kΩ]	76.2	159	334	690
	R_{sim} [kΩ]	80.4	161	333	681
	deviation [%]	5.47	1.01	-0.14	-1.33

Summary and Outlook

- Formation of low ohmic contacts is possible on Al implanted layers, with a net doping as low as $3\cdot10^{17}$ cm^{-3}
  → Ti_3SiC_2 is a high potential material to form low ohmic contacts on Al implanted SiC layers
- A first model to simulate Ti_3SiC_2 contacts on Al implanted regions was implemented and verified on processed samples
- Tunneling parameters of Ti_3SiC_2 contacts were determined
- Further simulations with different Al concentrations and annealing conditions have to be done in order to improve the simulation parameters
- Further investigations have to be done in order to reduce the carrier compensation and thus improve the ohmic behavior

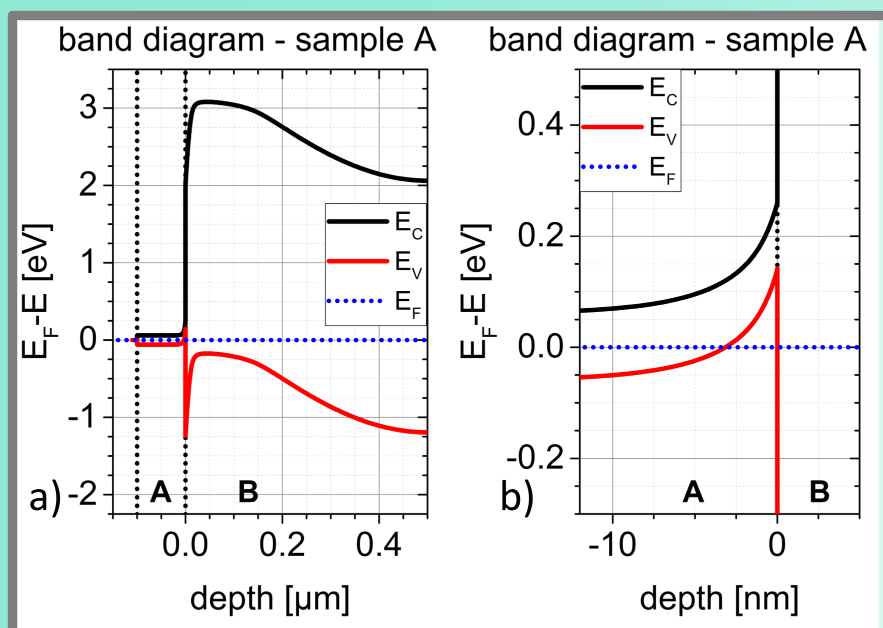


Fig. 3: Sample A: band diagram without applied voltage (A indicates the Ti3SiC2 layer; B the SiC layer)

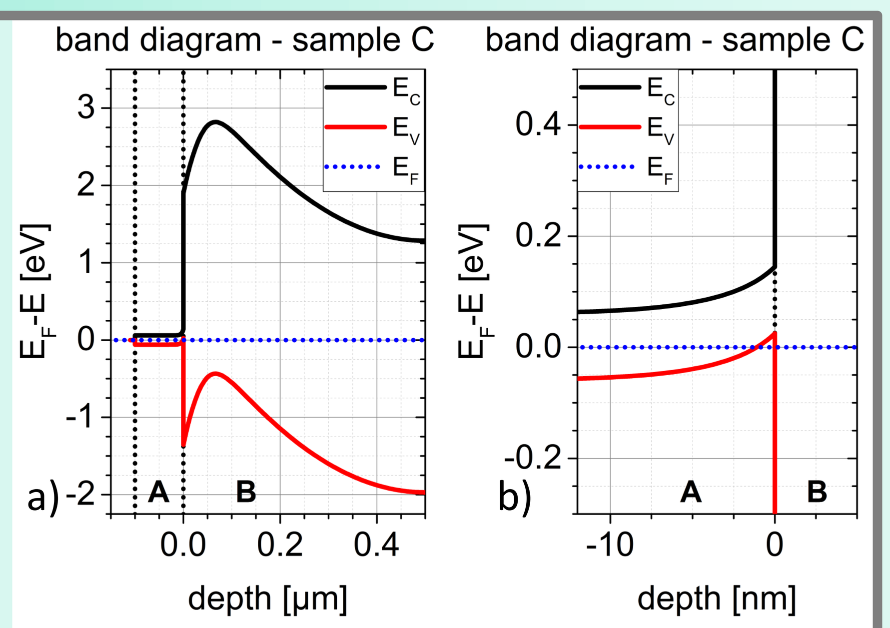


Fig. 4: Sample C: band diagram without applied voltage (A indicates the Ti3SiC2 layer; B the SiC layer)

References

- [1] T. Kimoto and J. A. Cooper, Fundamentals of silicon carbide technology: Growth, characterization, devices and applications. Singapore: Wiley IEEE, 2014.
- [2] Z. Wang *et al.*, "Ohmic contacts on silicon carbide: The first monolayer and its electronic effect," *Phys. Rev. B*, vol. 80, no. 24, p. 245303, 2009.
- [3] D. K. Schroder, *Semiconductor material and device characterization,* 3rd ed. [Piscataway, NJ], Hoboken, N.J.: IEEE Press; Wiley, 2006.
- [4] T. Abi-Tannous *et al.*, "A Study on the Temperature of Ohmic Contact to p-Type SiC Based on Ti_3SiC_2 Phase," *IEEE Trans. Electron Devices*, vol. 63, no. 6, pp. 2462–2468, 2016.
- [5] H. Yu *et al.*, "Thermal stability of Ni/Ti/Al ohmic contacts to p- type 4H-SiC," *Journal of Applied Physics*, vol. 117, no. 2, p. 25703, 2015.