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Process-based Modeling of 4H-SiC Double-trench MOSFETs with Reshaped Trench Geometries

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Introduction and Motivation

- A double-trench MOSFET is proposed due to the fact that the double trench structure in both gate and source regions is favorable for shielding a dielectric at the trench bottom where the dielectric breakdown mainly occurs during high drain-source voltage application [1].
- Previous studies showed trench structures are formed after ion implantation (trench-last process). Whereas maximal alignment accuracy can be obtained, a drawback of trench-last process is the difficulty to control the etching behavior of the implanted 4H-SiC [2, 3].
- In this work, the manufacturing process, in which a formation of trenches is followed by n^+-source and p-well implantation (trench-first process) based modeling of double-trench MOSFET and the influence of ion implantation parameters on electrical characteristics is described by using TCAD process- and device simulation implemented in Synopsis Sentaurus.

Employed process-modeling methods and fabrication technology

- For the manufacturing, an n-type 4H-SiC epitaxial layer was used with a donor concentration of 6×10^{15} cm^{-3} on 150 mm wafers.
- The epitaxial layer was dry etched to pattern the trenches using an oxide hard mask deposited by PECVD.
- After dry etching, a high temperature annealing was carried out to smoothen sharp corners.
- In the process simulation, the actual trench shape was modeled with the following dimensions: trench depth (1 µm), trench width (1 µm), reshaped angle (86 °).
- To model the actual ion implantation, the Monte Carlo (MC) option was used for self-aligned n^+-source or p-well regions under +7 ° and -7 ° for generating a symmetrical implanted geometry.
- The p^+-shielding implantation was simulated under the tilt angles of (+7 ° and -7 °) or (0 °, +45 °, -45 °) with a non-ideal resist mask replicating an actual implantation mask having flank angle of 85° patterned via photolithography.
- As depicted in Fig. 1, the darker area and the brighter area in the vicinity of mesa are n^+-source and p^+-shielding regions, respectively.
- The brighter area corresponds to the high concentration plateau of the box profile of the p-well region, which has a crucial role for the channel length as key contributor for channel resistance.

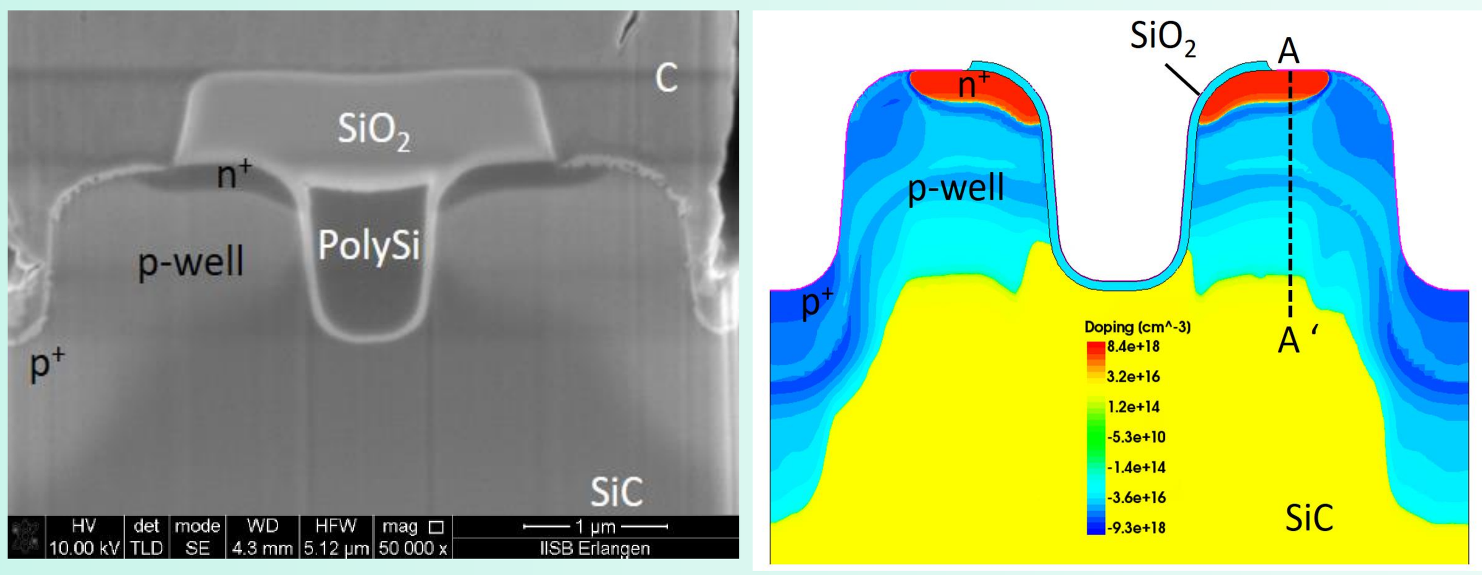

Fig. 1. Experiment (left): SEM cross-section image for N and Al dopant contrast / TCAD-simulation (right): The corresponding MC implantation profile simulated by using process simulation.

Results and Conclusions

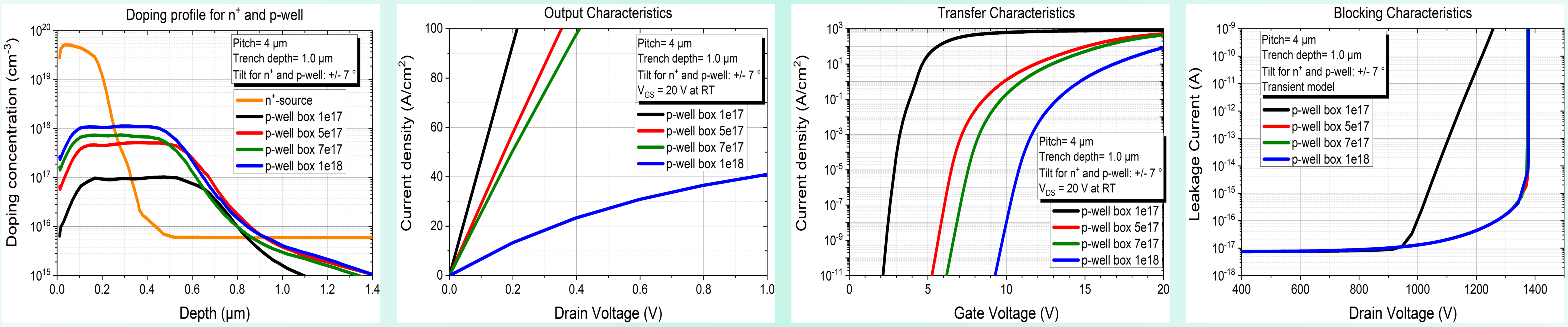

Fig. 2. Depth profiles of doping concentration simulated via process simulation across A-A` section (left, see Fig. 1 for A-A`), output characteristics (second from left), transfer characteristics (third left) and blocking characteristics (right) depending on doping concentration of p-well simulated via device simulation.

- The doping concentration of p-well region appears to have critical effect on electrical characteristics.
- The depth profiles of four different implantations for p-well region of which:
  - Total doses: 5.9×10^{12} cm^{-2} / 2.7×10^{13} cm^{-2} / 3.5×10^{13} cm^{-2} / 5.5×10^{13} cm^{-2}.
  - Energy range: 90 keV up to 480 keV.
- The depth profiles illustrate a box profile of which peak values of doping concentration are varied as:
  - 1.0×10^{17} cm^{-3} / 5.0×10^{17} cm^{-3} / 7.0×10^{17} cm^{-3} / 1.0×10^{18} cm^{-3}.
- The higher amount of doses for p-well implantation leads to:
  - The higher on-state resistance ($R_{DS,on}$) and the higher threshold voltage (V_{th}).
- The lower p-well doping, e.g. box profile for 1.0×10^{17} cm^{-3}, is particularly prone to reach-through effect causes to reduce the breakdown voltage (BV) [4].
- For this reason, it is favorable to use implantation parameters which result in p-well box profiles having plateau doping concentrations between: 5.0×10^{17} cm^{-3} and 7.0×10^{17} cm^{-3}.
- As depicted in Fig. 3, the higher tilted ion implantation (0 °, +45 °, -45 °, each 1/3 dose) presents improved BV compared with perpendicular or slightly tilted ion implantation (+7 ° and -7 °, each 1/2 dose).
  - It is beneficial for shielding owing to an extended p^+ region in the lateral direction.
  - On the other hand, the higher amount of doses for p^+-shielding can be deleterious to the $R_{DS,on}$ due to increasing an effectiveness of the JFET region between the p-body in both sides.

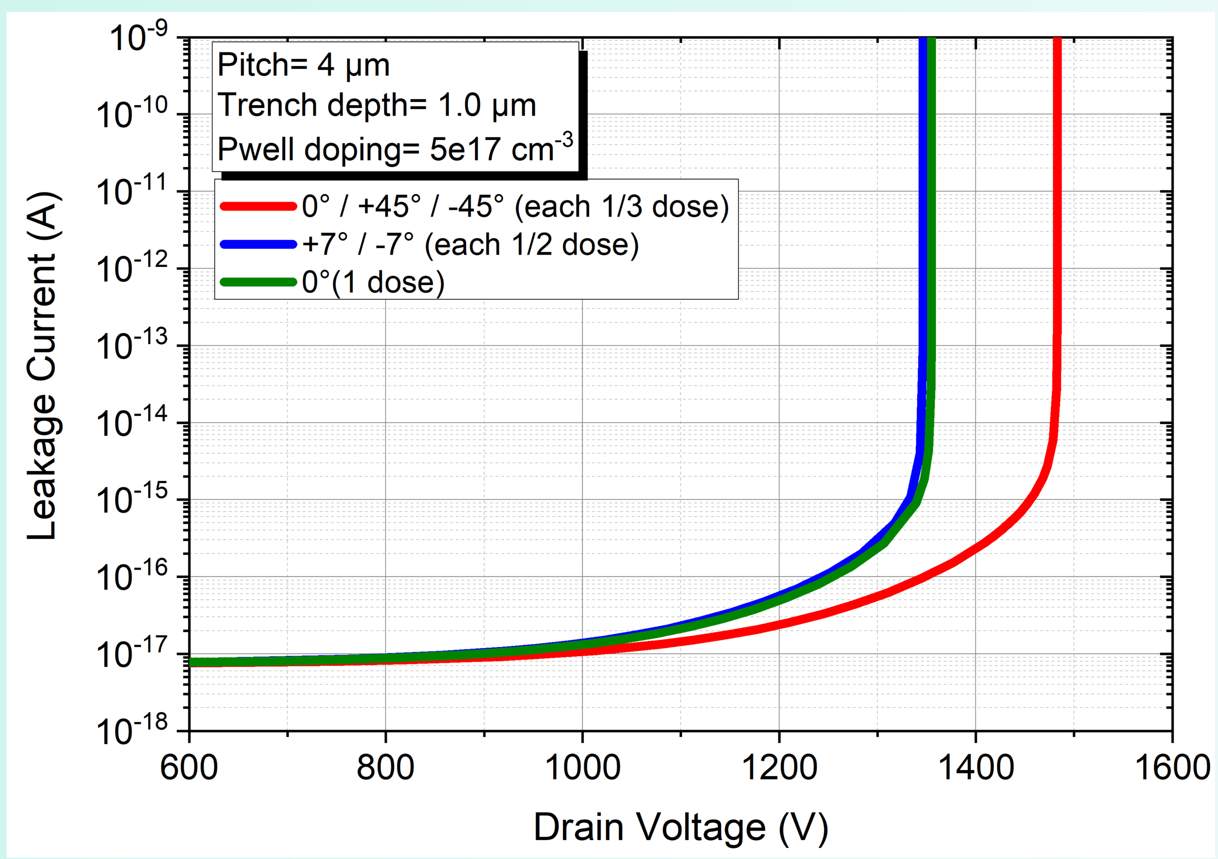

Fig. 3. Influence of the tilt angle for ion implantation for p^+-shielding on the blocking characteristic by using TCAD simulation.

References and Acknowledgement

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