Electrothermal simulations of a thermal sensor integrated with a 4H-SiC JFET

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Abstract

In this work we carried out electrothermal simulation of a temperature sensor. The sensor aims to probe the local temperature of a 4H-SiC JFET device during functioning. The change in resistance with the temperature of p-type SiC region is used to provide the sensing capabilities. This change is due to incomplete ionization of P-type *Al* dopants in SiC. The sensor provides a change in resistance of 80 Ohms in the range of temperature studied. We tested the sensor at fixed temperature and using electrothermal simulations. We used an anisotropic and temperature dependent thermal conductivity. The device and sensor doping profile are generated using Monte Carlo simulated implantation.

Introduction

SiC wafer fabrication technology and device manufacturing have been reach a substantial maturity. Commercial SiC MOSFET and JFET mainly for power application start to populate the markets. Today with an increasing manufacturing of electrical vehicles the need of efficient and compact converters and controllers are paramount.

Even though SiC devices can hold operate at high temperature, it is important to monitor the junction device temperature for protection and reliability purposes. This work aims to design a temperature sensor embedded in JFET. We carried out electrothermal simulations using a Drift-Diffusion/Poisson approach in concomitance with the heat equation.

(1)

Model and Results

The doping and dimensions of JFET devices and embedded sensors are shown in fig. 1. All p+ regions are completed using Monte Carlo simulations [1] to create realistic implanted profiles with a maximum depth of 1µm. The p-dopant used is aluminum with an ionization energy of 265 meV. Fig. 2 shows the dependency of the kx and ky with the temperature. kx is the thermal conductivity in the c-axis (Hexagonal axis) and ky in the planar direction. For 4H-SiC, thermal conductivity decreases strongly with increasing temperature (approximately 80%). Fig. 3 shows the temperature profile (all the 2D profiles are at Vd=15V), following this, the joule heat profile is shown in Fig 4. The joule heat is more concentrated in the JFET channels, which is the high resistance region of the device. The output characteristics of the JFETs using electrothermal and fixed temperature values of 300 K and 450 K are shown in Fig 5. The electrothermal curve matches the 300K curve at low bias, and the 450K at large bias as expected. Fig 6 shows the sensor resistance as a function of temperature. Our calculations show that the sensor current is independent of the drain bias of the device for fixed temperature simulations. This means that there is no influence from the depletion region and device currents to the sensor's resistance. In addition, the resistance is very sensitive to the doping profile and the annealing or activation of dopants. Our sensor resistance sensitivity is around 50 % much larger than [2] and relative of the same order of magnitude than [3], however our design requires fewer implantation steps to fabricate in practice.

References

[1] S. Tian, *Monte Carlo Simulation of Ion Implantation in Crystalline SiC with Arbitrary Polytypes*, IEEE Transactions on Electron Devices, **55,** 1991, (2008)

[2] K. Han et al. *1.2 kV 4H-SiC SenseFET With Monolithically Integrated Sensing Resistor*, IEEE Electron Device Letters, **41**, 437, (2020)

[3] M. Berthou et al. *Monolithically Integrated Temperature Sensor in SiC Power Mosfets*, IEEE transactions on Power Electronics, **29**, 4979, (2014)

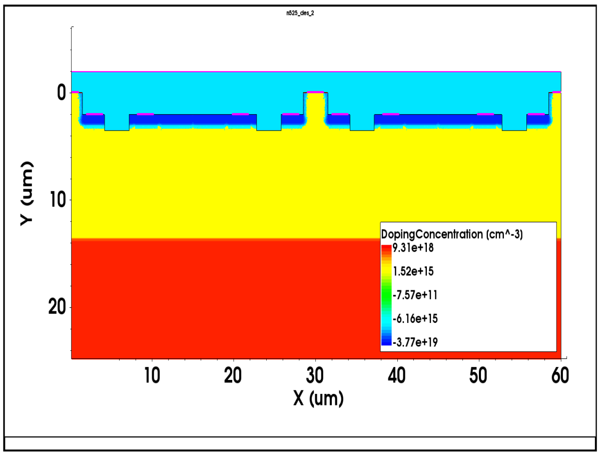

Fig. **1**. Doping profile of JFET with embedded sensor. The figure shows a full JFET cell in the centre, with half JFET cells shown at the edges of the image. Two sensor cells are also shown, one either side of the centre JFET.

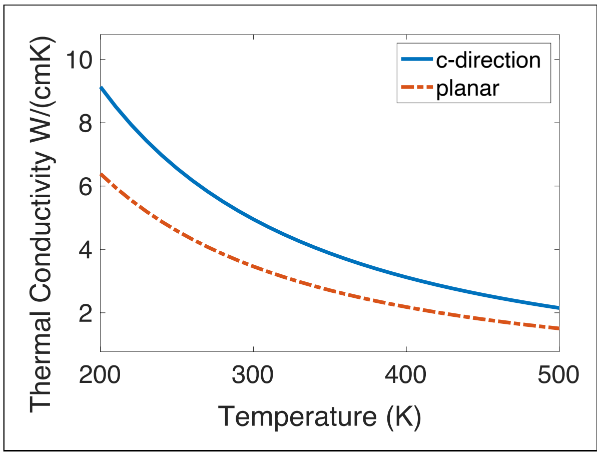

Fig. 2. Thermal conductivity vs temperature for c-axis and planar direction.

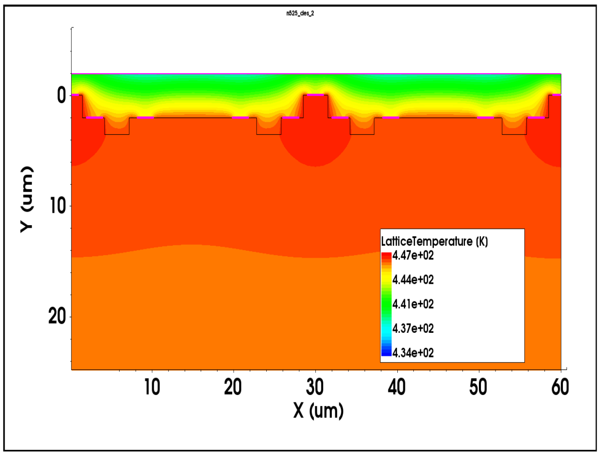

Fig. 3. Temperature profile for $V_{gs} = 0V$, $V_{ds} = 15V$,

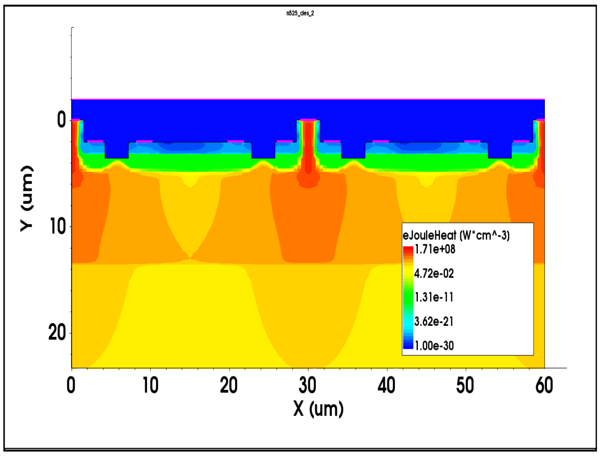

Fig. 4. The Joule heat profile corresponding to the case of Fig. 3.

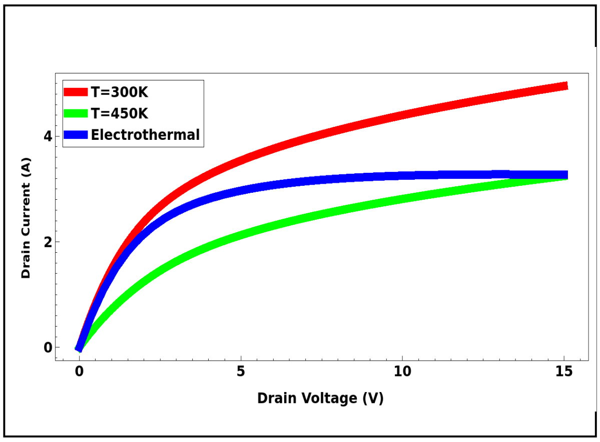

Fig. 5. Output characteristics of the JFET using electrothermal and at fixed temperatures (300K, 450K) at $V_{gs} = 0V$.

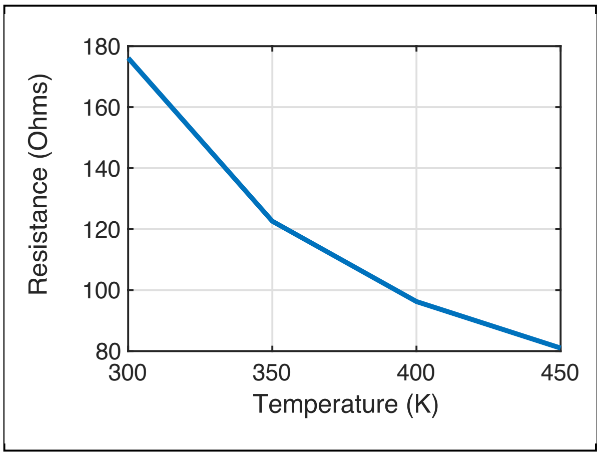

Fig. 6. Sensor resistance as a function of temperature