Carrier profiles measurements on 4H-SiC MOSFETs by Scanning Spreading Resistance Microscopy and Scanning Capacitance Microscopy

M. Zignale[1], P. Fiorenza[1*], E. Zanetti[2], M. S. Alessandrino[2], B. Carbone[2], A. Guarnera[2], M. Saggio[2], F. Giannazzo[1], F. Roccaforte[1]
[1]*CNR-IMM, Strada VIII 5, 95121 Catania, Italy*
[2]*STMicroelectronics, Stradale Primosole 50, 95121 Catania, Italy*

New generation of silicon carbide (4H-SiC) metal oxide semiconductor field effect transistors (MOSFETs) are increasing their performance in terms of On-resistance (RON), and maximum operating current also by shrinking of the cell-pitch and optimized thermal activation of the implanted regions [1].

In 4H-SiC MOSFETs, ion implantation is a very powerful technique to introduce dopand species (n-type: Phosphorous and p-type: Aluminium) in specific regions of the semiconductor, this process is followed by high-temperature annealing for the electrical activation [2,3]. As matter of fact, the designed doping level is chosen by TCAD simulation of the final device structure. However, a nanoscale measurement is needed to understand the real device performance, both the active doping concentration (or the material resistivity) and the real device geometry (e.g. size of the implanted region, junction depths, etc.).

In this context, two dimensional (2D) electrical scanning probe techniques (SPM), such as scanning capacitance microscopy (SCM) and scanning spreading resistance microscopy (SSRM), can give useful information both on the spatial distribution of the active dopants concentration and local resistivity in the region underneath the tip [4]. The SCM and SSRM have been widely employed for quantitative 2D carrier profiling in silicon-based CMOS structures [5]. Conversely, while there has been extensive exploration of the potentials of SCM [4] and SSRM [6] on wide bandgap semiconductors, there remains a necessity for focused endeavours to evaluate their 2D profiling capabilities. Specifically, a more in-depth investigation is required into the current injection mechanisms at the contact point between the SPM tip and 4H-SiC, aiming for a comprehensive quantification of the SSRM map. However, the complementary use of SCM and SSRM on identical device structures can provide precious information eventually on the discrepancy between the designed and the real device.

In this paper, SCM and SSRM analyses have been performed on the channel region of a vertical 4H-SiC power MOSFET, with the aim to determine the n-type and p-type distribution in real device, and to estimate the lateral resolution of these two complementary SPM methods and their capabilities on the detection of doping level variation across the unitary cell.

Fig. 1 shows the TCAD simulated structure of the planar power MOSFET in cross section, where two different cut lines are reported to estimate the free carrier concentration across the channel and the JFET regions.

Figs. 2a, 2b and 2c show, respectively, the AFM morphology, the SCM and the SSRM maps collected using conductive diamond coated Si tips on a MOSFET device, prepared with a bevel angle of 5° 44’, giving rise to a 10× magnification in the vertical direction. As can be noticed, the SCM image, based on local differential capacitance (dC/dV) measurements, is very sensitive to the majority carrier variations in the JFET depletion regions. On the other hand, the SSRM image, based on resistance measurements by a logarithmic current amplifier, shows clear signal variation in the gate region. To better illustrate the SSRM sensitivity and lateral resolution, the measured resistance across the gate insulator region is depicted in Fig,3. As can be noticed, an abrupt resistance variation across the SiO2/4H-SiC interface is detected. This information can be used to determine the lateral spatial resolution (from the 10% to 90% signal variation) of about 5 nm (red box in Fig. 3).

A quantification of the measured resistance maps to local resistivity requires a deeper understanding of the mechanisms of current injection from the conductive tip to the differently doped 4H-SiC MOSFET regions. To this aim, local current-voltage (I-V) characteristics were collected by the SSRM logarithmic current amplifier on a single point in the Drift, Body and Source regions, as shown in Fig. 4. The I-V collected on the drift and body regions are compatible with a forward n-type and reverse p-type Schottky-like conduction. On the other hand, the I-V collected on the source region shows a current value 4 orders of magnitude larger, compatible with current injection by thermionic field emission. Differently than for SSRM measurements on Si samples, where Ohmic contact formation between the tip and the semiconductor was achieved by applying a sufficiently high force, a non-linear behavior of I-V curves is observed on both p- and n-type doped 4H-SiC, even on the highly doped source region. Hence, both the tip/SiC contact and spreading resistance contributions must be considered to appropriately describe current injection in 4H-SiC, in order to make a quantification of SSRM signal to resistivity map.

Even though this aspect deserves further investigation, SSRM is promising for the investigation of shrunk latest MOSFETs generation in terms of lateral resolution.

This work is supported by Horizon EU AdvanSiC Project 101075709

References

1. P. Fiorenza, F. Giannazzo, F. Roccaforte, Energies, 2019 12, 2310
2. M.A.Capano, J.A. Jr. Cooper, M.R. Melloch, A.Saxler, W.C.Mitchel, J. Appl. Phys. 2000 87, 8773
3. M. Laube, et al, M. Maier. J. Appl. Phys. 2002 92, 549
4. P. Fiorenza et al Nanomaterials, 2021 11, 1626
5. P. Eyben et al Materials Science and Engineering B 2005 124–125, 45
6. J. Osterman et al Materials Science and Engineering B 2003 102, 128

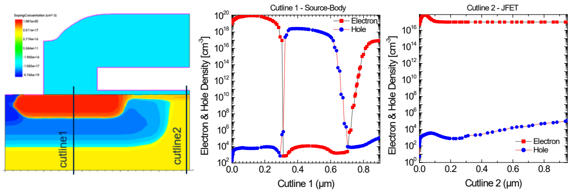

Fig. 1: TCAD free carriers simulation across the unitay cell in an ideal MOSFET.

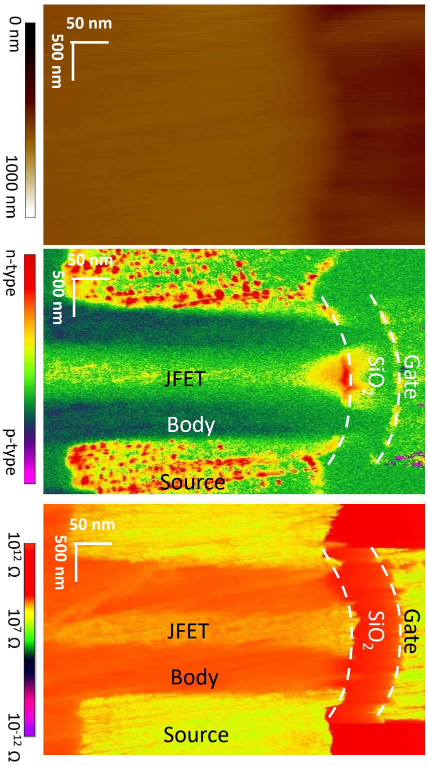

Fig. 2: (a) AFM morphology, (b) SCM and (c) SSRM signals.

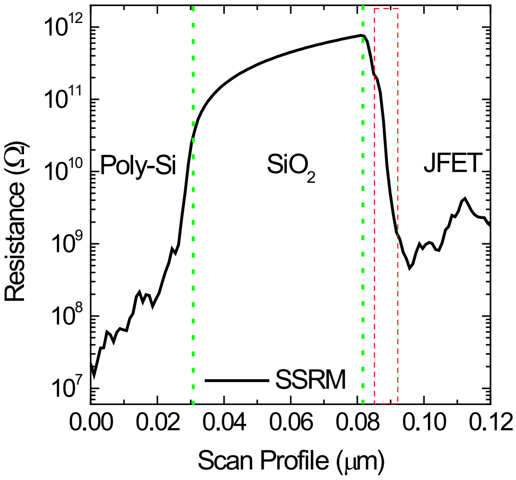

Fig. 3: SSRM profile across the gate insulator region.

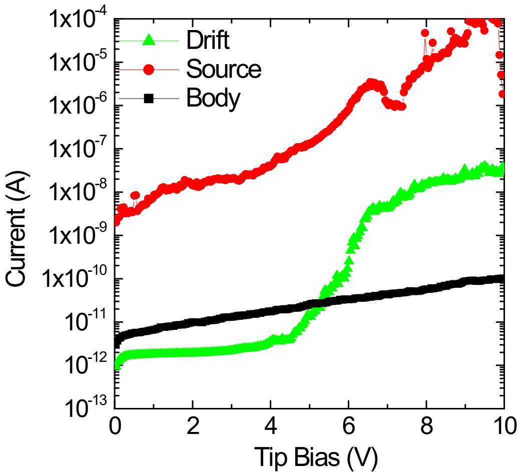

Fig. 4: Local I-V curves extracted from the SSRM signal in the Drift, Body and Source regions.

---

[*] *Corresponding author e-mail: patrick.fiorenza@imm.cnr.it*