Kelvin Force Microscopy and Micro-Raman Correlation Study of Triangular Defects in 4H-SiC

D. Marinskiy[1], M. Wilson[1], C. Almeida[1], S. Savtchouk[1], J. Lagowski[1]
S. Toth[2], Z. Szekrenyes[2], L. Badeeb[2] and A. Faragó[2]

[1]Semilab SDI, 12415 Telecom Dr., Tampa, FL 33637 USA; [2]Semilab ZRT, Prielle Kornélia u. 4/A. H-1117 Budapest, Hungary

Keywords: triangular defect, KFM, Raman, defect inspection, surface voltage

Abstract

Triangular defects in epitaxial 4H-SiC are considered device performance and yield killers. This property has been linked to involvement of 3C-SiC inclusions. In the present work, we address this aspect using micro-scale compositional and electrical characterization. Thus, micro-Raman TO mode mapping is used to distinguish 3C-SiC and 4H-SiC. The results clearly demonstrate a pattern of 3C-SiC within the triangular defect. Kelvin Force Microscopy images of the same defect show patterns similar to Raman. In case of KFM the pattern shows 3C-SiC as a higher work function region compared to the lower work function 4H-SiC. Another very strong electrical effect of the 3C-SiC is observed in KFM charge assisted measurements of the depletion layer leakage and corresponding rapid depletion voltage decay after charging. Such electrical activity is consistent with the lower energy gap of 3C-SiC and may explain the detrimental effect of triangular defects on device performance.

INTRODUCTION

Control and elimination of extended crystal defects represent very important tasks for improving silicon carbide device performance and manufacturing yield. A great deal of attention in this area has been devoted to triangular defects. In epitaxial growth of 4H-SiC they develop easily due to incorporation of 3C-SiC inclusions and preferable nucleation of this polytype [1]. As a result of 3C-SiC inclusion and 4H-SiC overgrowth, the triangular defects may exhibit different microstructures [1]. In our recent study combining UV-photoluminescence imaging and micro-scale Kelvin Force Microscopy, we have found that micro-regions within triangular defects show different electrical activity [2].

The present study is a continuation that incorporates micro-scale Raman imaging. The micro-KFM and micro-Raman results enable us to see for the first time, a relationship between 3C-SiC Raman signal and electrical properties in the triangular defect microstructure.

EXPERIMENTAL RESULTS AND DISCUSSION

Measurements were performed on n-type epitaxial 4H-SiC wafers with 8e15cm^{-3} dopant concentration. The QUAD (Quality, Uniformity, and Defect) map of the surface voltage, shown in Fig. 1 reveals electrical defects that are manifested as sites with different voltages compared to surroundings [2,3]. The QUAD automated defect count identified 82 defects. The map in Fig. 1 was measured using a 2mm diameter Kelvin probe and a charge enhanced technique capable of revealing defects with sizes smaller than the probe, however without imaging of actual defect micro-structure. The electrical micro-structure of triangular defects is of primary interest in this study. The micro-Kelvin Force Microscopy image of the triangular defect in Fig. 2a represents the work function pattern obtained using 8μm diameter KFM micro-probe with the calibrated work function. In this image, the larger work function regions contain 3C-SiC inclusion, compared to the lower work function of 4H-SiC. The partial derivative, KFM pattern of this defect shown in Fig. 2b, reveals characteristic micro-structure elements discussed in Ref. 1.

The micro-Raman results in Fig. 3 are based on the intensity of the LO Raman mode with 797 cm^{-1} and 777 cm^{-1} lines representing 3C-SiC and 4H-SiC, respectively. The Raman image indicates a 3C-SiC pattern similarity to that in Fig. 2. It reveals: the downfall defect at the apex; the strong 3C-SiC intensity near the triangular top, the faceted 3C-crystal line; and finally decreasing at the base region overgrown by 4H-SiC.

The present results are consistent with the 3C-SiC involvement in the triangular defects investigated in Ref [1] and based also on Raman imaging of defect.

The KFM charge transient results in Table 1 quantify significant differences in depletion leakage current in the micro-regions. These results are based on charge bias pulsing to depletion and micro-KFM measurement of time resolved depletion voltage. The two leakage indicator parameters in Table 1 are the voltage magnitude ΔV just after charging and the current density $J_D = C_D \cdot dV/dt$ where C_D is the depletion capacitance. Both quantities demonstrate a much larger leakage in the 3C-SiC region compared to the region of 4H-SiC outside the defect.

REFERENCES

[1] J. Guo et al., Journal of Crystal Growth, 480 (2017) 119-125.
[2] M. Wilson, et.al in CS Mantech Conference Digest 2020
[3] M. Wilson, Compound Semiconductor, 25-6 (2019), pp. 20-26.

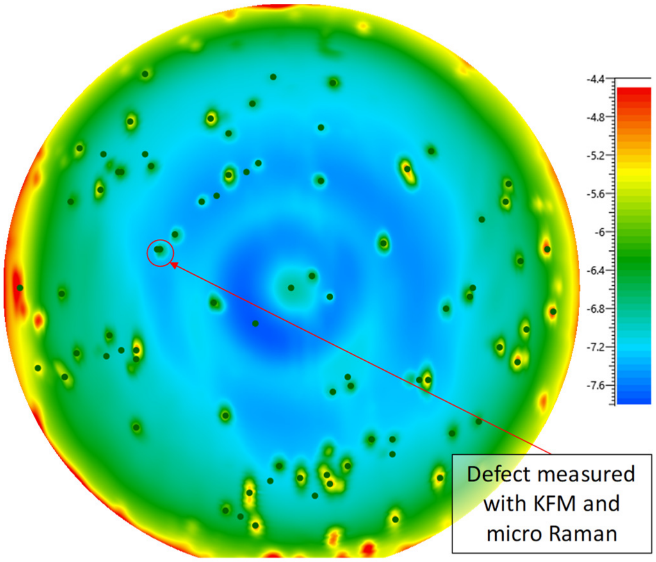

Figure 1. The QUAD map of electrically active defects in epitaxial 4H-SiC wafer.

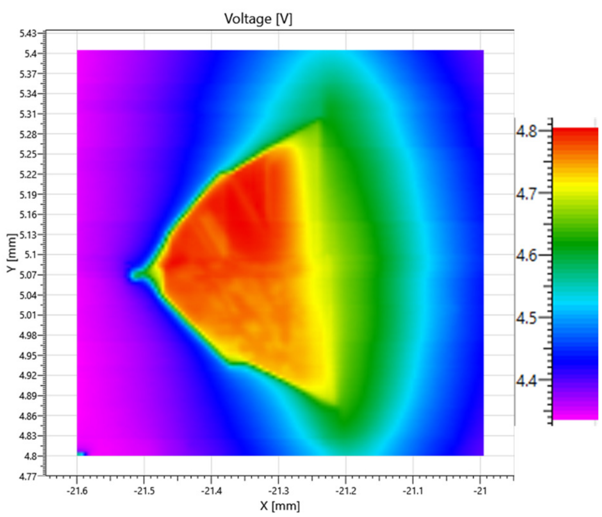

Figure 2a. Work function of a triangular defect measured with the KFM showing as much as 4.8eV for 3C-SiC within a defect decreasing to 4.3eV for 4H-SiC outside the defect.

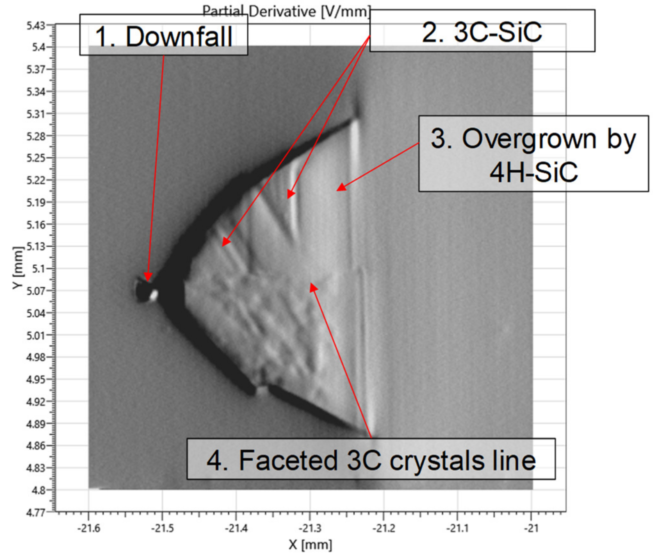

Figure 2b. 4 elements identified on the differential KFM map: downfall, 3C-SiC, faceted 3C crystals line, and the base with 3 C-SiC overgrown by 4H-SiC.

Table 1. Depletion leakage current indicators.

Indicator	4H-SiC outside defect	3C-SiC region inside defect
Depletion voltage magnitude, ΔV;	-45V	-4.8V
Leakage current indicator J_D at -5V (arb. units)	0.025	0.20

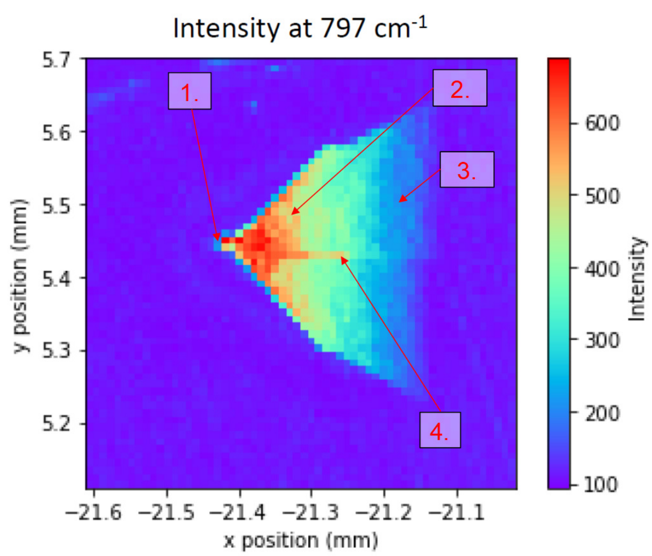

Figure 3. Micro Raman intensity of 797 cm^{-1} line that corresponds to 3C-SiC.