Compositional characterization of SiC-SiO_2 interfaces in MOSFETs

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Silicon carbide (SiC) is extendedly studied for its use in power electronic devices working at particular conditions thanks to its advantageous physical properties. Among the different polytypes, 4H-SiC is the most attractive due to its largest bandgap, high electron bulk mobility and availability. Nevertheless, the development of metal oxide semiconductor field effect transistors (MOSFETs) based on this material is limited because of the mobility degradation such as the low carrier mobility in the inversion layer [1,2]. Lately, it has been proposed that bulk traps in SiC reduce electron mobility and they are related to carbon (C) clusters (0.10-0.15 nm) at the SiC-SiO_2 interface [3] or C-enrichment over few to few tens nm across the SiC-SiO_2 interface, as it has been observed by Electron Energy Loss Spectroscopy (EELS) [4].

In the context of the MobiSiC project (Mobility engineering for SiC devices) [5], we study 4H-SiC MOSFETs with the aim to get more insight in the C distribution and nature across the SiC-SiO_2 interface and to correlate the results with electron mobility measurements. Investigations are based on the combination of structural and compositional analyses carried out by high resolution transmission electron microscopy (HRTEM) and spatially resolved EELS.

Two sets of samples with n-channel planar MOSFETs are studied. The first set (p-epi) and the second (p-imp) were fabricated on p- and n- type 4°-off 4H-SiC (0001) Si-face epilayers, respectively. The substrates were provided by CREE Inc. The gate oxides were grown by oxidation in N_2O atmosphere at 1553 K and subsequently annealed at the same temperature for 30 min under N_2 ambient. Further details about the sample fabrication process and the mobility results can be found in references [6,7].

TEM investigations have been performed on a field emission FEI Tecnai™ F20 microscope operating at 200 kV. This microscope is equipped with a corrector for spherical aberration dedicated for the direct observation of atomic structures at interfaces with substantially reduced contrast delocalization in the images. It allows us the analysis of defects in the SiC side and eventual C clusters in the amorphous SiO_2. Local EELS studies were conducted with a scanning stage (STEM) allowing a focused one nanometre-sized probe to be scanned over the sample area of interest and an imaging filter (Gatan GIF TRIDIEM) used as a spectrometer. From this, elemental profiles across the SiC/SiO_2 interface have been acquired. TEM-lamellas have been prepared by focused ion beam (FIB).

Additionally to the common difficulties to prepare TEM-lamellas, especially by FIB, these samples are even more difficult since the SiC is harder than SiO_2, so a gradient of thickness around 30% is observed at the interface whatever the process used for the fabrication of the sample (p-epi and p-imp). Structural investigations by HRTEM but also by weak beam electron diffraction reveals no defects in the SiC except those related to the dopant implantation and also no extended C cluster in the SiO_2. From elemental profiles, we do not see C over-stoichiometry across the interface but rather an area of smoothly compositional variation that we defined as transition layer (TL). The only difference between both studied samples is the width of the TL, being larger for the p-epi than for the p-imp. This result can be related to the better mobility of the p-imp sample than the p-epi [6, 7].

To complete these studies, additional chemical and structural investigations are performing such as atom probe tomography and strain studies.

The detailed analyses of the compositional distribution at the interface help us to understand the mobility results and work on its improvement in order to achieve the best design for MOSFETs with sufficiently high mobility to build more energy efficiency devices.

References

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