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Channel transport limiting mechanisms in 4H-SiC MOSFETs: Review and latest developments

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4H-SiC electronics is rapidly emerging as an enabling technology for energy efficiency in various high voltage power electronics applications. Among the various devices available, the power MOSFET (metal-oxide-field-effect- transistor) is extremely attractive for power circuit and system designers. While 4H-SiC DMOSFETs (double-implanted MOSFET) are now commercially available from few vendors, the performance and stability is far from the theoretical potential of SiC. One of the critical factors that limit the SiC MOSFET performance is the channel resistance. Historically, low electron mobility in the inversion channel has been the biggest obstacle for practical applications of these devices. The poor mobility was associated with an extremely high density of interfacial electron traps (D_{it}), spatially located at or near the SiO_2/4H-SiC interface and energetically located near the conduction band-edge of 4H-SiC. With the introduction of post-oxidation nitridation processes [1], the D_{it} was substantially reduced and practical DMOSFETs became a reality. The channel resistance in state-of-the-art DMOSFETs, while acceptable for devices with blocking voltages ≥ ~1000 V, still contributes to about 50% of the total device on-resistance. With nitridation, the channel mobility is still only about 5% of the bulk mobility of 4H-SiC. It is therefore highly desirable to develop processes for further enhancement of the channel mobility for next-generation devices. In addition, understanding of the transport physics in greater detail is also imperative.

The channel transport is intricately tied to the electro-chemical nature of the dielectric-semiconductor interface. In this talk, the focus will be on latest developments with regards to nanoscale passivation processes using new methods involving nitrogen and phosphorus as interfacial impurities. It is generally accepted that using nitridation, the channel mobility scales with the D_{it} [2] and trapping and Coulomb scattering are the main transport limiting factors [Fig. 1]. Latest results highlight that the scaling may not be universal [Fig.1.]. Other mechanisms such as the transverse electric field induced surface roughness scattering may be playing an increasingly important role for devices with a reasonably low D_{it} [3]. Transport limitation as a consequence of surface roughness scattering and the presence of a possible transition layer between SiC and the oxide [REF] will be discussed in detail. Key differences between the nitrogen and Phosphorus passivated devices will be pointed out in this context. The limitation of interfacial nitrogen's ability to enhance the mobility any further will also be discussed in the light of recent results obtained using a plasma based nitrogen passivation process. In addition, stability and reliability concerns with these novel interfaces will also be discussed in detail.

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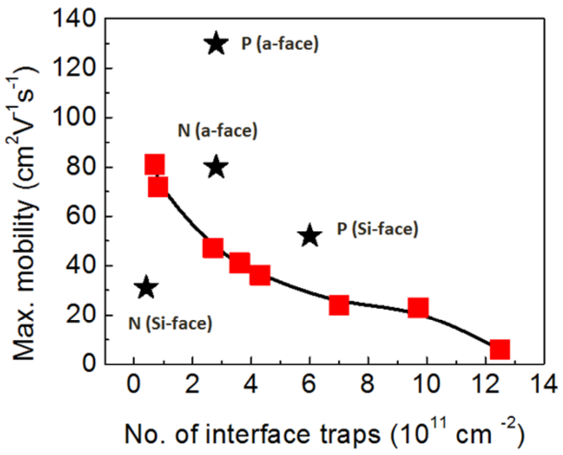

Figure 1. Maximum field-effect mobility as a function of total number of interface traps between 0.2 and 0.6 eV from the conduction band-edge of 4H-SiC. The red dots correspond to different devices with varying amount of the interfacial nitrogen. A qualitative scaling can be observed between mobility and interface traps. Latest data indicated by the star symbols obtained on MOSFETs fabricated on the conventional (0001) Si-face and the non-polar (11-20) a-face using new interface passivation schemes involving Phosphorus and Nitrogen indicate that the scaling is not universal. This strongly suggests that trapping and Coulomb scattering are no longer the dominant channel transport limiting mechanisms in 4H-SiC MOSFETs.