Contribution ID: **213** Type: **Poster**

Investigation of doping and dopant dependence of n-type 4H-SiC with low-energy muon spin spectroscopy

Tuesday, 30 August 2022 18:40 (20 minutes)

Silicon carbide (4H-SiC) is a wide-bandgap semiconductor with applications in high power devices. Epitaxial growth of SiC is crucial to produce structures with controlled thickness and doping concentration. Ion implantation with nitrogen (N) and phosphorus (P), on the other hand, is used to create spatially defined n-type regions in SiC. Implantation is usually followed by a post-implantation annealing step, to ensure lattice recovery and electrical activation of the donors. However, mitigating implantation-induced defects remains a challenge.

The narrow defective regions (200-300 nm) are not accessible by conventional techniques, but can be studied with low-energy muon-spin spectroscopy (LE-μSR). The LE-μSR experiments were performed at the low-energy muon facility at the SμS (PSI, Switzerland). The 4H-SiC samples were either doped with N during epitaxial growth ($N_D = 4\times10^{15}$ and 1×10^{17} cm^{-3}) or using ion-implantation of N and P ($N_D = 1\times10^{17}$ and 1×10^{18} cm^{-3}). The goal was to compare the different doping processes and to establish a μSR baseline for different doping concentrations in n-type SiC.

We find that an effective electron concentration (*n*) of 4×10^{15} cm^{-3} in SiC is below the sensitivity limit of LE-μSR. For $N_D > 1\times10^{17}$ cm^{-3}, there is an intermediate space charge region where muonium (Mu^0) formation dominates and the diamagnetic fraction (F_D) decreases. In the deeper probed region, F_D increases with doping concentration due to Mu^- formation. F_D also increases between 10 and 0.5 mT indicating delayed Mu^- formation, having a Mu^0 precursor state. For the implanted samples, 10 K measurements indicate higher defect density for 1×10^{18} cm^{-3}, which can be related to the higher implantation dose.
Furthermore, Monte Carlo simulations were used to generate muon decay histograms for different electron capture rates, to determine F_D and the phase of the diamagnetic signal as function of *n*, which agree with the experimental results. This means, that *n* can be determined for a SiC sample with unknown carrier concentration by comparing the experimental results of F_D and the phase with the results of the simulation.

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Session Classification: Posters

Track Classification: Semiconductors