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Defects in Ion-Implanted Silicon Carbide.

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13. ABSTRACT (Maximum 200 words)

Defects that introduce electrically active deep levels in ion-implanted Silicon Carbide (SiC) were studied by performing capacitance Deep- Level Transient- Spectroscopy (DLTS) and transconductance frequency dispersion measurements on fully implanted MESFETs in bulk semi-insulating 4-H SiC, MISFETs in 6-H SiC and double implanted p-n and n-p junction diodes in 4-H SiC. The junction diodes made with aluminum and phosphorus implantations exhibited higher reverse leakage current compared to those made by nitrogen and boron implantations. In all samples implanted with nitrogen a defect complex involving nitrogen and a point defect (introduced by the ion-implantation process) is observed with a trap level introduced at 0.51 eV above the valence band. Phosphorus implant-native defect related peaks are observed at 0.6 and 0.7 eV above the valence band. In all boron implanted samples, a prominent electrically active boron related D-center defect is seen at 0.62 eV above the valence band. In aluminum implanted samples an intrinsic vacancy related defect is seen at 0.78 eV above the valence band. Surface state related defects were observed in the N-implanted channel region at energies 0.18 eV, 0.3 eV and 0.4 eV. Several defects were observed in the gate insulator and insulator/channel interface.

14. SUBJECT TERMS
Defects, Deep-Levels, Silicon Carbide (SiC), DLTS, transconductance frequency dispersion.

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Grant Fund Code: DAAD19-00-1-0490
Principle Investigators: Mulpuri V. Rao and D. Ioannou
Army Research Lab Collaborator: Kenneth Jones, Adelphi, Maryland.
Graduate Students Supported by the Grant:

1. Souvick Mitra (His Ph. D. thesis work was entirely supported by this ARO Grant)
2. Taizo Okayama (Masters Student)

Listing of Peer-reviewed Journal Article Publications Acknowledging the ARO Grant:

1. S. Mitra, M. V. Rao, K. Jones, N. Papanicolaou, and S. Wilson, "Deep levels in ion-implanted field-effect-transistors in SiC", Solid-State Electronics, Vol. 47 (2), Feb. 2003, pp. 193-198
2. M. V. Rao, "Maturing ion-implantation technology and its device applications in SiC", Solid-State Electronics, Vol. 47 (2), Feb. 2003, pp. 213-222.
3. S. Mitra, M. V. Rao, N. Papanicolaou, K. A. Jones, M. Derenge, O. W. Holland, R. D. Vispute, and S. R. Wilson, "Deep-level transient spectroscopy study on double implanted n^+-p and p^+-n 4H-SiC diodes", Journal of Applied Physics, Vol. 95 (1), Jan. 2004, pp. 69-75.
4. S. Mitra, M. V. Rao, and K. A. Jones, "Transconductance frequency dispersion measurements on MESFETs made on bulk semi-insulating 4H-SiC by nitrogen ion-implantations", Solid-State Electronics, Vol. 48 (1), Jan. 2004, pp. 143-147.

Statement of the Problem Studied: Ion-implantation is the only reliable technique for planar selective area doping of Silicon Carbide (SiC) devices[1]. Ion-implantation technology for both donor- and acceptor- dopants in SiC has been developed[2]. Ion-implantation has been used to create channel, source and drain regions of SiC field-effect-transistors[3-5] and p- and n-regions of p-n junctions[6]. The performance and reliability of these SiC devices remains a problem, partially due to channel/insulator, channel/substrate interface and p-n junction interface deep-level defects. In this project, deep-level defects: (a) at the interface of double implanted 4H-SiC p-n and n-p junction diodes, (b) at the interface of channel/gate insulator in n-channel 6H-SiC Metal-Insulator-Semiconductor Field-Effect-Transistors (MISFETs) and (c) at the gate/channel and channel/substrate interface of n-channel 4H-SiC MEtal-Semiconductor Fild-Effect-Transistor (MESFET) have been studied. The MISFETs were made in p-type epitaxial layers and the MESFETs in semi-insulating bulk substrates. Deep levels in the double-implanted p-n and n-p junction diodes and MISFETs were studied by capacitance Deep-Level-Transient-Spectroscopy (DLTS), where as the deep levels in MESFETs were studied by both capacitance DLTS and transconductance frequency dispersion spectroscopy.

Summary of the Most Important Results:

Devices used in this study were made by nitrogen, phosphorus, aluminum, and boron implantations, to study the defects introduced by implantations of various species[3,5,7].

In all samples implanted with nitrogen a defect complex involving nitrogen and a point defect (introduced by the ion-implantation process) is observed with a trap level introduced at 0.51 eV above the valence band[7-9]. In n^+-p junction diodes made using phosphorus implantation the defect density is very high yielding poor device performance. In the phosphorus ion-implanted samples, phosphorus implant-native defect related peaks are observed at 0.6 and 0.7 eV above the valence band[7]. In all boron implanted samples, a prominent electrically active boron related D-center defect is seen at 0.62 eV above the valence band[7]. In aluminum implanted samples an intrinsic vacancy related defect is seen at 0.78 eV above the valence band, and a background nitrogen at carbon lattice site complex defect is seen at 0.15 eV above the valence band[7]. Several unidentified defects are seen in Al implanted samples[7]. The lattice damage in Al-implanted samples is so high that the p^+-n junction diodes made using Al-implantation yielded poor device performance. The concentration of traps in p-n and n-p junction diodes made by phosphorus and aluminum implantations is very high compared to the diodes made by nitrogen and boron implantations, resulting in high junction leakage currents in the former[6,7].

In the transconductance frequency dispersion measurements performed on MESFETs made in vanadium-doped semi-insulating 4H-SiC, a vanadium deep donor is observed at 0.65 eV below the conduction band and a nitrogen dopant-defect complex at 0.52 eV[9]. The vanadium deep donor is intentionally introduced to obtain semi-insulating behavior in the bulk 4H-SiC substrate. The defect involved in the complex responsible for the 0.52 eV peak is a point defect. Three surface state related defects were observed in the N-implanted channel region at energies 0.18 eV, 0.3 eV and 0.4 eV[9]. For low concentration (~ 6×10^{17} cm^{-3}) nitrogen implanted MESFET channel, the magnitude of transconductance frequency dispersion is comparable to dispersion in epitaxially grown channel layer, indicating the attractiveness of nitrogen implantation to achieve lightly doped n-type channel regions in SiC MESFETs.

Five gate dielectric traps and eight interface hole/electron traps were revealed for MISFETs. Gate dielectric traps were distinguished by different activation energies of 0.109, 0.132, 0.15, 0.4 and 0.6 eV[8]. Two shallow gate dielectric/semiconductor interface traps were identified at E_v +0.2 eV (hole trap) and E_c -0.362 eV (electron trap)[8]. Four deep level traps were found in the activation energy range of 0.6-0.8 eV above the valance band edge with capture cross-section ~10^{-16} -10^{-17} cm^2. Other traps were detected at E = 0.437 and 0.47 eV above E_v[8]. For both MESFETs and MISFETs, effective channel mobility is much smaller than the bulk mobility due to residual implant lattice damage and/or dielectric/ SiC interface traps and channel/substrate interface traps[3-5].

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9. S. Mitra, M. V. Rao, and K. A. Jones, Solid-State Electronics.48, 143(2004).

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