Understanding Proton Radiation Effects on the Defect Spectrum in High-Mobility MOCVD-Grown (010) β-Ga2O3

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Abstract: Gallium oxide has compelling material properties that have generated a large and growing interest for applications in opto-electronics, power devices, and RF devices. The wide bandgap of ~4.6-4.8 eV leads to a large breakdown field that increases the Baliga and Johnson figures of merit, indicating potentially superior performance in high power and high frequency devices. Additionally, the large bandgap has a propensity for better radiation hardness due to higher required displacement energies. An application for β-Ga2O3 based devices is a harsh radiation environment in space applications. There has been significant work to understand the impact of radiation on the GaN based material and devices, which degrades device performance due to the introduction of crystal defects. Ga2O3 has been shown to have higher displacement energies compared to GaN, so it may have improved radiation tolerance.

Recently, beta phase gallium oxide (β-Ga2O3) grown by metal organic chemical vapor deposition (MOCVD) has demonstrated excellent material quality having high electron mobility of 184 cm2/Vs.[1] In this work, MOCVD material is exposed to proton radiation at an energy of 1.8 MeV to understand how proton damage will influence the defect spectrum. Since intrinsic defects respond to radiation, radiation can be used to identify if a defect level is intrinsic. The 1 μm thick

MOCVD sample was grown in an Agnitron Agilis R&D MOCVD system using TEGa (triethylgallium) and O2 precursors at a substrate temperature of 880°C. The doping level was targeted to be 1×1017 cm-3 on a commercially available Sn-doped (010) EFG substrates at constant growth rate of 0.7 μm/hour.

Characterization of the MOCVD grown samples are done through multiple methods, mainly C V, admittance spectroscopy (AS), and deep level transient and optical spectroscopy (DLTS/DLOS). The electron concentration is extracted from the C V on the Schottky diodes and monitored for each fluence to determine the carrier removal rate. The carrier removal rate of 185 cm-1 for 1.8 MeV proton radiation in MOCVD Ga2O3 is significantly lower than published work on the same energy proton radiation in n-type GaN Schottky diodes.[2] There have been other reports on proton radiation in UID EFG β Ga2O3 and HVPE doped β Ga2O3 to date which have identified radiation sensitive defects through DLTS.[3], [4] This work uses multiple trap spectroscopy measurements (AS, DLTS and DLOS) to identify the changes in specific defects due to the proton radiation. AS measured a rather shallow trap level in the MOCVD material at EC 0.12 eV which was unaffected by radiation. DLTS identifies the generation of four new defect states compared to pre-radiation at EC 0.35 eV, EC 0.6 eV, EC 0.7 eV, and EC 1.0 eV, with the EC 0.7 eV level showing the highest concentration. Furthermore, DLOS measurements were done to identify levels beyond ~1 eV from the conduction band through an optical excitation process. The DLOS spectrum showed three trap levels with an increase in the concentration of the EC 1.2 eV trap and a large increase for the EC 2.0 eV trap level, which is the main compensating center. The trap at EC 4.4 eV is not sensitive to radiation, which is consistent with our work on neutron radiation on UID EFG β Ga2O3.[5]

This work will focus on understanding the changes caused by proton radiation for each defect level. With the knowledge of which defects are intrinsic and respond to radiation, theoretical studies for the displacement energies and possible intrinsic defects associated with each level will be discussed.

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[4] A. Y. Polyakov et al., Appl. Phys. Lett., vol. 112, no. 3, p. 032107, Jan. 2018
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