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Lifetime Limiting Defects in 4H-SiC

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Introduction: Efforts are under way to develop electrical power systems for Naval vessels and aircraft to be controlled by small, efficient, and reliable solid-state electronic devices, such as high-power (>10 kV) switching diodes. This has provoked significant interest in advancing technology based on 4H-SiC, as this semiconductor is much more capable of withstanding the required high power densities than is Si, which has been the standard material for these applications. Development of these devices requires that the SiC material be of sufficient purity, since defects (alterations from the perfect periodic lattice of Si and C atoms) can trap mobile charge carriers (electrons or holes), thus causing degradation of important electrical properties, such as the average lifetime of the minority carriers. In order to reduce the concentration of these defects (or "traps"), it is important to determine their chemical structure, so that appropriate strategies may be applied during or after material growth to minimize their incorporation.

Experiment: In this work, the defects that limit the minority carrier lifetime (MCL) are investigated by carrying out measurements of both carrier lifetimes and defect concentrations in a carefully characterized set of samples. Defects are identified and their concentrations are determined by deep-level transient spectroscopy (DLTS), in which the measurement of the temperature-dependent rate of emission of trapped carriers from the defects determines the characteristic thermal energy necessary to free the carriers from the traps. This temperature dependence is employed to establish a fingerprint that identifies the defect. The chemical nature of the defect is generally determined by independent correlations between these DLTS signatures and other measurements that reflect the local defect structure. Carrier lifetimes are measured by time-resolved photoluminescence (TRPL), in which a short pulse of laser light creates free electrons and holes in the material, and the measured decay rate for the recombination of these excess carriers provides a measure of the average MCL.[1] Measurements are carried out on a set of 4H-SiC samples grown with varying layer thickness between 9 and 104 μm. By fitting the variation of the measured lifetimes with layer thickness to a theoretical expression, two competing contributions to the lifetime can be separated—recombination in the bulk and recombination at the sample surface. As the inverse of the bulk lifetime is proportional to the concentration of the defect that limits the lifetime, it is the bulk lifetime that is of interest in correlating carrier lifetime with defect concentration.

Results: Figure 3 shows typical DLTS spectra for these layers, the peaks representing signatures of defects that trap electrons (a) and holes (b). These are the dominant defects that affect the electrical properties of the material. Z1/Z2 and EH6/EH7 are DLTS designations of two important electron traps. A Ti-related electron trap and two boron-related hole traps, B (boron impurity) and the "D-center," are observed; the latter is a boron impurity bonded to a nearby defect. An as-yet unidentified hole trap at 0.85 eV and electron trap at 1.1 eV (not shown) are also observed.

The correlation between the measured defect concentrations and the measured carrier lifetimes is shown in Fig. 4(a) as a function of layer thickness. It is clear from the figure that the defect concentration and inverse carrier lifetime (blue) exhibits strong correlation only for the Z1/Z2 center (red), suggesting that this is the dominant defect that limits the lifetime. In Fig. 4(b) the measured dependence of the carrier lifetime on layer thickness (circles) is compared to the fitted value (squares). The bulk lifetimes obtained from this fit are plotted versus Z1/Z2 concentration in the inset. The resulting linear relationship confirms the identification of Z1/Z2 as the defect that controls the MCL.

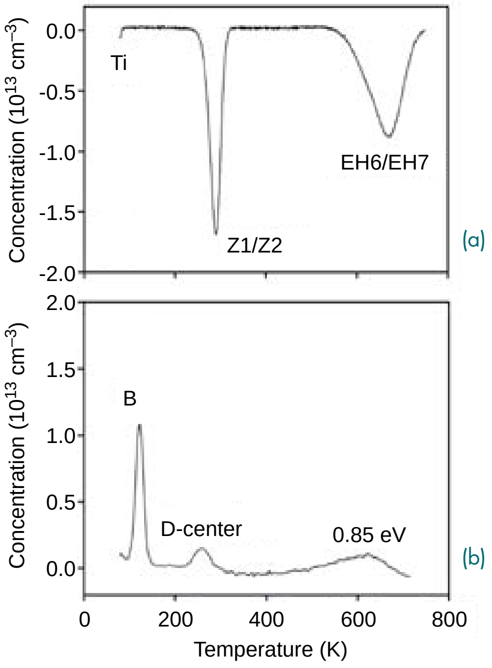

FIGURE 3
Typical DLTS spectra of the dominant electron traps (a) and hole traps (b) in 4H-SiC.

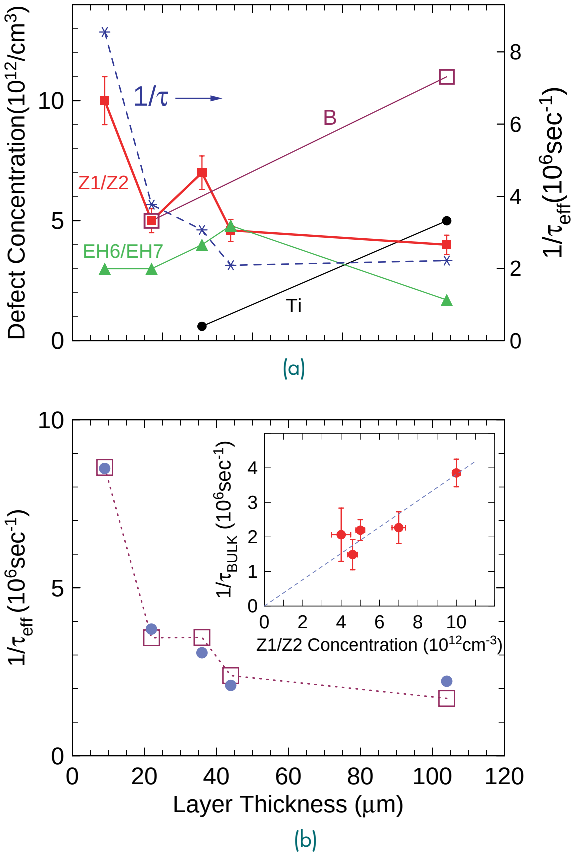

FIGURE 4
Dependence upon 4H-SiC layer thickness of the (a) concentrations of the dominant defects and the inverse carrier lifetime (blue); and (b) comparison of the measured (circles) and fitted (squares) thickness dependence of the carrier lifetime. From this fit, the linear dependence of the inverse bulk lifetime with Z1/Z2 concentration (inset) is determined.

This conclusion is further confirmed by carrying out DLTS measurements within a device structure, where a large concentration of minority holes could be injected into the material by applying a voltage across the device. Trapping of these holes on filled (negatively charged) electron traps changes the electrical charge on the trap, so that it no longer contributes to the DLTS signal. Under these conditions, a large decrease in the Z1/Z2 DLTS signal was observed, indicating rapid minority hole capture, while there was little effect on the other electron traps. Hence, these cannot be effective traps for minority holes, so that Z1/Z2 alone must control the MCL in these materials. The Z1/Z2 defect has been identified[2] as containing a carbon vacancy (i.e., a missing carbon atom). Thus, with this identification of Z1/Z2 as the dominant lifetime killer, it becomes possible to increase carrier lifetimes by varying material growth parameters or by post-growth annealing at high temperatures, where vacancies are no longer stable.

Conclusions: These measurements have identified Z1/Z2—a carbon-vacancy related defect—as the dominant defect controlling the minority carrier lifetime in 4H-SiC material. With appropriate changes in material growth parameters or with high-temperature annealing, the concentration of these defects may be reduced and the carrier lifetimes increased, thus enhancing the material properties for device applications.

[Sponsored by ONR and NRL]

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