Transient Photocapacitance Spectroscopy of Deep-levels in (001) β-Ga_2O_3

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Ga_2O_3 is an emerging ultrawide semiconductor for high-power applications due to its outstanding intrinsic properties. Among others, β-Ga_2O_3 phase is the most thermodynamic stable. It has a large bandgap (4.5−4.8 eV), high critical electric field (~8 MV/cm), and high Baliga's figure of merit (BFOM) (~3444) [1]. Nowadays, promising β-Ga_2O_3 device structures such as SBD, MESFET, MOSFET and MODFET have been reported [2]. Although β-Ga_2O_3 shows significant progress at this early stage of development, the basic properties of β-Ga_2O_3 are still not fully understood [3]. One of the issues is the physical nature of defects in β-Ga_2O_3 and their effects on the basic properties of the material remains unclear. In this work, defect levels in (001) β-Ga_2O_3 were investigated by transient photocapacitance (TPC) spectroscopy. Using the Pässler and CVB models of the optical cross-section (σ), the thermal ionization energy (E_T), Franck-Condon shift (D_{FC}) and effective phonon energy (ε) were calculated.

A 11.5-µm-thick Si-doped β-Ga_2O_3 epitaxial layer was grown by HVPE on a 640-µm-thick highly conductive Sn-doped (001) β-Ga_2O_3 substrate (Novel Crystal Technology Inc). Si and Sn concentrations were expected to be 2.1×10^{16} cm^{-3} and 7×10^{18} cm^{-3}, respectively. A 100-nm thick of Ti/Pt/Au metallics stack was deposited by electron beam (EB) evaporation on the bottom side of the substrate and annealed for 20 minutes at 400 °C (under vacuum conditions) to achieve ohmic contacts. A thin Pt metal (5 nm) was deposited on the epitaxial layer to achieve optically transparent Schottky. The transient photocapacitance induced by the pulse bias voltage was measured in the dark and under monochromatic light. The difference in capacitance transients (with and without light) was integrated over a fixed time window and then normalized to the photon flux to yield the TPC signal.

TPC measurements revealed the signatures of two distinct deep-levels denoted Trap 1 and 2 (see **Fig. 1**). Using the Pässler and CVB models, the E_T and D_{FC} values of both Traps 1 and 2 were calculated as a function of temperature (30–360 K). At 300 K, the calculated E_T of Traps 1 and 2 were 1.15 eV and 1.79 eV, respectively. The D_{FC} of Traps 1 and 2 were 0.11 eV and 0.66 eV, respectively. The E_T and D_{FC} were relatively constant as the temperature increased from 30 K to 360 K. Moreover, the TPC signals related to trap 1 decreased as temperature increased. From the fitting results, it was also observed that ε increased as a function of temperature. Indeed, ε was of 86 meV at 30 K. At 360 K, an ε of 126 meV was calculated. The temperature dependence of ε can be related to the the thermal expansion (TE) of the lattice and the anharmonic phonon-phonon decay process. While the decrease of TPC signal related to Trap 1 was ascribed to the thermal quenching process. Based on the analysis, a sketch of a configuration coordinate diagram (CCD) was shown in **Fig. 2**. Trap 2 exhibits larger D_{FC}, which indicates stronger lattice relaxation compared to Trap 1 as shown in the CCD model.

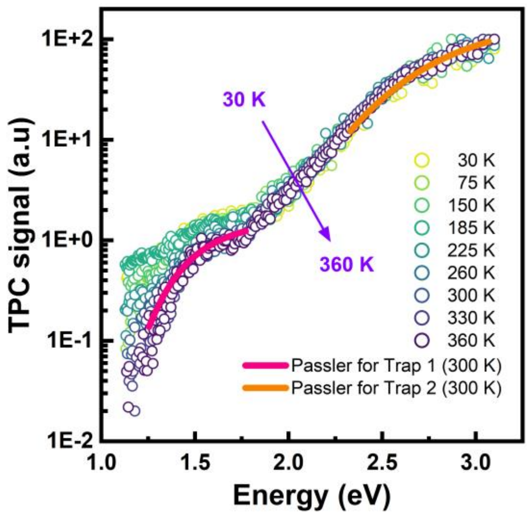

Figure 1. Temperature-dependence of TPC signal 30–360 K (symbols). Solid lines showing the fitting results.

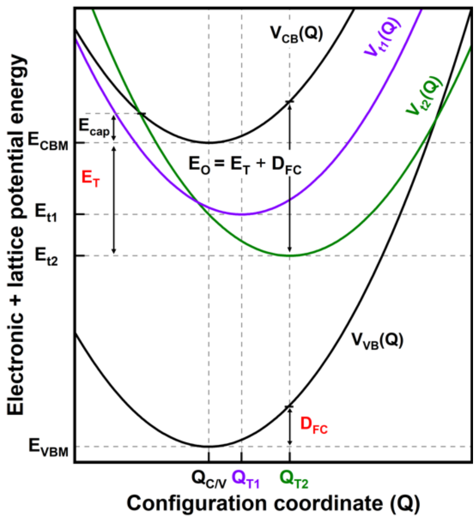

Figure 2. Sketch of configuration coordinate diagram illustrating coordinate dependency of Trap 1 (purple) and Trap 2 (green).

References:

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