Low-Background Carrier Density (10^{15} cm^{-3}) Intentionally and Unintentionally Doped (010) β-Ga_2O_3 Thick Drift Layers with High Mobilities

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We report on the growth of both intentionally low-doped and UID β-Ga_2O_3 homoepitaxial films (10^{15} cm^{-3}) using MOCVD with high room temperature mobilities and thicknesses of up to 187-190 cm^2/V.s and 6.2 µm respectively. Growth was performed on Fe and Sn-doped (010) β-Ga_2O_3 substrates from Novel Crystal Technologies in a vertical showerhead cold wall far injection Agnitron Agilis 100 MOCVD reactor using TEGa as the gallium precursor, pure O_2, Silane (SiH_4) as the Si dopant source, and Argon as the carrier gas. All samples were pre-treated with a solvent clean followed by a ~30min 49% HF solution before loading into the growth chamber. For the UID films, reactor pressure and TEGa were varied systematically to control the background carrier density. Due to the growths being carried out in the mass-transport limited regime (850-880 °C), the TEGa flow strongly influenced the growth rate, leading to growth rates of up to 4.5 µm/hr. Additionally, decreasing the pressure also increased the growth rate with all other variables constant. Increasing the growth rate was found to decrease the background carrier density, scaling from 3 x 10^{16} cm^{-3} to 5 x 10^{15} cm^{-3} up until ~2.2 µm/hr., where the films became prohibitively rough. Further optimizing the VI/III ratio enabled the growth of a 6.3 µm UID film with a flat charge density profile (verified by isolated hall and C-V measurements) of 2.4 x 10^{15} cm^{-3}, a high hall mobility of 190 cm^2/V.s, and RMS surface roughness values of 0.8-3.8 nm. Vertical Schottky barrier diodes were formed on the 6.3 µm thick drift layer and the J-V measurements showed a high rectification ratio of >10^9 with an ideality factor of 1.24. The drift mobility was also estimated to be 132 cm^2/V.s. Finally, breakdown measurements were performed and the parallel plane field at the center of the anode was found to be 2.05 MW/cm, which is the highest reported for any MOCVD grown vertical diode. For the intentionally doped films, the growth conditions for the most consistent UID level (5 x 10^{15} cm^{-3}) were chosen as a baseline recipe and 4.5 µm thick films were then grown at a growth rate of 1.9 µm/hr. Silane was introduced into the reactor at three different molar flow rates for these growths. The lowest silane flow had the same carrier density as the UID sample, indicating a baseline required silane flow to introduce intentional doping. The higher silane flows produced films with hall carrier densities and hall mobilities of 7.3 x 10^{15} cm^{-3}, 9.3 x 10^{15} cm^{-3} and 184 cm^2/V.s, 177 cm^2/V.s respectively. Vertical C-V diodes were fabricated on Sn-doped substrates to check the charge profile. The doped films were found to have flatter charge profiles and less lateral variability when compared to the UID film. The mobility values in the intentional and unintentionally doped films are the highest reported at these background concentration levels and suggest very low compensation in the grown films. The growth of these high-mobility and low background concentration thick β-Ga_2O_3 films is a crucial step forward towards realizing more efficient high-voltage vertical power devices and emphasizing the importance of MOCVD in this field.

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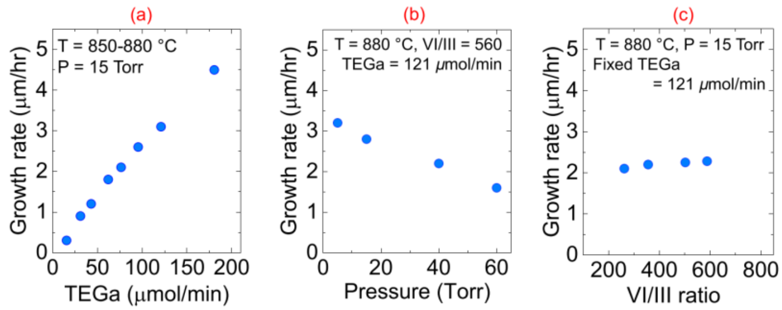

Fig.1: Growth rate as a function of (a) TEGa flow, (b) chamber pressure, and (c) VI/III ratio. Growth rate is shown to scale from 0.3-4.5 μm/hr.

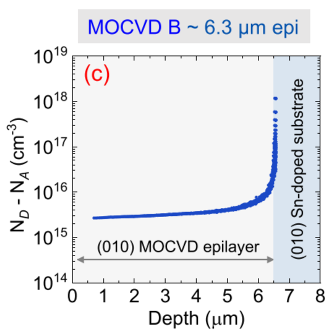

Fig. 2: C-V charge density profile of the 6.3 μm UID epilayer

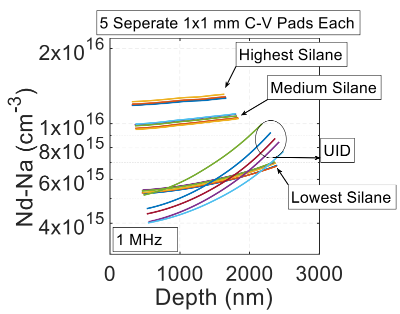

Fig. 3: C-V charge density profiles of the intentionally doped epilayers

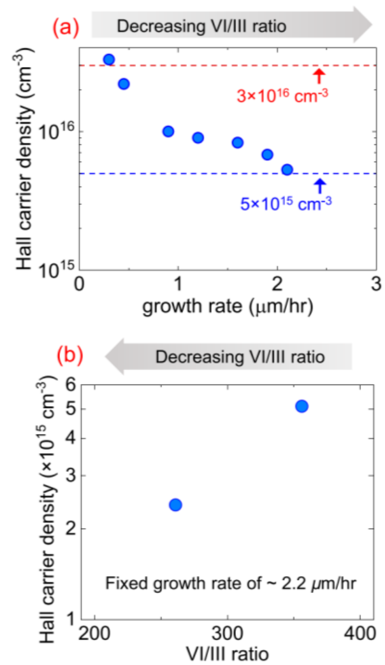

Fig. 4: Hall carrier density as a function of (a) growth rate and (b) VI/III ratio.

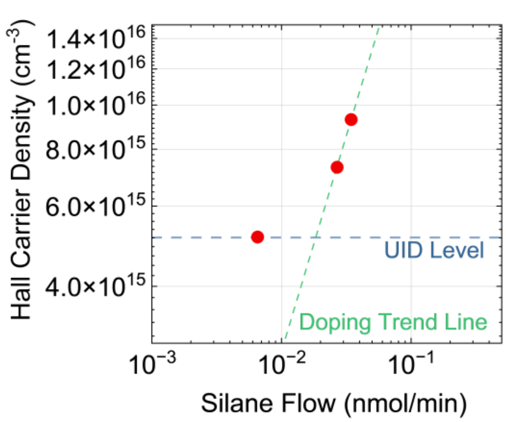

Fig. 5: Hall mobility vs. silane molar flow for the intentionally doped samples

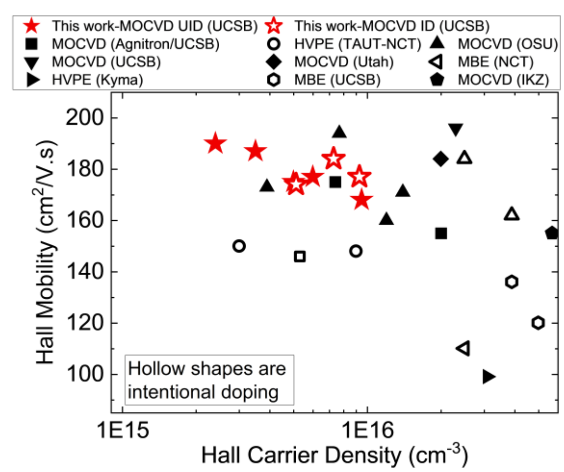

Fig. 6: Hall mobility vs. Hall mobility benchmark plot