Mg acceptor doping in MOCVD (010) β-Ga_2O_3

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Metalorganic chemical vapor deposition (MOCVD) of β-Ga_2O_3 thin films have been demonstrated with record-high room temperature and low-temperature mobilities that approach the theoretically predicted limit. [1,2] The extracted low acceptor concentration (N_a < 10^{15} cm^{-3}) is extremely encouraging for its potential application in high power electronics. Among various impurities in MOCVD grown β-Ga_2O_3, Si represents the dominant one that contributes to the conductivity in the unintentionally doped (UID) films. It is commonly observed the Si spike at the growth interface between Ga_2O_3 substrate and the epitaxial layer. The existence of interface charges not only severly impacts charge transport characteristics [2], but also detrimentally affects device performance, such as causing buffer leakage current in lateral power devices. [3] In addition, controllable charge compenstation serves as a key component in device designs, e.g., forming current blocking layer. Without effective p-type β-Ga_2O_3, an alternative route is to use semi-insulating layer to engineer the electric field in devices. Thus far, there are limited reports on the epitaxy of semi-insulating β-Ga_2O_3.

Among various acceptors in β-Ga_2O_3, Mg represents one of the most promising candidates with relatively shallow acceptor level and the lowest formation energy as compared to other cation-site acceptors from DFT calculation. [4] In this study, Mg in-situ doping in MOCVD β-Ga_2O_3 was conducted for the first time. Trimethylgallium (TEGa) and O_2 were used as Ga, O precursors and Ar as the carrier gas. Mg doping was introduced by using Cp_2Mg as precursor. Chamber pressure was set at 60 Torr in this study. The MOCVD growth temperature for β-Ga_2O_3 was expanded to the range from 650 °C to 900 °C. The growth was conducted on commercial Fe-doped (010) β-Ga_2O_3 substrates. From secondary ion mass spectroscopy (SIMS), in-situ Mg doping concentration was tuned in the range of 10^{18} cm^{-3} to 10^{20} cm^{-3} by the variation of Cp_2Mg molar flow. H impurity concentration exhibits an obvious companion with Mg doping concentration, indicating possible Mg-H complex configurations in as-grown MOCVD Mg-doped β-Ga_2O_3. In addition, we analyzed the SIMS diffusion characteristics of Mg acceptor under different growth temperature of 700 °C to 900 °C. Experimental results indicate Mg incorporation has a minimum dependence on the growth temperature. Instead, the Mg diffusion has a strong dependence on the growth temperature. The diffusion barrier energy of Mg in MOCVD β-Ga_2O_3 was estimated at ~0.9 eV based on numeric analysis of the SIMS profile. Capacitance-voltage (C-V) on lateral Schottky diode structures, with an Mg-doped buffer layer and a Si-doped channel layer, also verified the depletion of interface charge, demonstrating the effective charge compensation by in-situ Mg doping.

In summary, we demonstrated in-situ Mg acceptor doping in MOCVD growth of (010) β-Ga_2O_3 thin films. The growth conditions for Mg-doped MOCVD β-Ga_2O_3 were established with controllable doping between 10^{18} cm^{-3} to 10^{20} cm^{-3} and a wide growth temperature regime, ranging between 700 °C and 900 °C. The as-grown thin films were characterized to be electrically insulating despite the Mg-H chemical companion. Mg diffusion was observed strongly dependent on the growth temperature. With low growth temperature, Mg diffusion can be significantly suppressed while maintaining high crystalline quality. The demonstration of in-situ Mg-doping in MOCVD β-Ga_2O_3 can provide new routes for high-performance device design and device fabrication.

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