Expanding growth window for MOCVD 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. [1-3] The extracted low acceptor concentration ($N_a < 10^{15}$ cm^{-3}) is extremely encouraging for its potential application in power electronics. Si impurities were discovered as the primary contributor to the background n-type conductivity in MOCVD β-Ga_2O_3. [2] Si impurities exist at the substrate interface, where it creates parasitic conductive channel in lateral device structures, posing negative impact on device performances. In our study, the interface charge also interfered the transport characterization on thin films with ultra-low charge density. [2] To address this issue, in-situ Mg acceptor doping was established in MOCVD β-Ga_2O_3. [3] However, Mg diffusion was found to be significantly dependent on the growth temperature, where the lower temperature is preferred due to the confined doping profile. In this study, we expanded the growth window of MOCVD β-Ga_2O_3 in terms of lowering growth temperature of β-Ga_2O_3, as well as increasing growth rate for thick drift layers with low charge density, which are critical to future high-performance β-Ga_2O_3 power electronics.

In our early works, [1] the high quality epitaxy was designed within relatively high growth temperature regime ranging 800 ~ 920 °C. Si incorporation was found to be enhanced at elevated growth temperatures. Defects characterizations combining deep level transient/optical spectroscopy and admittance spectroscopy also registered the deviation in trap states, although the concentration of these traps were much lower as compared to β-Ga_2O_3 synthesized by other methods. [5] In our most recent studies, the growth conditions for MOCVD (010) β-Ga_2O_3 was explored with growth temperature set between 650 ~ 800 °C. As the temperature reduced, the growth rate decreased monotonically. With Si doping concentration at ~1×10^{17} cm^{-3}, room temperature Hall mobilities were measured at ~150 cm^2/Vs for samples grown at 700, 750 and 800 °C. For the growth temperature at 650 °C, the Hall mobility was significantly impacted (~60 cm^2/Vs) due to possible defects formation and reduced crystalline quality. Secondary Ion Mass Spectroscopy (SIMS) analysis revealed that as growth temperature reduces, the carbon concentration eventually increases above the detection limit of SIMS, with concentration of 7×10^{17} cm^{-3} corresponding to growth temperature of 700 °C. The slightly increased charge density in films grown at 700 °C may indicate carbon serving as an donor type impurity in β-Ga_2O_3. However, the role of carbon in Ga_2O_3 still requires further investigation. Surface roughness also increased at lower growth temperature, possibly due to the limited surface adatom mobility.

In summary, we expanded and established the growth conditions for MOCVD (010) β-Ga_2O_3 in the low temperature regime. The charge transport characterization indicates that high-quality (010) β-Ga_2O_3 could be achieved under growth temperatures as low as 700 °C. The extended growth window to lower temperature regime can allow us to fully utilize the high-quality epitaxial thin films while manage sharp doping profile for high-performance device fabrication. And this expanded growth window was utilized to develop high quality Mg doping in β-Ga_2O_3 with sharp profile and effective charge compensation.

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References:

[1] Z. Feng et al., Appl. Phys. Lett., 114, 250601 (2019).
[2] Z. Feng et al., Phys. Status Solidi RRL 14, 2000145 (2020).
[3] Z. Feng et al., Appl. Phys. Lett. 117, 222106 (2020).
[4] G. Seryogin, et. al, Appl. Phys. Lett. 117, 262101 (2020).
[5] H. Ghadi et al., Appl. Phys. Lett. 117, 172106 (2020).

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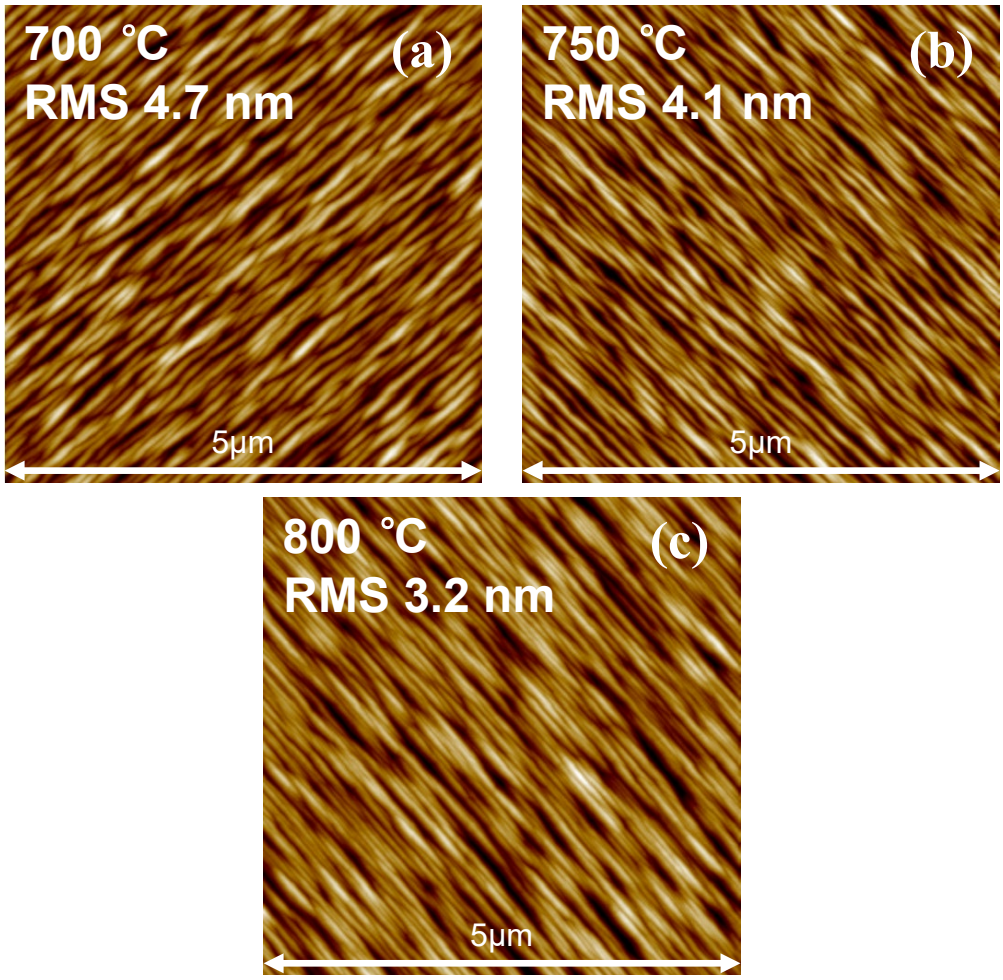

Figure 1. Surface AFM images on the surface of all as-grown samples under different temperatured, (a) 700 °C, (b) 750 °C, (c) 800 °C. The epilayers were all grown with target thickness of 1 μm.

Table. 1 Summary of the MOCVD Si-doped β-Ga_2O_3 samples grown under lower temperatures. Samples were all grown with a target thickness of 600 nm. Other growth parameters such as VI/III ratio and growth chamber pressure were consistent.

Sample	Growth Temperature (°C)	Growth rate (μm/h)	RT Bulk Carrier Concentration (cm^{-3})	RT Hall Mobility ($cm^2/V{\cdot}s$)	Carbon Concentration (from SIMS)
#1	800	0.74	1.2×10^{17}	150	1×10^{17} cm^{-3}
#2	750	0.72	1.1×10^{17}	152	--
#3	700	0.70	1.7×10^{17}	144	~7×10^{17} cm^{-3}
#4	650	0.68	1.9×10^{17}	60	--