Metal-Organic Vapor-Phase Epitaxy Growth, Fabrication, and Characterization of III-V Nitride Optoelectronic Devices

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ABSTRACT

III-V nitride epitaxial growth using metal-organic vapor-phase epitaxy (MOVPE) is presented. The working principle and growth mechanism are discussed. Characterization methods including X-ray diffraction (XRD), atomic force microscopy (AFM), and photo-luminescence (PL) are introduced. *AlGaN ultra violet (UV) light-emitting diodes (LEDs)* emitting at 310 nm $\leq \lambda \leq$ 350 nm are discussed and demonstrated. A kinetic model, which takes into account the growth rate ratio between GaN and AlN ($g_{\text{GaN}}/g_{\text{AlN}}$), is developed and it explains a concave bowing relationship between the Al-mole fraction (for $0 \leq x \leq 1$) and the relative TMAl volume flow. Very high quality AlN buffer layer have been achieved on sapphire substrates. Si-doped $Al_{0.3}Ga_{0.7}N$ grown on c-plane sapphire is optimized by employing a superlattice (SL) layer and the characterization results show that n-type $Al_{0.3}Ga_{0.7}N$ grown on a SL layer gives high-quality crystalline and electrical properties. AlGaN based UV LEDs with peak wavelength of 345 nm on AlN bulk substrates are fabricated and the characterization results show a narrow emission peak at 345 nm with a FWHM of 15 nm with sub-bandgap emission being strongly suppressed. At a current of 30 mA, the light-output power of the devices on AlN substrates is higher than devices grown on sapphire. The improved performance is attributed to reduced defects due to the closer thermal and lattice match of AlN substrates to the epitaxial layers and very high thermal conductivity of the AlN substrates. A comprehensive theoretical model for the dependence of the diode-forward voltage (V_f) on junction temperature (T_j) is developed taking into account for the first time the temperature dependence of the energy gap and the temperature coefficient of the diode resistance. The difference between the junction-voltage temperature coefficient (dV_j/dT) and the forward-voltage temperature coefficient (dV_f/dT) is shown to be caused by diode series resistance. The data indicate that the n-type neutral regions are the dominant resistive element in deep-UV devices. Junction and carrier temperature of AlGaN based deep UV LEDs and GaInN based UV LEDs are presented as a function of the dc injection current. The accuracy of forward-voltage method is ± 3 °C.