Epitaxial growth and properties of AlGaN-based UV-LEDs on Si(111) substrates

M.Sc. Phannee Saengkaew

Abstract

An increasing demand for bright and efficient ultraviolet light emitting diodes (UV-LEDs) is generated by numerous applications such as biochemical sensors, purification and sterilization, and solid-state white lighting. $Al_xGa_{1-x}N$ is a promising material to develop UV-LEDs due to the direct wide-bandgap material for emission wavelengths in the UV range and the capability of n- and p-type doping. To develop UV-LEDs on Si substrates is very interesting for low-cost UV-light sources since the Si substrate is available at low cost, in large-diameter size enabling the integration with well-known Si electronics.

This work presents the first crack-free AlGaN-based UV-LEDs on Si(111) substrates by MOVPE growth. This AlGaN-based UV-LED on Si(111) substrate consists of $Al_{0.1}Ga_{0.9}N$:Si layers on LT-AlN/HT-AlN SL buffer layers and an active layer of GaN/$Al_{0.1}Ga_{0.9}N$ MQWs followed by Mg-doped (GaN/$Al_{0.1}Ga_{0.9}N$) superlattices and GaN:Mg cap layers. It yields a ~350 nm UV electroluminescence at room temperature and a turn-on voltage in a range of 2.6 - 3.1 V by current-voltage (I-V) measurements.

The novel LT-AlN/HT-AlN superlattice buffer layers efficiently improve the crystalline quality of $Al_xGa_{1-x}N$ layers and compensate a thermal tensile strain in $Al_xGa_{1-x}N$ layers after cooling as observed by in-situ curvature measurements. The dislocation density could be reduced from 8.4×10^{10} cm^{-2} in the AlN-based SLs to 1.8×10^{10} cm^{-2} in the $Al_{0.1}Ga_{0.9}N$ layers as determined by cross-sectional transmission electron microscopy (TEM) measurements. Crack-free $Al_xGa_{1-x}N$ layers grown on these LT-AlN/HT-AlN superlattices with $0.05 \le x \le 0.65$ are achieved on Si substrates with good crystalline, optical, and electrical properties. The best crystalline quality of $Al_{0.1}Ga_{0.9}N$ is obtained with a ω-FWHMs of the (0002) and (10-10) reflections of ~700 and ~840 arcsec, respectively. The good optical qualities of $Al_{0.1}Ga_{0.9}N$ and $Al_{0.65}Ga_{0.35}N$ are presented with a low yellow luminescence and narrow near-bandgap emissions at 330 and 240 nm, respectively as determined by cathodoluminescence (CL) measurements. The maximum electron concentration of 2.6×10^{18} cm^{-3} in *n*-type $Al_{0.1}Ga_{0.9}N$:Si layers and a hole concentration of 2.4×10^{17} cm^{-3} of Mg-doped GaN/$Al_{0.1}Ga_{0.9}N$ superlattices are achievable.

These high-quality $Al_xGa_{1-x}N$ materials with good optical and electrical properties are the main factors to accomplish AlGaN-based UV-LEDs on Si(111) substrates. It is demonstrated that it is also a promising approach to achieve deep UV-LEDs on Si substrates with a higher Al content layers.