AlGaN UV light-emitting diodes emitting at 340 nm grown on AlN bulk substrates

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Abstract

AlGaN ultraviolet (UV) light-emitting diodes (LEDs) emitting at 340 nm have been grown on AlN bulk substrates by metal-organic vapor-phase epitaxy using a single-wafer horizontal-flow reactor with radio-frequency heating. The structure consists of multiple AlN/AlGaN buffers layers deposited on AlN (0001), a 600 nm thick Si-doped $Al_{0.3}Ga_{0.7}N$ lower confinement layer, five $Al_{0.17}Ga_{0.83}N$ (10 nm) / $Al_{0.1}Ga_{0.9}N$ (4 nm) quantum wells, a 10 nm thick Mg-doped $Al_{0.3}Ga_{0.7}N$ electron-blocking layer and a 300 nm thick Mg-doped GaN layer serving as a p-type confinement and contact layer. For comparison, UV LEDs with identical active regions were grown on sapphire substrates. X-ray diffraction, atomic force microscopy, secondary ion mass spectrometry, photo-luminescence, and Hall-effect measurements were used to evaluate the material properties. Fig. 1 shows the AFM images of $Al_{0.3}Ga_{0.7}N$ grown on AlN bulk substrate. Clear and straight step-flow pattern is observed which infers that the epitaxial layer is of extremely high crystalline quality. Hall measurement shows the n-type AlGaN films with an electron carrier concentration of 2×10^{18} cm^{-3} and a room-temperature mobility around 80 $cm^2/(V\,s)$. The p-type GaN layer also shows high crystalline quality with a hole carrier concentration of 2×10^{18} cm^{-3} and a room-temperature mobility around 5 $cm^2/(V\,s)$. A photo-luminescence emission peak at 334 nm with full width at half maximum of 15 nm is observed from the five-period $Al_{0.17}Ga_{0.83}N$ (10nm)/ $Al_{0.1}Ga_{0.9}N$ (4nm) quantum wells structure, as shown in Fig. 2. Device structures with 300×300 μm^2 and 1×1 mm^2 geometries were fabricated for both types of substrates. Access to the n-type $Al_{0.3}Ga_{0.7}N$ lower confinement layer was made by chemically assisted ion-beam etching using a Cl_2 chemistry. The n-type contact consisted of Ti (20 nm) / Al (100 nm) / Ti (45 nm) / Au (55 nm) annealed at 850° C for 1 minute in an N_2 ambient. A top p-type contact was formed by Ni (5 nm) / Au (5 nm) using e-beam evaporation. The p-type contact was annealed at 550° C for 1 minute in an O_2 ambient.

The AlGaN UV LEDs on AlN bulk substrates show a narrow emission peak at 345 nm with a FWHM of 15 nm with sub-bandgap emission being strongly suppressed, as shown in Fig.3 (a). At 30 mA drive current, the light-output power of the devices on AlN substrates was 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.

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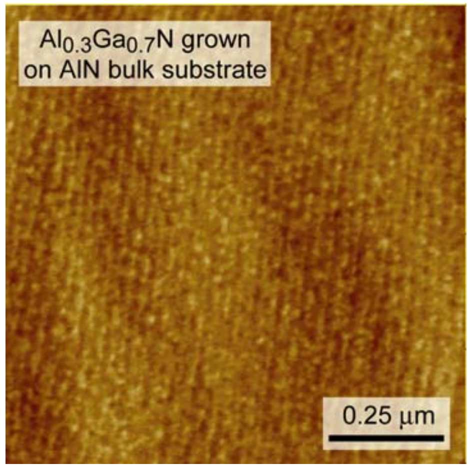

Fig. 1 AFM image of $Al_{0.3}Ga_{0.7}N$ grown on AlN bulk substrate.

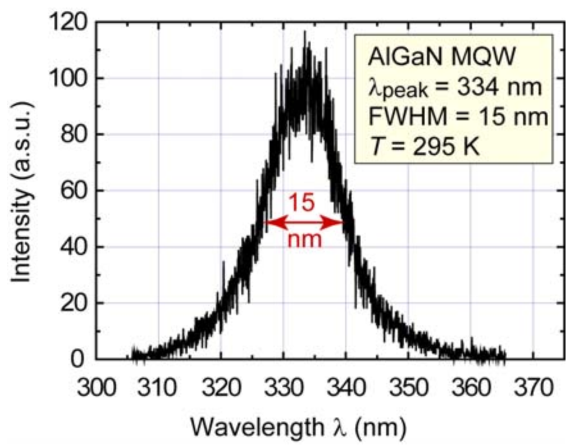

Fig. 2 Photo-luminescence of five-period $Al_{0.17}Ga_{0.83}N$ (10 nm)/ $Al_{0.1}Ga_{0.9}N$ (4 nm) quantum wells at room temperature.

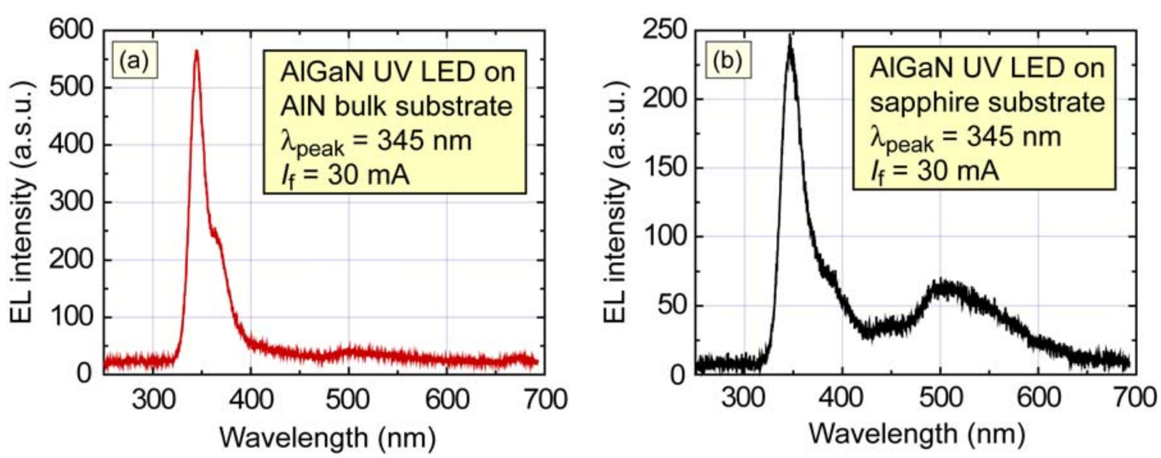

Fig. 3 Electron-luminescence of AlGaN UV LEDs emitting at 345 nm grown on a) AlN bulk substrate and b) sapphire substrate.