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AlN/AlGaN Bragg Reflectors Grown by Gas Source Molecular Beam Epitaxy

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We describe gas source molecular beam epitaxy (GSMBE) of AlN/AlGaN Bragg reflectors (BRs) designed for the spectral region of 250–450 nm. To minimize absorption these structures are grown without GaN layers. BRs described here were grown on sapphire substrates and sapphire substrates with AlN buffers deposited by hydride vapor phase epitaxy (HVPE). The growth mode and surface structure were monitored with reflection high-energy electron diffraction (RHEED). Growth rates and compositions were controlled using in-situ interferometric pyrometry. The BRs described here show excellent reflectivities and are free of cracks over 2 inch diameter wafers.

Bragg reflectors are needed in microcavity devices, both detectors and light sources, operating in the near ultraviolet (UV) region of the optical spectrum [1–4]. In order to minimize absorption such reflector structures use quarter wavelength thick layers of AlN and AlGaN with high Al content. Layers of GaN should not be used, even for the purpose of providing a buffer layer, since bottom illumination or light output are often desired. This work describes Bragg reflector structures on $Al_{0.4}Ga_{0.6}N$. Reflector stacks containing ten pairs of AlN and AlGaN layers were grown by gas source molecular beam epitaxy. Such structures are designed for linewidth reduction in resonant cavity light emitting diodes where reflectivities of approximately 90% are required. Examples of such applications might be fluorescence excitation spectroscopy or highly wavelength selective photodetectors.

In the GSMBE growth on bare sapphire, the AlN-buffer layer was initiated in three-dimensional (3D) growth mode, after the initial substrate nitridation. Ammonia was introduced into the growth chamber through a mass-flow controller. The substrate temperature was measured by a pyrometer, corrected for the emissivity of the substrate. The buffer layer of AlN was grown in the temperature range of (860 ± 30) °C. Buffer layers of AlGaN, with the Al content varying from 0.25 to 0.6, were grown at (780 ± 20) °C [5–7]. BRs structures were grown at the same temperature.

To provide strongly oriented films with definite Al-polarity, sapphire substrates were annealed under ammonia at temperatures in excess of 900 °C. Following the nitridation step, a 40 nm AlN buffer was grown at 850 °C. The formation of this layer was monitored by RHEED. We found, that in order to prevent formation of cracks in the subsequent growth, formation of nitrided islands is important. The optimum coverage of

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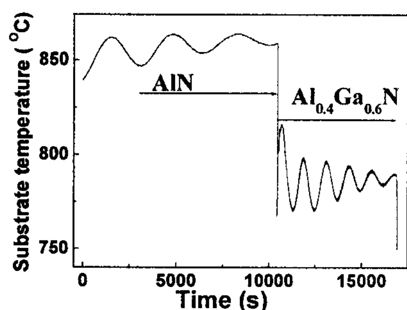

Fig. 1. Real time temperature oscillation during growth of AlN and $Al_{0.4}Ga_{0.6}N$ layers

the sapphire substrate by AlN was achieved by varying the duration of the nitridation process. When the islands are completed, the growth of AlN progresses through two stages. In the first stage, growth of AlN is started with high supersaturation of Al and active nitrogen. The flux values required for the subsequent coalescence of the AlN islands are much higher than those necessary for a subsequent long-term growth which requires the III/V ratio close to 1:1. Two-dimensional (2D) nucleation was observed after deposition of 30–40 nm of AlN. Once the 2D growth was obtained, an additional $Al_xGa_{1-x}N$ ($0.25 < x < 0.60$) buffer layer, ~0.3 μm thick, was deposited prior to the BR structure.

We also prepared BR structures on composite substrates on which AlN layer was deposited by hydride vapor phase epitaxy (HVPE). Thin AlN layers were grown on *c*-plane sapphire substrates using a hot-wall atmospheric pressure reactor. The thickness of the HVPE AlN layers was 0.2 μm [8].

A typical BR structure contained ten quarter-wavelength pairs of AlN and AlGaN. Layer thicknesses and the composition of AlGaN were adjusted to produce the desired wavelength of high reflectivity, from 280 to 450 nm, and RHEED observations show the AlGaN/AlN interface is always as sharp as the AlN/AlGaN interface. This demonstrates that $Al_xGa_{1-x}N$ ($x < 60$) grows on AlN, and vice versa, in a two-dimensional (2D) mode.

BRs designed for the spectral range of 300–450 nm showed optical reflectivities from 78% to 92%, in excellent agreement with calculated values. Reflectors designed for shorter wavelength showed lower reflectivities of ~35%, attributed to absorption in AlGaN layers. Higher Al content is needed to obtain larger reflectivities at these short wavelengths.

High quality BR structure requires good reproducibility of all layer thicknesses and compositions. For instance, a BR structure designed for high reflectivity at 350 nm, would consist of layers of AlN, 40.9 nm thick, and AlGaN, 35.7 nm thick. A slight change in the thickness of the AlN layer, to 42 nm, would shift the reflectivity peak to ~360 nm. In order to control the growth we rely on in-situ pyrometric spectroscopy [9]. A typical experimental trace showing the changes in the output of a pyrometer as a function of time is shown in Fig. 1. The period

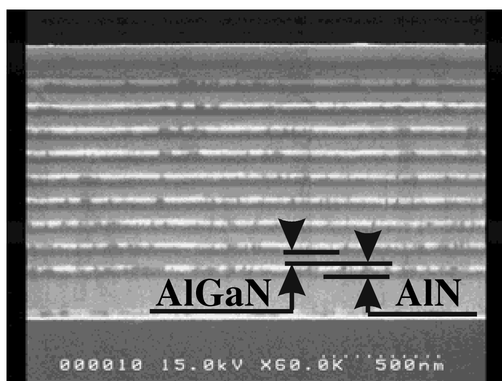

Fig. 2. SEM cross-section of an $Al_{0.3}Ga_{0.7}N$/AlN Bragg reflector

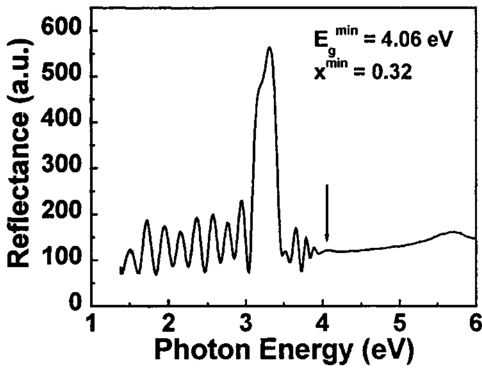

Fig. 3

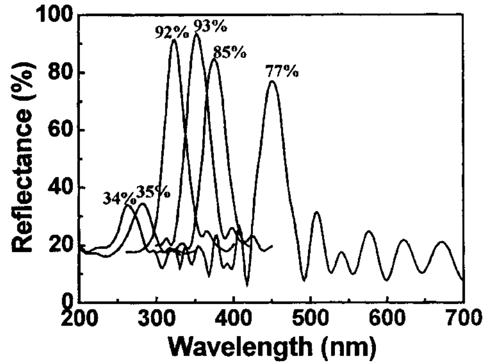

Fig. 4

Fig. 3. Measured reflectance spectra of an AlN/AlGaN BR

Fig. 4. Reflectance spectra of six AlN/AlGaN BRs with peak reflectance of 77%, 85%, 93%, 92%, 35%, and 34% at center wavelengths of 451, 375, 352, 324, 282, and 263 nm, respectively

of intensity oscillations in the temperature allows us to monitor the thickness of the AlN and the subsequently grown AlGaN. This can be used for determination of the composition of AlGaN layer.

Figure 2 shows a scanning electron microscopy (SEM) cross-section of $Al_{0.3}Ga_{0.7}N$/AlN BR. The lighter layers represent AlN while the darker ones AlGaN. No formation of cracks was observed in the BR stack with a total thickness greater than 0.75 μm.

Optical reflectance measurement of a test sample is illustrated in Fig. 3. The data analysis follows standard interpretation of reflectivity data of uniform epitaxial layers. At low energies, below the bandgap of AlGaN, where the entire BR stack is transparent, we observe interference fringes. At higher energies, fringes disappear due to absorption, allowing us to determine the bandgap of the AlGaN layer. In the sample illustrated in Fig. 3 the bandgap is at 4.06 eV. Since the bandgap dependence of AlGaN on the Al content is well known [7], we determine the composition of the AlGaN layer in this sample to be $x = 0.32$.

Figure 4 summarizes our optical reflectivity measurements for a number of AlN/AlGaN Bragg reflector structures. In all of these structures the Al content in AlGaN layers was less than 0.4. We observe Bragg reflectivities of slightly over 90%, in good agreement with claculations for ten-period structures, for wavelength as short as 320 nm. At shorter wavelengths, the reflectivity drops due to absorption in the AlGaN layer. Experiments with high Al content structures are now in progress. However, since the index of refraction contrast between AlGaN and AlN decreases with increased Al content, larger number of periods will be needed to reach the design reflectivity of 90%.

In summary, we describe growth procedures resulting in high quality Bragg reflectors based on AlN and AlGaN. High reflectivity is obtained at wavelengths as short as 320 nm. 2D growth of AlN and AlGaN is crucial to a good performance of these structures.

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