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Editor's Choice

AlGaN/AlN distributed bragg reflectors for deep ultraviolet wavelengths

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Distributed Bragg reflectors with up to 21 periods consisting of AlN and $Al_{0.58}Ga_{0.42}N$ layers were grown by metalorganic chemical vapor deposition. A periodic structure and good interface quality was verified by both transmission electron microscopy and X-ray diffraction, and was shown to be dependent on the composition of the underlying AlGaN base layer. Reflectivities of 49.8% at 285 nm and 66.6% at 245 nm were obtained with ten period superlattices. A reflectivity of 82.8% at 278 nm was measured for a twenty period structure.

As of late significant progress has been made in the growth and fabrication of AlGaN deep ultraviolet light emitting diodes (LEDs), both on sapphire [1–3] and silicon carbide [4] substrates. One disadvantage to the SiC substrate is that it is not transparent at the desired wavelengths ($\lambda < 300$ nm), resulting in light output of devices grown on SiC being currently less than that measured on many sapphire-based devices. This light output may be increased with the insertion of a distributed Bragg reflector (DBR) between the substrate the quantum well. Such DBRs have been shown to increase light output by 67% in visible wavelength LEDs [5].

Nitride DBRs grown by MOCVD [6, 7] and MBE [8, 9] have been demonstrated for VCSEL applications in the visible wavelengths; these have mostly consisted of GaN/AlGaN or GaN/AlN superlattices. AlGaN/AlN DBRs with reflecting wavelengths as low as 356 have been reported [10] by MBE, but no such work has been done in the deep ultraviolet region. Here we report the fabrication of UV DBRs by MOCVD.

It has been shown [11, 12] that the index of refraction of AlGaN alloys for ultraviolet light varies considerably as both a function of aluminum composition and a function of wavelength. Because of this, relatively large differences in index of refraction can be obtained with only a small difference in alloy composition, and this index difference increases with decreasing wavelength. As the indices change with small changes in wavelength, the DBR should have a smaller pass-band filter than is typically observed in longer wavelengths.

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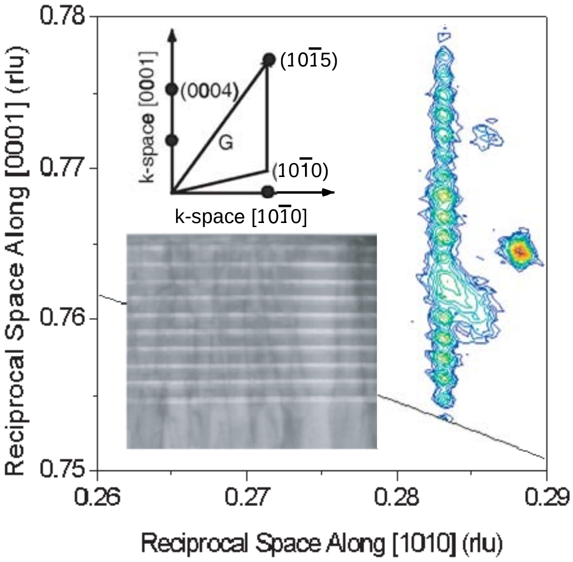

Fig. 1 Reciprocal space map of a 21 period DBR. Inset: TEM of a 10 period DBR sample. The sample in question had a peak reflectivity of 46.5% at 257.6 nm.

Initial growth targets were based on indices of refraction calculated from the model put forth by Ambacher et al. [13] for a desired wavelength of 275 nm: (2.13 for AlN, 2.50 for $Al_{0.64}Ga_{0.36}N$, and 2.70 for $Al_{0.55}Ga_{0.45}N$).

All DBR samples were grown in a vertical close-spaced MOCVD reactor on double side polished, type 6H silicon carbide provided by Cree, Inc. A 60 nm AlN nucleation layer was first grown, followed by a 440 nm AlGaN base layer with compositions between 76% and 100% Al content. The periodic $AlN/Al_{0.55}Ga_{0.45}N$ structures were grown at a thermocouple-measured susceptor temperature of 1245 °C and a pressure of 100 Torr. The TMA and TMG flow rates were 12.81 and 20.71 µmol/min, respectively, and the NH_3 flow rate was 1.4. The inset of Fig. 1 shows a representative transmission electron microscope (TEM) image of a ten period DBR.

Early structures grown on an AlN buffer did not exhibit a periodic structure. Upon the implementation of an AlGaN base layer in an attempt to strain match the underlying layers to the average composition of the DBR, high quality interfaces and periodic layer thicknesses were achieved, as shown in the X-ray diffraction (XRD) spectra in Fig. 2. The reciprocal space map in Fig. 1 taken near the asymmetric (10$\bar{1}$5) AlN reflection shows the DBR structure to be fully strained to the underlying base layer. The effects of

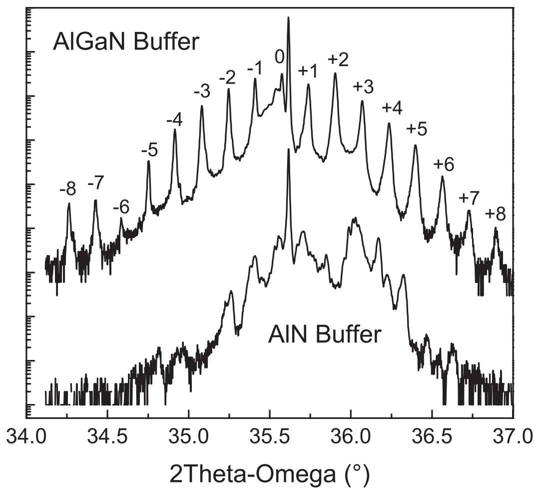

Fig. 2 (0002) 2Theta-omega triple axis scans of DBR samples grown on $Al_{0.83}Ga_{0.17}N$ and AlN bases. The sharp peak at 35.6° is the (0006) SiC substrate peak.

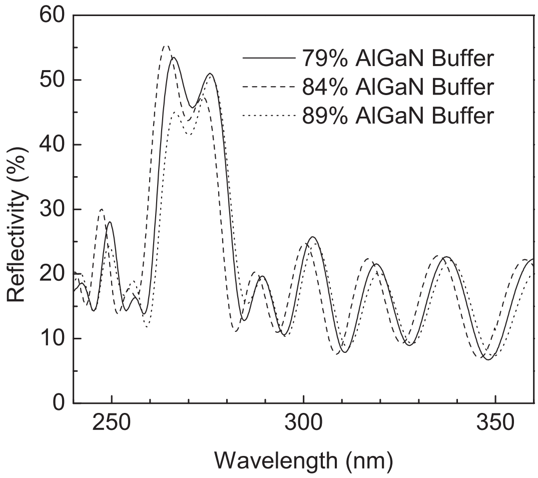

Fig. 3 Reflectivity of three 10 period DBR samples with different AlGaN base layer compositions.

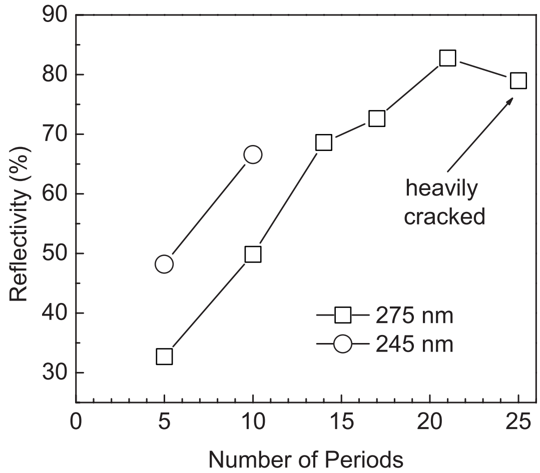

Fig. 4 Reflectivity as a function of period number for DBRs centered at 275 and 245 nm.

slight variations in AlGaN base layer composition between 79% and 89% are illustrated in Fig. 3. Whereas the reflectivities measured for samples with lower AlGaN base layer compositions were between 52 and 56%, for the sample with the an AlGaN base layer composition of 89% the reflectivity dropped below 50%, due to the beginning degradation of the structural properties of the DBR similar to the samples grown on AlN.

The DBR period for each sample was easily calculated from the average satellite peak spacing. For the sample displayed in the inset of Fig. 1, the obtained thickness of 539 closely matches the observed value of 543 Å. For expediency purposes, the period values below were all obtained by XRD.

DBR samples were grown with 5, 10, 14, 17, 21, and 25 periods at peak wavelengths of 275 and 245 nm, with the resulting reflectivities plotted in Fig. 4. The refelectivity increases as a function of period in a manner similar to that observed in GaN/AlGaN DBRs, [7] reaching 82.8% for the 21 period sample. The high quality of the 21 period sample is also reflected in the reciprocal space map in Fig. 1. At 25 periods, the sample surface was fully cracked, although XRD examination revealed the periodicity observed in lesser period structures remained intact. As expected, higher reflectivities were obtained at lower periods for shorter wavelength DBRs, where there is a greater index difference between AlN and AlGaN. At 245 nm, a third more light (66.6%) was reflected than was observed at 278 nm (49.2%). Increasing the AlGaN composition while keeping layer thicknesses constant showed a reduction in reflectivity due to the reduced difference in index, but no change in peak reflected wavelength (Fig. 5).

Further examination showed the peak wavelength reflected to depend almost entirely on the overall period of the DBR, with composition of the AlGaN superlattice layers having a lesser effect. Varying the individual AlN and AlGaN thicknesses by 5% while holding the overall period constant resulted in a reflectivity change of less than 2%, similar to results presented by Ng et al. [14].

Calculated spectra, using the Ambacher model for the indices of refraction, predicted much higher reflectivities than those achieved experimentally –92% for ten periods and 99% for 21. In addition, the reflected wavelength observed was routinely shorter than that expected by the model. To examine this discrepancy, reflectivity measurements were performed on single AlN layers on SiC, and AlGaN on AlN on SiC. By fitting calculated curves to these measurements, we estimate indices of 2.28 for AlN, 2.36 for $Al_{0.64}Ga_{0.36}N$ and 2.44 for $Al_{0.55}Ga_{0.45}N$ at 275 nm. Inserting these values in calculations, the predicted reflectivities are significantly closer to those obtained in measurement, both in wavelength and reflected intensity, as demonstrated in Figure 6. (It should be noted that all calculations were done assuming a constant index of refraction over all wavelengths for simplicity, hence the the curve fits should be less

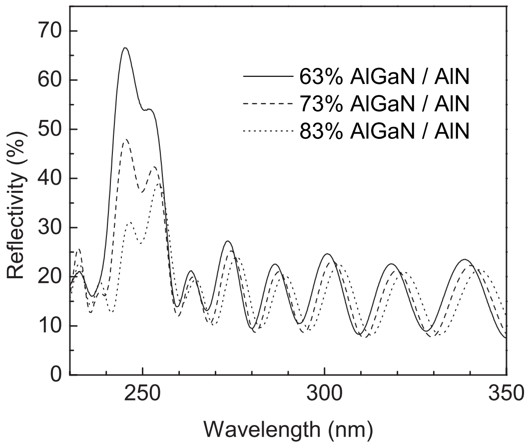

Fig. 5 10 period AlN/AlGaN DBRs, with varied AlGaN composition.

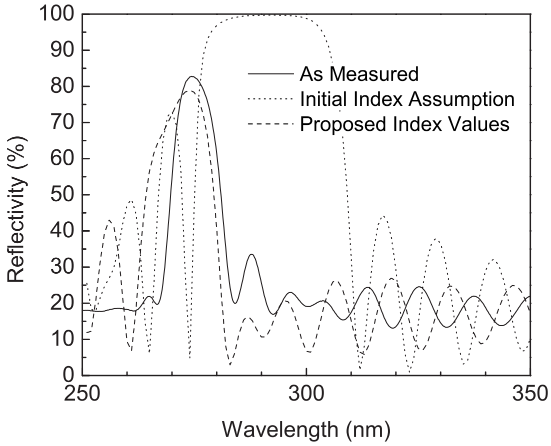

Fig. 6 Calculated DBR spectra using both currently accepted index values and those we suggest, compared to achieved results.

reliable at wavelengths far away from 275 nm). Further investigations are necessary to obtain consensus index values in the ultraviolet region.

In conclusion, distributed Bragg reflectors as high as 82.8% were fabricated by 21 periods of AlN and and $Al_{0.58}Ga_{0.42}N$, grown by MOCVD. Maintaining the strain of the individual layers with the appropriate composition base layer was critical to obtaining a periodic structure and flat interfaces. Ten-period DBRs have been inserted into LED structures with improved output powers, the results of which will be published in a forthcoming paper.

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