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Growth of Submicron AlGaN/GaN/AlGaN Heterostructures by Hydride Vapor Phase Epitaxy (HVPE)

D. Tsvetkov (a), Yu. Melnik (a), A. Davydov (b), A. Shapiro (b), O. Kovalenkov (a), J. B. Lam (c), J. J. Song (c), and V. Dmitriev (a)

(a) Technologies and Devices International, Inc., 8660 Dakota Dr., Gaithersburg, MD 20877, USA

(b) NIST, Gaithersburg, MD, USA

(c) Center for Laser and Photonics Research, Noble Research Center 413, Stillwater, OK, USA

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Multilayer AlGaN/GaN epitaxial structures were grown on SiC by HVPE method. Characterization of the grown structures was performed using SEM, SIMS, mercury probe, electroluminescence and photoluminescence techniques. Thicknesses of nitride layers in nanometer range were achieved. Stimulated emission from double confined heterostructure grown by HVPE was detected at room temperature under optical pumping. Short wave UV electroluminescence ($\lambda_{max} \approx 340$–$350$ nm) was measured for p-AlGaN/n-AlGaN structures having up to 38 mol% and 9 mol% of AlN in p-AlGaN carrier emitter layers and n-AlGaN light emitting layers, respectively.

Introduction Group-III nitride semiconductors such as AlN, GaN, InN and their alloys are playing a major role in development and fabrication of short wavelength light emitters, photodetectors, and high power high-frequency transistors. High performance devices have been shown to require quantum size layers. These devices are based on multilayer epitaxial structures grown by MOCVD or MBE techniques. The main goal of this work is to prove that AlGaN/GaN structures with submicron thicknesses can be grown by HVPE technology.

Recently, we have demonstrated AlGaN/GaN heterostructures grown by HVPE [1]. Stimulated emission has been detected from HVPE grown multilayer structures for the first time [1]. These results open an opportunity to develop a new epitaxial technology for quantum size epitaxial structures based on HVPE approach. In this paper we describe four different types of AlGaN/GaN heterostructures with nanometer thick layers grown by HVPE.

Experiment The structures for this study were grown at TDI, Inc. using HVPE growth technique [1, 2]. The HVPE growth machine is equipped with an atmospheric pressure quartz horizontal hot-wall reactor and two-zone resistively heated furnace. The reactor consists of the main quartz tube, six inlet quartz gas tubes for metal sources, and pedestal for substrates. This setup is equipped with multichannel gas distribution system with high accuracy mass flow controllers to control HCl flowes through source channels (Al, Ga, In). In our growth processes, Ar is used as carrier gas and ammonia is used as the nitrogen source. Boats containing metallic Ga (6N) and Al (5N) are used as Ga and Al sources. Epitaxial structures were grown on (0001)Si faces of on-axis 6H-SiC wafers. The growth temperature ranged from 1030 to 1050 °C. Growth rates for

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AlGaN and GaN layers were about 20 nm/min and 40 nm/min, respectively. All structures exept the fourth one were undoped. Composition of AlGaN layers was measured using X-ray diffraction.

Results *First type structure* contains a thin AlGaN top layer and a GaN layer grown on the SiC substrate. Composition depth profiles measured by SIMS (Fig. 1) showed the thin (<20 nm) $Al_{0.1}Ga_{0.9}N$ layer existing on the top of the structure. Results of capacitance–voltage measurements (Fig. 1) performed using a mercury probe also indicated that there is a layer with higher concentration $N_d - N_a$ on the top of the sample. This value of $N_d - N_a$ is typical for undoped $Al_{0.1}Ga_{0.9}N$ layers grown by HVPE. The structure illustrates that HVPE is useful for the fabrication of AGaN/GaN structures with AlGaN layers having thickness in nanometer scale range.

Second type structure consists of 200 nm thick $Al_{0.25}Ga_{0.75}N$ layer grown directly on the 6H-SiC substrate and then followed by three GaN wells with different thicknesses separated by ~70 nm thick $Al_{0.15}Ga_{0.85}N$ barriers. The structure was grown in a single run. The GaN well was varied by changing the growth durations. We studied this structure using field emission SEM (Fig. 2). The study showed sharp interfaces between the GaN well layers and AlGaN barrier layers. GaN well thickness for different wells ranged from 30 to 80 nm.

The third structure was $Al_{0.22}Ga_{0.78}N/Al_{0.16}Ga_{0.84}N/GaN/Al_{0.16}Ga_{0.84}N/Al_{0.22}Ga_{0.78}N/$SiC double confinement heterostructure. This structure was investigated by X-ray diffraction to determine the AlN composition in both AlGaN cladding layers. On the X-ray diffraction curve $Al_{0.16}Ga_{0.84}N$ and GaN signals are seen as shoulders in the vicinity of the $Al_{0.22}Ga_{0.78}N$ peak. Due to the small thickness of the $Al_{0.16}Ga_{0.84}N$ and GaN layers, corresponding signals were very weak. The structure was also investigated using SEM technique to determine thickness of each layer. The total thickness of the structure is about 600 nm. Figure 3 shows the SIMS depth profile of the double confinement structure. Thickness of GaN active layer was about 30 nm. Under optical pumping, stimulated emission at room temperature was observed at a wavelength of about 370 nm. The pump power density threshold was $\approx$700 kW/cm^2. The red shift of the peak posi-

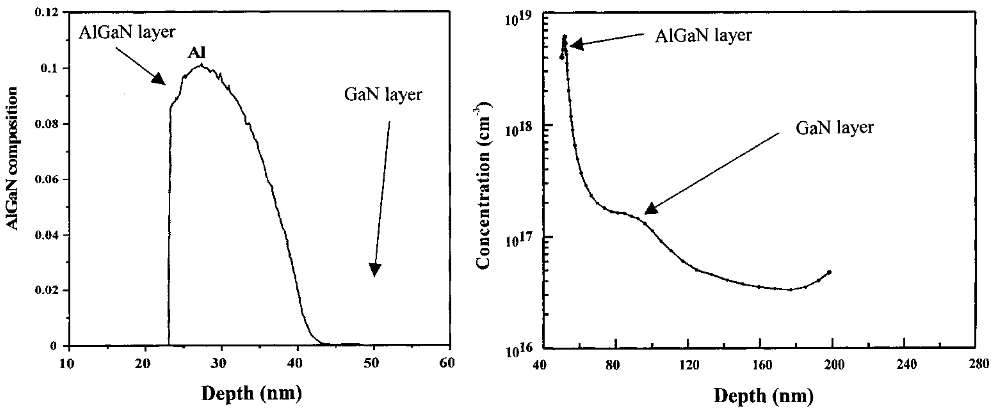

Fig. 1. SIMS depth profile for HVPE grown AlGaN/GaN/SiC heterostructure with 15 nm thick AlGaN layer (left) and concentration $N_d - N_a$ depth profile for the same AlGaN/GaN heterostructure (right)

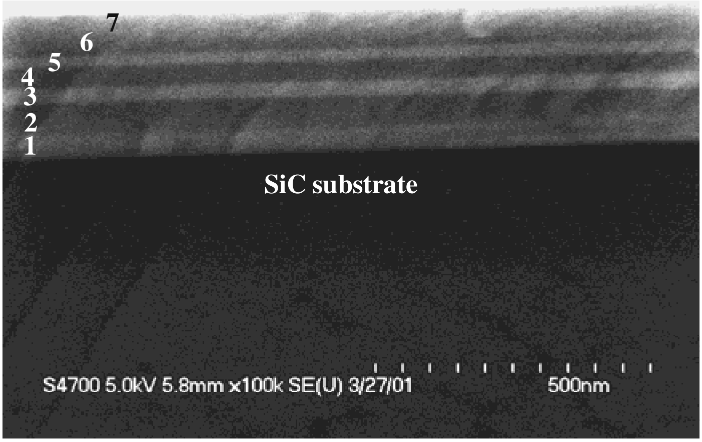

Fig. 2. Field emission SEM image of the cleaved edge of an AlGaN/GaN three-period quantum-well structure grown on 6H-SiC by HVPE method: (1) $Al_{0.25}Ga_{0.75}N$ initial layer; (2), (4), and (6) GaN wells with different thicknesses; (3), (5), and (7) $Al_{0.15}Ga_{0.85}N$ barrier layers

tion with increasing pump power indicates that coherent emission is a result of electron–hole plasma generation in the GaN active layer.

The fourth type of structures was p-GaN/p-AlGaN/n-AlGaN/n-AlGaN/SiC heterostructure with an n-AlGaN narrow bandgap active region sandwiched between AlGaN layers with higher AlN concentration. The p-type layers were doped with Mg. The maximum AlN concentration in p-AlGaN layer determined by X-ray measurements was 38 mol%. The maximum AlN concentration in the active light emitting region was 9 mol%. Electroluminescence (EL) was measured at room temperature (Fig. 4). De-

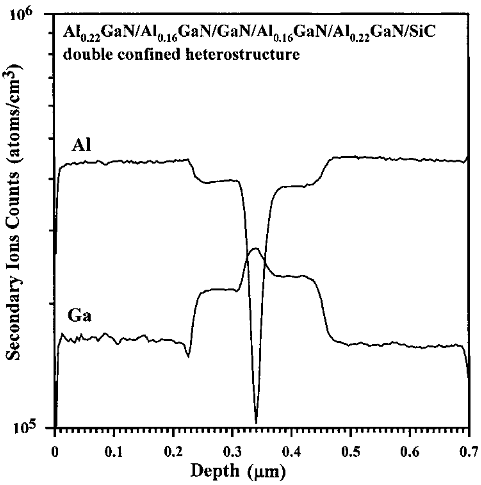

Fig. 3

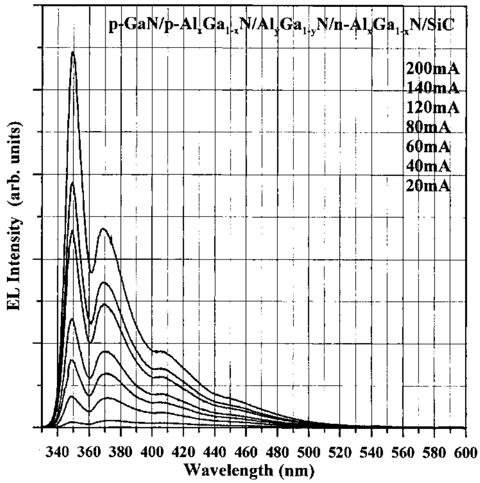

Fig. 4

Fig. 3. SIMS depth profile for AlGaN/GaN double confined structure grown by HVPE

Fig. 4. Electroluminescence spectra for UV LED structure grown by HVPE (300 K). Light emitting n-$Al_{0.1}Ga_{0.9}N$ layer is sandwiched between p-$Al_{0.38}Ga_{0.62}N$ and n-$Al_{0.38}Ga_{0.62}N$ layers

pending on the AlN concentration in the light emitting region, the peak EL wavelength varied from 340 to 350 nm. To the best of our knowledge, this is the first UV LED structure with such high AlN concentration in a p-type emitter layer.

Summary Multilayer heterostructures with submicron GaN and AlGaN layers with thickness ranged from 15 to 70 nm were grown by HVPE technology, for the first time.

First double confinement AlGaN/GaN structure grown by HVPE was demonstrated. Thickness of active GaN layer of this structure was about 30 nm. Stimulated emission from this structure under optical pumping was observed at room temperature.

Multilayer LED p–n structures for UV emission were grown by HVPE. Electroluminescence peaking at 340–350 nm was measured for p-AlGaN/n-AlGaN/n-AlGaN structures having single-well AlGaN emitting layer. AlN concentration in p-type AlGaN carrier emitter layer and in n-AlGaN light emitting layer obtained in this work reached 38 mol% and 9 mol%, respectively.

These results show a high potential of HVPE growth technology for fabrication of GaN-based device structures.

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