Stimulated Emission from As-grown GaN Hexagons by Selective Area Growth Hydride Vapor Phase Epitaxy

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Abstract

We report room temperature stimulated emission from as-grown GaN hexagons by selective area growth hydride vapor phase epitaxy. We found the threshold for bulk stimulated emission to be 3.4 MW/cm^2 with an emission linewidth of 1.2 nm.

We present the first observation of optically pumped stimulated emission from individual, as-grown GaN hexagons formed by selective area growth hydride vapor phase epitaxy (SAG-HVPE). The recent development of blue/UV LEDs and lasers based on the III-nitride system has pushed these materials into the forefront of optoelectronic research.[1,2] Although the vast majority of the advances have been made on MOCVD grown III-nitrides, other growth methods are being pursued for further improvement of the material technology.[3,4] Recently, there has been renewed interest in the HVPE method for the growth of thick (>10 μm) GaN layers which can be subsequently used for the homoepitaxy of GaN devices, thus reducing the problems associated with epitaxy on lattice mismatched substrates such as sapphire, silicon carbide etc.[5] Here we report the SAG of GaN by the HVPE method on patterned sapphire substrates. The SAG- HVPE technique makes it possible to fabricate optical devices without the need for any post-growth etching for device definition, thus simplifying and reducing the cost of processing. These structures are very important for fabrication of light emitting devices, especially laser structures based on as-grown optical cavities.

Epitaxial growth of the GaN layers was carried out on SiO_2 patterned c-plane (0001) sapphire substrates. The patterns were spaced so that coalescence of the growth islands was not possible in the growth times employed. After chemical degreasing, the substrates were introduced into the HVPE system and heated in a N_2 ambient for thermal outgassing at the growth temperature of 1050^{o}C for 30 min. This was followed by the exposure of the substrates to ammonia for surface nitridation. After nitridation, HCl gas was introduced in the reactor to initiate the growth. Typical growth rates of 15-25 μm/hr were employed. Details of the growth conditions are described elsewhere.[6] After the growth, the samples were etched in buffered oxide etch to remove the SiO_2 layer, resulting in the periodic array of GaN hexagons, as shown in Fig.1 (a). The patterns consist of GaN hexagonal structures with near vertical walls of $(1\bar{1}00)$ planes, nucleated in the oxide openings, as shown in Fig.1 (b).

Optical studies of the SAG-GaN hexagons were carried out at room temperature on a metallurgical microscope. Positioning stages were used to center a hexagonal structure in the field of view of the microscope and bring an optical fiber up to a side face of the hexagon to collect the emission. A nitrogen laser pump at 337 nm with a peak power of 40 kW (10 ns

pulse duration) was used as the optical excitation. The pump beam was focused on the top of the hexagon using a 0.22 NA, 10x objective. The slightly diverging nitrogen laser beam came to a focus 400 μm below the sample, allowing the entire hexagon to be illuminated by a beam with a spot size of 100 μm as measured with a scanning knife-edge. Ultra-violet grade reflecting neutral density filters were used to attenuate the incident pump beam. The emission was collected from the side of the sample with a 200 μm diameter 0.3 NA optical fiber. The output facet of the fiber was imaged onto the slits of a 0.64 m spectrometer and dispersed with a holographic grating onto a liquid nitrogen cooled back-thinned CCD camera, which provided a spectral resolution of 0.1 nm.

The peak intensity and emission full width at half maximum (FWHM), as a function of pump power density are plotted in Fig. 2. At an incident power density of 3.4 MW/cm^2 we observed the threshold for stimulated emission. Linewidth narrowing to a value less than $k_BT/2$ was observed at room temperature. The slope of the peak intensity versus power density was found to increase by a factor of 172 above threshold.

A series of emission spectra from a single SAG-HVPE GaN hexagon are shown in Fig. 3 as a function of incident pump power. At the threshold for stimulated emission, the luminescence spectrum was peaked at 377 nm. As the pump beam power was increased, the emission red shifted to 377.8 nm, consistent with previous reports.[7] The emission linewidth had a minimum FWHM of 1.2 nm (11 meV) at twice the threshold pump intensity. At very high pump beam intensity (>12 MW/cm^2) the emission was observed to slowly decrease over time and physical evidence of sample damage could be observed.

Since these samples have smooth and parallel sidewalls, as determined from SEM images, we expected to observe longitudinal lasing modes. However, the hexagonal structure does not have simple Fabry-Perot cavity modes and the electron-hole density varies greatly over the spectral collection time, resulting in a time dependent optical path length. Thus no longitudinal modes were observed in the spectra.

In conclusion, we performed spectroscopic measurements of the power dependence of the optical emission of SAG-GaN hexagons. We found the threshold power density for room temperature stimulated emission to occur at 3.4 MW/cm^2. R. Singh would like to thank A. Chin for helpful discussions and R. Barrett for technical assistance. This research is partially

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Figure Captions

Fig. 1 (a) Top view of the SAG-HVPE hexagonal structures (b) Side view of the structures

Fig. 2 Peak intensity and emission linewidth as a function of incident power density.

Fig. 3 Emission spectra as a function of the optical pump power. The linear and log plots display spectra from different pump intensities.