Optical properties of self-organized GaN nanostructures grown by plasma-assisted molecular-beam epitaxy

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Successful application of III-nitrides for ultraviolet and blue light emitting and laser diodes stimulates fundamental research and further improvement of the growth methods. New perspectives in development of nitride-based lasers can be reached with a reduction of the dimensionality of the active layer to quantum wires or quantum dots, which is expected to lead to a decrease of the threshold current and increase of the laser efficiency. Self-organized growth processes are considered now as very promising for fabrication of low-dimensional quantum structures based on III-nitrides.

In this paper we report on recent progress in the area of self-organized GaN columnar nanostructures grown by plasma-assisted molecular beam epitaxy (PA MBE) using an original source of activated nitrogen with a rf capacitively-coupled plasma discharge. Results of structural and optical characterization, obtained by scanning electron microscopy (SEM), transmission electron microscopy (TEM), time-resolved photoluminescence (PL) and spatially resolved cathodoluminescence (CL) are presented and discussed. The GaN nanostructures were grown in Ga-rich regime by the vapor-liquid-solid (VLS) mechanism on Al_2O_3 (0001) substrates. Some samples were grown with low-temperature GaN buffer layers with thickness of ~200 Å, while some structures were grown directly on substrates without buffers. The substrate temperature was T_S~770ºC. The growth rate has been varied depending on samples from 0.8 up to 1 µm/h.

SEM images (see Fig. 1) of the surface morphology of the GaN structures reveal that the self-assembling GaN columns demonstrate a regularly distribution on the substrate surface. The column density is about 10^{10} cm^{-2}. The diameter of the columns depends on the Ga flax, low temperature buffer layer and in our case averages to 50-100 nm or even less up to 20 nm. Some of the columns form perfect hexagonal single crystals, however, some columns often coalesce and then the whisker shape is usually more complex. The column height is estimated to be approximately 1-2 µm in all samples (see Fig. 2). TEM analysis shows that the columns having a diameter less than 50 nm are free from dislocations.

The typical low temperature (5 K) CL spectra are dominated by a strong line centered at 3.39 eV. We note that this luminescence process is strong even at room temperature. The luminescence spectra contain also the GaN near-band gap transition located at 3.46 eV. This emission is more clearly seen in the structures grown with the buffer layers. We have found from spatially resolved CL images that the origin of the 3.39 eV line is connected with the GaN nanocolumns. The width of this line seems to correlate with the number of columns under study, however it does not exceed 25 meV. We succeed to obtain the CL spectrum from one of the GaN whisker, where the linewidth has been measured to 9 meV.

To further understand the nature of the emission bands in the self-organized GaN nanostructures characterization by time-resolved PL, temperature and power excitation dependent PL measurements will be reported.

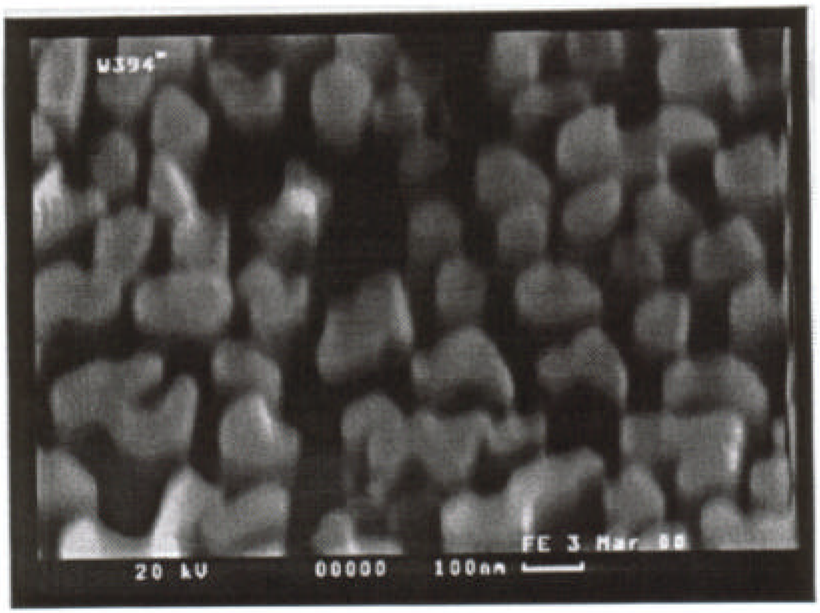

Fig. 1. Bird's eye view SEM image of the GaN columnar nanostructures.

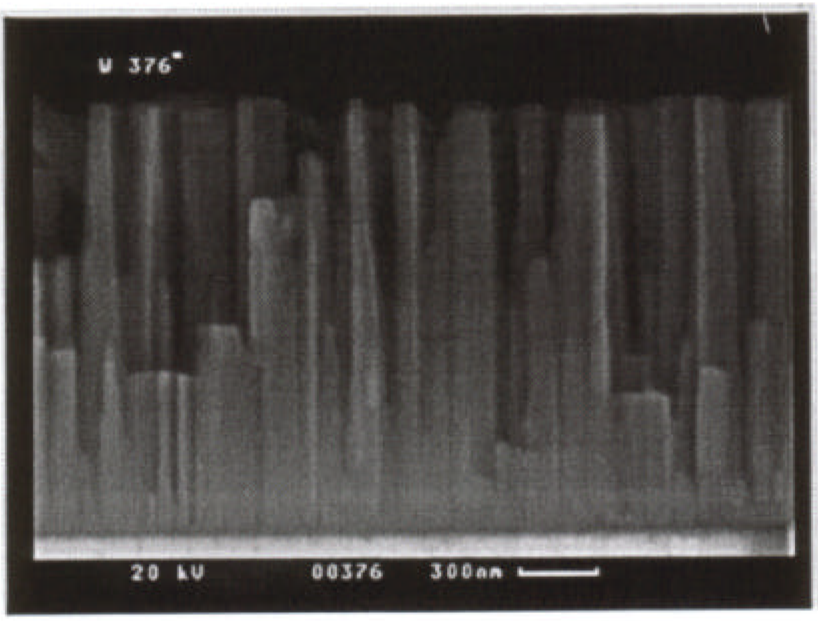

Fig. 2. Cross-sectional SEM images of the GaN structure with nanocolumns.