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GaN grown on (101) neodium gallate by MBE with magnetron RF plasma source

V. V. Mamutin†, *V. A. Vekshin*†, V. N. Jmerik†, T. V. Shubina†,
A. A. Toropov†, A. V. Lebedev†, N. A. Sad'chinov†, N. F. Kartenko†,
S. V. Ivanov†, P. S. Kop'ev†, A. Wagner‡, W. Strupinski‡ and A. Jelenski‡

† Ioffe Physico-Technical Institute, 194021 St. Petersburg, Russia
‡ Inst. of Electronic Mat. Technology, Warsaw, Poland

The MBE technology is a very promising technique to grow GaN-based nanostructures for different optoelectronic applications. However, the lack of a suitable lattice-matched substrate is especially critical for the MBE technology due to the severe rate restriction on the buffer layer thickness. The sapphire, commonly used as a substrate for growing GaN related materials is characterized by a large difference (16%) in the lattice parameter with gallium nitride. New $NdGaO_3$ substrates have the much better lattice matching ($\sim 1\%$) and, hence, are promising for the nitrides epitaxial growth [1]. Another serious problem is a lack of efficient enough nitrogen exciter that limits a maximum growth rate of high-quality epilayers.

In this paper we report on the first successful attempt of MBE GaN epitaxial growth on the neodim gallate substrates. We demonstrated also the feasibility for the III-nitrides MBE growth of an original compact coaxial magnetron (CCM) plasma source with radio-frequency (RF) capacitively coupled discharge, compatible with modern MBE requirements. This source has allowed us to reach the growth rates as high as $0.1 \sim 0.5$ μm/h with good GaN crystalline quality. Electrical, structural and luminescence properties of GaN films have been examined.

GaN epilayers have been grown by plasma-assisted molecular beam epitaxy (MBE) on Al_2O_3 (0001) (as reference samples) and $NdGaO_3$ (101) substrates in a home made EP 1203 MBE setup. The 13.56 MHz RF power up to 200 W is applied to the central electrode of the CCM RF source. In addition to the RF electric field, an axial constant magnetic field tunable up to 0.8 T is produced by solenoid coils. The central electrode and the plasma chamber walls are covered with pirolytic boron nitride. This movable source mounted on a $4.5''$ flange of the MBE installation provides a 40–140 mm variation of distance between the output source aperture and a substrate surface. Nitrogen background pressure in the growth chamber is slightly higher than 10–4 Torr. Turbo-molecular pump with effective pumping rate of ~ 350 l/s is used.

Preliminary testing of the plasma source characteristics reported in [2] has been performed using optical emission spectra (OES) recording in the 350–790 nm wavelength range. The characteristic lines of excited N_2 molecules and molecular ions are dominant in the spectrum, while there is no pronounced lines of excited atomic nitrogen. In general features, this discharge is closer to that of electron cyclotron resonance source rather than to that of inductively coupled source. An increase in the discharge pressure up to 1 Torr, as well as both the rf power and the magnetic field result in a monotonous increase in intensities of all the lines, while the intensity ratio between ions and molecules changes. It allows us to vary the temperature and concentration of
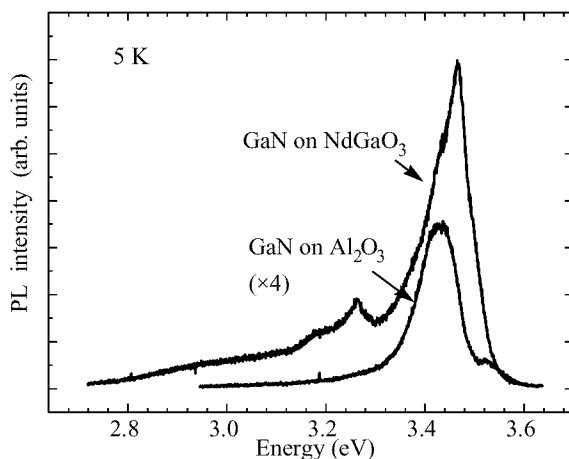
Fig 1.

electrons in the discharge in a wide range, and, hence, to change both qualitatively and quantitatively the output nitrogen flux.

Slight nitridization was used before growth and then low-temperature GaN buffer layers were grown at 550 °C. The GaN layers were grown at 700–750 °C. The temperature was measured by an infrared optical pyrometer. The growth rates were in 0.07–0.2 μm/h range. The substrates were not chemically etched but only rinsed in solvents and were thermally cleaned at ~ 700 °C in vacuum just before the growth.

Deposited GaN films were characterized by scanning electron microscope (SEM), x-ray diffraction (XRD), photoluminescence (PL), Raman spectroscopy and capacity-voltage (C/V) measurement. Crystalline quality was determined by RHEED (reflection high energy electron diffraction) and XRD using CuKα radiation. PL measurements were performed from 5 K up to room temperature using a He–Cd laser as an excitation source. Surface morphology and thickness were studied by Cam Scan electron microscope. Electrical properties of the GaN epilayers were determined by C/V measurements.

RHEED demonstrated streaky pattern during growth both on Al_2O_3 and $NdGaO_3$ substrates. XRD established monocrystalline GaN film with the same (0001) orientation as an Al_2O_3 substrate and with x-ray rocking curve width of GaN (002) peak of about $1°$. GaN on $NdGaO_3$ was of the same orientation and of comparable quality. The room-temperature electron concentration for GaN both on Al_2O_3 and on $NdGaO_3$ was $n \sim 10^{16}$ cm^{-3}.

The typical PL spectra are shown in Fig. 1. The low-temperature spectrum of GaN on $NdGaO_3$ (solid line) shows main peak at 3.47 eV, which is attributed to emission of a donor-bound exciton [3-5], and the lower laying peaks near 3.26 eV, which may be associated either with the donor-acceptor pair transition and it's phonon replica, or with D^0x transition in cubic GaN inclusions [6]. The former explanation looks more reasonable and is also confirmed by the fast decrease of the peaks intensity with the temperature increase (see Fig. 2). The 3.475 eV line in the $n-$ type layers is a well known transition due to the recombination of the excitons bound to neutral donors

GaN on NdGaO$_3$

10 K
15 K
30 K
50 K
80 K
150 K
220 K
300 K

PL intensity (arb. units)

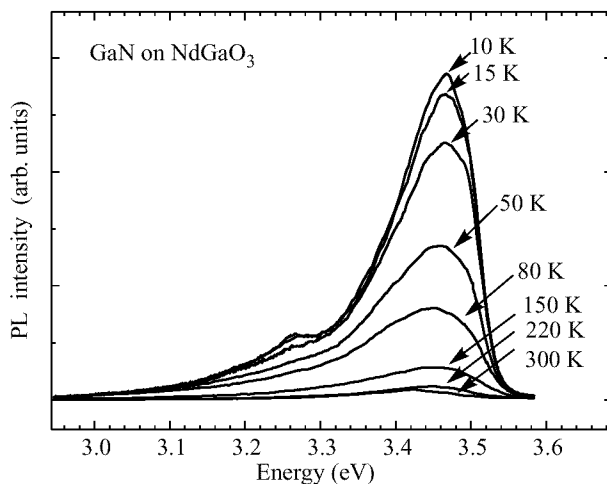3.0   3.1   3.2   3.3   3.4   3.5   3.6

Energy (eV)

Fig 2.

associated with nitrogen vacancies [7]. The origin of the donors can be either native defects or residual impurities [8] and is the subject of future investigations. The spectra exhibit a negligible intensity of the yellow emission band at both room and liquid helium temperatures. The dotted curve in Fig. 1 represents a low temperature PL spectrum of a GaN grown on a Al$_2$O$_3$. The linewidth is slightly less than for the GaN on NdGaO$_3$, however, the latter displays about twice higher PL efficiency.

In summary, we have demonstrated a feasibility of new NdGaO$_3$ substrates for MBE growth of GaN layers. Additionally, we report a compatibility of a new type plasma-source with MBE requirements and it's capability to provide the growth rate up to 0.5 μm/h.

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