Intraband emission of GaN quantum dots at λ =1.5 µm via resonant Raman scattering

L. Nevou, F. H. Julien, M. Tchernycheva, F. Guillot, and E. Monroy

***Abstract*—We report on the observation of room-temperature emission at telecommunication wavelength from GaN/AlN quantum dot under optical pumping at λ=1.34 µm. The quantum dots exhibit intraband absorption in the conduction band ascribed to the s-p_z transition. The emission arises from Raman scattering enhancement by the intraband resonance of the quantum dot. Prospects for intraband nitride-based quantum dot lasers will be discussed.**

***Index Terms*—GaN/AlN quantum dots, Raman scattering, optical pumping, luminescent devices.**

I. Introduction

Semiconductor heterostructures based on group-III nitrides are promising candidates for unipolar intersubband (ISB) devices operating at fiber-optics telecommunication wavelengths. Thanks to their large conduction-band offset—which, for instance, is of the order of 1.7 eV at the GaN/AlN heterointerface—ISB transitions in the 1–3 µm wavelength range can be obtained. Several groups have observed ISB absorption at 1.3–1.55 µm wavelength in GaN/Al(Ga)N quantum wells grown by molecular-beam epitaxy (MBE) [1]. GaN quantum dot (QD) systems are also of great interest for optoelectronic applications because of their high density and of the 3D carrier confinement. Short-wavelength intraband absorptions of GaN/AlN quantum dots (QDs) have been observed at room temperature [2,3]. QD-based intraband photodetectors operating at λ=1.3-1.5 µm have also been demonstrated [4-5].

Recently we have reported the ISB luminescence at 2.1 µm from GaN/AlN quantum wells [6]. In this study, we report on the observation of room temperature emission at λ≈1.5 µm from a stack of GaN/AlN QDs through resonantly enhanced Raman scattering. The QDs are shown to exhibit p-polarized intraband absorption peaked at λ =1.55 µm linked to the intraband transition from the ground shell s to the p_z excited state with one node of the envelope function along the growth axis. Under optical pumping at λ =1.34 µm, narrow emission lines appear at 1.52 µm and 1.48 µm. The QD emissions are strongly p-polarized. With respect to the pump photon energy, the emission energy is red-shifted by 110 meV and 90 meV, which correspond to the energy of AlN and GaN LO-phonons, respectively. Separate experiments on bulk GaN and AlN samples do not reveal any measurable emission in the investigated energy range. The exaltation of the emission in the QD sample is attributed to the resonant enhancement of Raman scattering by the s-p_z intraband transition [8].

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II. Experimental Results

The sample investigated in this work consists of 200 periods of GaN QD layers with 3-nm-thick AlN barriers, grown by plasma-assisted MBE on 1µm-thick AlN-on-sapphire (0001) templates. The QDs are formed by deposition of 4 monolayers (ML) of GaN on an AlN surface under nitrogen-rich conditions. Under these conditions, the growth starts layer by layer, leading to a 2 ML GaN wetting layer and then strain is relaxed by forming three-dimensional islands (Stranski–Krastanov growth mode) [7]. The QDs are doped with Si at $1x10^{20}$ cm^{-3}. An additional QD plane was deposited on the surface to allow atomic force microscopy (AFM) characterization of the QD shapes and density. The QD density is very high ($1.2x10^{12}$ cm^{-2}) and the average QD height is about 1 nm.

Photoluminescence (PL) experiments were carried out at low temperature (4K) using the UV excitation line at λ =244 nm of a frequency-doubled continuous-wave Ar^+ laser. The PL signal was focused into a 0.46 m focal length monochromator, and detected with a charge coupled device camera. Figure 1 shows the PL spectrum. The PL signal is peaked at 3.77 eV, which is typical of dots with a height of 4–5 MLs (1–1.3 nm) [3]. The full width at half maximum (FWHM) is 190 meV. This value is remarkably small for nitride QDs and suggests a good size homogeneity of the 200 periods QD sample. A weak emission peak is observed at high energy (4.05 eV), which is attributed to the wetting layer's luminescence.

The ISB absorption was measured at room temperature using Fourier Transform Infrared (FTIR) spectroscopy. Figure 2 shows the absorption spectra of the samples measured at Brewster's angle of incidence (blue curve) and in a multipass waveguide configuration (red curve). The absorption at 0.8 eV, only observed for p-polarized light, is ascribed to the s-p_z

intraband transition. At Brewster's angle of incidence, the absorption magnitude is 12% and the FWHM is only 125 meV, which is a remarkably small value for a GaN/AlN QD superlattice. In the multipass waveguide configuration with 15 total internal reflections, the absorption attains 95% but the broadening strongly increases.

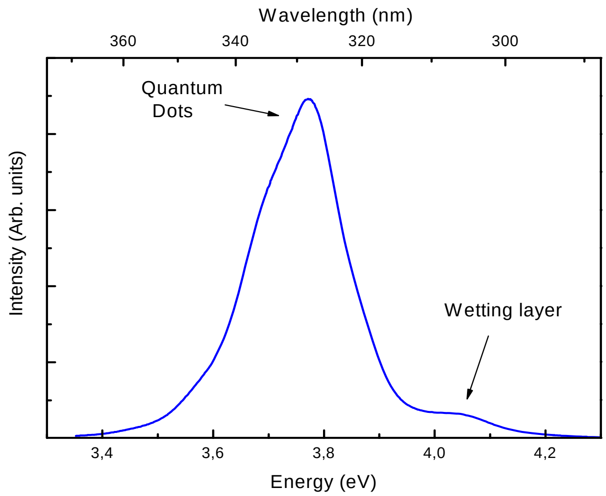

Figure 1: PL spectrum of the QD sample recorded at 4K.

For the emission measurements, the input facet of the sample was polished at 90° angle. Optical excitation was provided by a continuous wave YVO4 laser emitting at λ=1.34 µm. The laser was focused at normal incidence onto the polished facet of the QD sample using a microscope objective. The retro diffused light from the facet was directed onto the emission port of the step-scan FTIR spectrometer. Detection was performed by an InGaAs detector. Interferential filters were used to reject the residual pump laser beam.

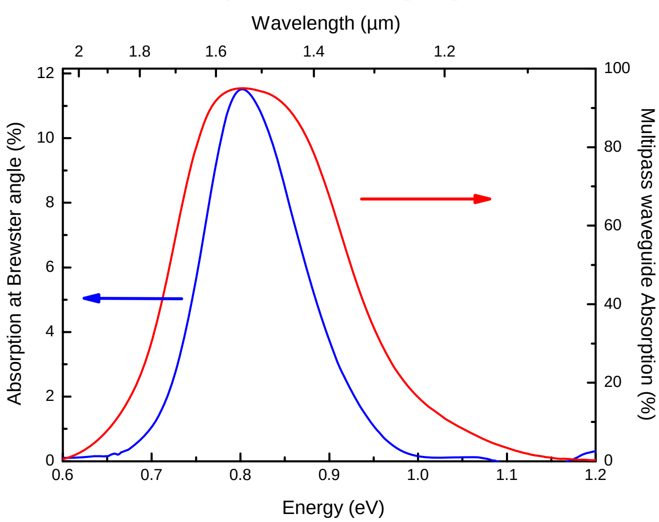

Figure 2: 300 K absorption spectrum at Brewster angle of incidence (blue curve) and in a multipass waveguide configuration (red curve).

Figure 3 shows the emission spectrum of the sample at room temperature for p-polarized excitation (red curve) compared with the intraband absorption spectrum at Brewster's angle (blue curve). The peak at 0.925 eV is the pump laser emission (black curve). The emission spectra have been corrected for the spectral response of the optics, filter and detector. For p-polarized excitation, on top of a broadband background signal two narrow emission peaks are observed at 1.52 µm and 1.48 µm. With respect to the pump laser energy the peaks are shifted to low energy by 90 meV and 110 meV, respectively. These values correspond to the LO-phonon energies of GaN and AlN, respectively. For s-polarized excitation, the broad-band background signal is still observed while the narrow emission peaks disappear. The peaks are ascribed to the p_z-s intraband emission of the dots. The Raman scattering process is enhanced by the presence of the large oscillator strength intraband transition, as illustrated in the inset to Fig.3. Separate experiments on two reference samples (3.5 µm thick GaN layer on sapphire substrate and 1 µm thick AlN layer on sapphire substrate) do not show any detectable emission at these energies within experimental accuracy.

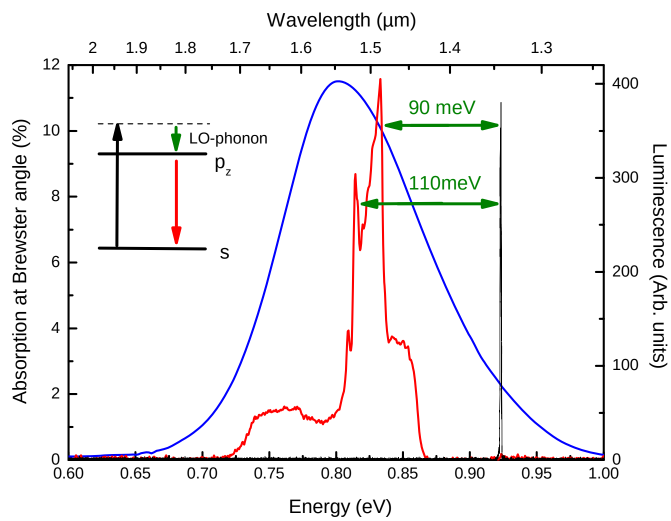

Figure 3: Room temperature emission spectrum of the QD sample (red curve), intraband absorption of QDs (blue curve) and the laser pump spectrum (black curve). Inset: Raman scattering scheme.

The observation of intraband emission through resonantly enhanced Raman scattering opens prospects for GaN/AlN QD lasers at telecommunication wavelengths. We will show that this process provides room for population inversion.

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