Room-temperature Intersubband Emission from GaN/AlN Quantum Wells at λ≈2 μm

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

Abstract—**We report on the observation of room-temperature intersubband luminescence at λ=2.1-2.3 μm from GaN/AlN quantum wells under optical pumping at λ=0.98 μm. The quantum wells are designed to exhibit three bound states in the conduction band. The emission arises from the e_3e_2 intersubband transition. Photoluminescence excitation spectroscopy shows that the emission is only observed for p-polarized excitation in resonance with the e_1e_3 intersubband absorption. Prospects for optically-pumped intersubband nitride-based lasers will be discussed.**

Index Terms—**GaN/AlN quantum wells, luminescent devices, optical pumping, quantum well intersubband lasers.**

I. Introduction

BECAUSE of their large conduction band offset (~1.75 eV for GaN/AlN) and remote lateral valleys, III-nitride semiconductors are excellent candidates for intersubband (ISB) light-emitting devices at near-infrared wavelengths, including the spectral range of interest for optical-fiber telecommunications (λ=1.3-1.55 μm) [1]. Despite a few proposals for nitride-based ISB emitting devices [2], as well as the recent demonstration of light generation at λ≈1 μm through ISB enhancement of second-harmonic nonlinear processes [3], the observation of ISB luminescence in this material system has proven elusive until recently. One major difficulty is the expected weak luminescence efficiency resulting from the ultra-short electron-LO phonon scattering rates (0.15-0.4 ps) in these highly-ionic semiconductors [4].

We report here on the observation of short-wavelength ISB luminescence at room temperature from GaN/AlN quantum wells (QW) [5, 6]. The QWs are designed to exhibit three bound states in the conduction band. The ISB luminescence associated with the e_3e_2 radiative transition is observed under optical excitation in resonance with the e_1e_3 absorption. The latter transition is allowed in hexagonal-phase GaN/AlN QWs because of the asymmetric potential induced by the internal field. Depending on sample, the peak emission wavelength is λ=2.1-2.3 μm. The observation of room-temperature ISB luminescence is a step forward towards the realization of optically-pumped quantum fountain lasers or amplifiers operating at short infrared wavelengths. We will finally present the investigation of GaN/AlN coupled quantum well structures designed to exhibit population inversion.

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II. Experimental Results

The two samples investigated in this study, A and B, were grown by plasma-assisted molecular beam epitaxy on a 1 μm-thick AlN buffer on *c*-sapphire. The substrate temperature was fixed at 720°C, and the growth rate was 0.28 monolayers (ML) per second, determined by the nitrogen supply. The active region of sample B (A) contains 200 (250) periods of 2.1-nm-thick (2.1 nm = 8 ML) GaN QWs separated by 3-nm-thick AlN barriers. Sample A is nominally undoped, and the electronic population of the ground state is provided through residual doping. The QWs of sample B are n-doped with silicon at a concentration of 5×10^{19} cm^{-3}.

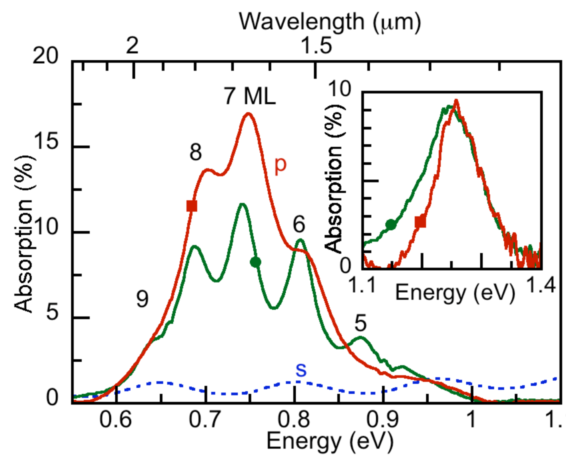

Fig. 1. Absorption spectrum at 300 K of samples B (squares) for p- and s-polarized light and A (circles) for p-polarized light at Brewster's angle of incidence. The inset shows the e_1e_3 absorption for p-polarized light of samples B (squares) and A (circles) measured in a multi-pass waveguide.

The ISB absorption was measured at room temperature using Fourier Transform Infrared (FTIR) spectroscopy. Figure 1 shows the absorption spectra of samples A and B measured at Brewster's angle of incidence. The absorption at 0.6-0.9 eV, only observed for p-polarized light, is ascribed to the e_1e_2 ISB transition. The ripple visible in the absorption spectra of Fig. 1 is due to fluctuations of the QW thickness corresponding to an integer number of monolayers, as previously reported in Ref [7]. For sample A, the multi-structured absorption is well reproduced by adding the ISB absorptions of 5, 6, 7, 8 and 9 ML thick QWs with a Lorentzian line shape and a FWHM of 41 meV. For sample B, which contains a smaller number of periods, the contribution of 5 and 9 ML thick QWs is not observed. The homogeneous broadening of each peak is larger (60 meV FWHM) probably because of the contribution of electron-impurity scattering. With respect to sample A, the peaks of sample B are slightly blue-shifted, as a consequence of many-body effects associated with the larger electron concentration in the wells [7].

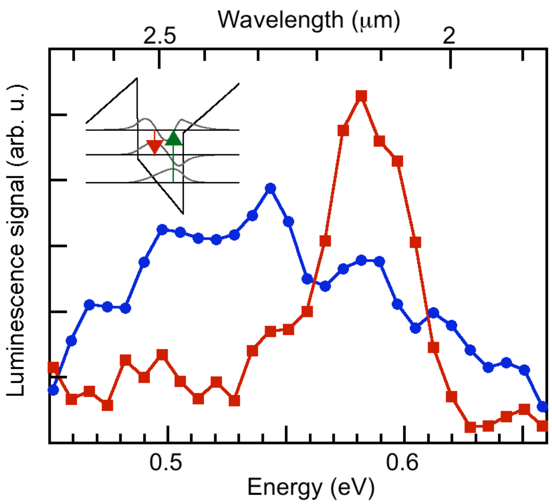

Fig. 2. ISB luminescence spectrum at 300 K of samples A (circles) and B (squares) under excitation at λ=0.98 µm wavelength. The spectra have been corrected for the spectral response of the optics, filter and detector. The inset shows the conduction band profile and energy levels of an 8 ML thick QW.

For the emission measurements, the input and output facets of the sample are polished at 45° angle and 90° angle, respectively. Excitation at λ=0.98 µm in resonance with the e_1e_3 transition energy is provided by a tunable Ti:Sapphire laser operated at 1 W in continuous wave. The light exiting from the output facet is directed to the emission port of the step-scan FTIR spectrometer. Detection is performed by a liquid nitrogen cooled InAs detector.

Figure 2 shows the emission spectra of samples A and B for p-polarized excitation. The emission is peaked at λ=2.13 (2.3) µm with a FWHM of 60 (160) meV for sample B (A). The luminescence is mainly p-polarized, the ratio between p- and s-polarization exceeding a factor of 3. For sample B, the emission at 0.58 eV is ascribed to the e_3e_2 radiative transition of 8 ML thick QWs, in agreement with spectroscopic measurements. For sample A, 9 ML thick GaN QWs also contribute to the luminescence, which explains the larger broadening at low energy and the longer emission wavelength.

Figure 3 shows a photoluminescence excitation spectrum of sample B obtained by tuning the pump wavelength. The excitation spectrum closely follows the e_1e_3 ISB absorption of the pump radiation for p-polarized excitation. This confirms that the emission arises from an ISB transition in the QWs. The external quantum efficiency of the e_3e_2 ISB emission under p-polarized excitation is measured to be 10 pW per Watt of pump power, while the internal quantum efficiency is estimated at ~0.3 µW per Watt.

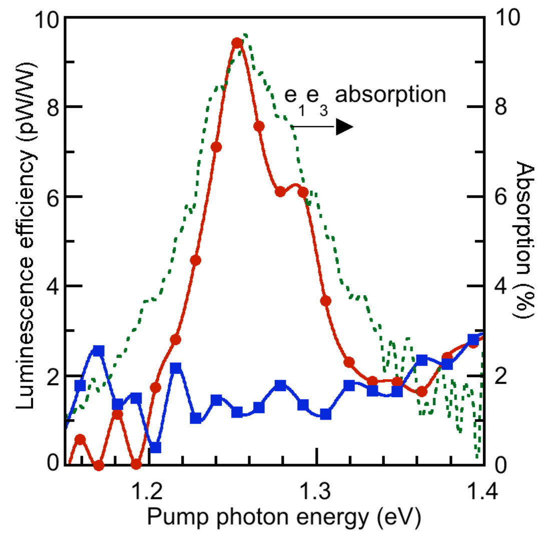

Fig. 3. ISB luminescence efficiency of sample B versus pump photon energy at room temperature for p- (circles) and s- (squares) polarized excitation (full curves). Right scale: e_1e_3 absorption spectrum of sample B (dotted curve).

In conclusion, we have measured the ISB spontaneous emission from optically-pumped GaN/AlN quantum wells. The peak emission wavelength at room temperature is λ=2.1-2.3 µm, which is the shortest value reported for an ISB light emitting device. It should be noted that the 3-level single QW design is not suitable for reaching population inversion, because the non-radiative scattering time is expected to be longer for the e_2e_1 transition than for the e_3e_2 transition based on the respective value of the transition energies. In order to achieve population inversion, more sophisticated designs are required. We will show that large stimulated gains at λ=1.5 µm can be achieved using GaN/AlN coupled QWs.

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