Effect of Strain Relaxation and Screening on Intersubband Transitions in GaN/AlGaN Multiple Quantum Wells

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Intersubband transitions (ISBTs) in nitride semiconductor systems have advantages over those in conventional materials for application to ultrafast optical modulators and/or cascade lasers in 1.5 μm telecommunication networks [1]. In this work, we report on the influence of strain relaxation and carrier induced screening of the polarization field on ISBTs in GaN multiple quantum wells (MQWs). Sharp ISBT spectra were observed for high-quality GaN/AlGaN MQWs, and the dependence of ISBT peak energy on the number of QW periods and the doping level were systematically investigated. With increasing the number of QWs from 5 to 30, the ISBT spectra were found to red-shift. This result can be explained by the polarization field in the QW layers being reduced due to partial relaxation of the QW layers, seen in asymmetric reciprocal space maps in x-ray diffraction. A red-shift was also observed with increasing the level of doping, because of carrier induced screening of the polarization field.

Samples were *n*-type GaN (N_D = 7x10^{18}cm^{-3}) / nondoped $Al_{0.56}Ga_{0.44}N$ MQWs containing different number of QW periods, viz., 5, 10, 30 QWs, grown in an atmospheric-pressure two-flow MOCVD system. The thicknesses of the well (L_W) and the barrier (L_B) were 4.3 nm and 4.5 nm, respectively. In addition we have grown two 5 period MQW samples having $Al_{0.56}Ga_{0.44}N$ barriers (L_B = 3.8 nm) and *n*-type GaN wells (L_W = 3.5 nm) with doping concentration N_D = 7x10^{18}cm^{-3} and 1x10^{19}cm^{-3}.

Intersubband absorption spectra were measured at room temperature using a Fourier transform infrared spectrometer attached to an ATR (attenuated total reflectance) unit with Ge prism in order to avoid the optical interference usually arising from reflection at the surface and at the GaN/sapphire interface [2]. A polarizer was introduced to polarize the incident light. The absorption was measured for two different polarizations. In *p*-polarization, there is an electric field component perpendicular to the plane of the MQWs, whereas in *s*-polarization the electric field is parallel to the plane. Intersubband Absorption should be allowed only for *p*-polarized light.

Sharp intersubband absorption spectra are observed for 5, 10, and 30 period QWs for *p*-polarized light, as shown in Fig. 1. No absorption peaks were observed for *s*-polarized light. The polarization results show that the absorption can be attributed to ISBTs. The absorption of samples increases with increasing the numbers of wells because of the larger total number of carriers. The ISBT peak energies of 5, 10 and 30 period QWs are 0.32 eV, 0.32 eV and 0.30 eV, respectively. These values are much larger than the calculated value (0.2 eV) for a flat band structure. This demonstrates that a huge polarization field exists in the QW layers [3, 4]. The tilting of the band edge by the built-in field results in a reduced effective well thickness, and thus shorter wavelength ISBTs. We have evaluated the strain configuration of these samples by asymmetric ($10\bar{1}5$) reciprocal space maps

(RSMs) in high-resolution x-ray diffraction spectra. The RSMs show that the QW layers are fully strained in the 5 and 10 period MQWs. The 30 period MQWs, however, show partial relaxation of the QW layers. The relaxation results in reduced polarization field, and thus a red-shift of the ISBT from 0.32 eV to 0.3 eV.

Fig. 2 shows the dependence of the ISBT spectrum on doping level. The absorption increases with increasing doping level because of the larger number of carriers. Red-shift of the ISBT spectra is clearly observed with increasing doping. This implies that with higher doping, screening of the polarization field is enhanced and results in a decreased ISBT energy.

In summary, we have investigated sharp intersubband absorption spectra in GaN /$Al_{0.56}Ga_{0.44}N$ MQWs. Red-shift of the ISBT energy occurred with relaxation of strain in the QW layers and carrier induced screening. Understanding these effects is crucial for designing ISBT devices, since the devices must have high carrier densities and multilayered structures for good performance.

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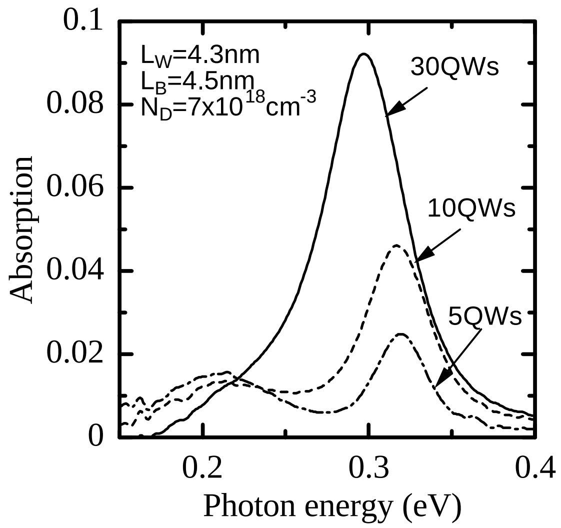

Fig. 1. Intersubband absorption spectra of GaN/$Al_{0.56}Ga_{0.44}N$ MQWs with different numbers of QW periods for *p*-polarized

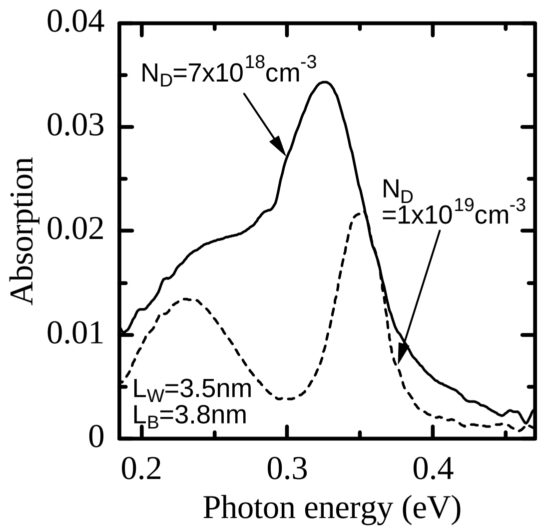

Fig. 2. Intersubband absorption spectra of GaN/$Al_{0.56}Ga_{0.44}N$ 5QWs with different doping levels for *p*-polarized light.