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Electroluminescence of GaNAs/GaAs MQWs p–i–n junctions grown by RF-MBE using modulated nitrogen radical beam source

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ABSTRACT

We have investigated the electrical and optical properties of p–i–n junction structures in which un-doped GaNAs/GaAs multiple quantum wells (MQWs) were sandwiched by p- and n-doped GaAs layers. The samples were formed on the GaAs (001) substrates by plasma assisted molecular beam epitaxy (RF-MBE) using the modulated N radical beam method. We have prepared several samples for various GaNAs MQW structures. The electroluminescence (EL) measurements showed slightly different spectra to those of photoluminescence (PL) and the EL intensities were almost proportional to the applied currents. The room temperature EL measurement revealed strong electron confinement of GaNAs/GaAs MQW.

1. Introduction

Diluted nitride semiconductor GaNAs and GaInNAs have attracted many interests for their variability of the energy gap, which strongly depends on their nitrogen compositions [1,2]. High thermal stabilities of GaNAs optical properties have been reported in some papers [3–5], where the temperature dependence of emission peak position is small for the GaNAs/GaAs hetero structures. In previous studies of our group [6–8], we have observed photo excited emission at room temperature from the GaNAs/GaAs MQWs [7]. From the above-mentioned advantages, application of Ga(In)NAs for long wavelength devices, multi-junction solar cells [10–14] and quantum dot solar cells [15] have been expected. There are also researches of p–i–n junction structures, where the GaNAs layers were used for strain-compensating layers for InAs quantum dots (QDs) to minimize the net average lattice strain [11–14]. However, EL properties of GaNAs aren't fully figured out, furthermore the p–i–n junctions which utilize the electrical characteristics of GaNAs have not been reported.

In our previous studies [8], un-doped GaNAs often shows n-type conductivity, which might be attributed to crystalline defects such as interstitial nitrogen. In addition, Mg doped GaNAs doesn't necessarily show p-type conductivity, and this uncertainty of carrier type makes difficult to fabricate a GaNAs p–n junction. Then we have fabricated p–i–n junctions in which GaNAs/GaAs MQWs were sandwiched by GaAs p–n junctions, and characterized their electrical and optical properties. Clear rectification properties were observed in I–V curves of their p–i–n junctions. Improved photovoltaic properties by inserting of GaNAs/GaAs MQW p–i–n junctions were also observed [9].

In this report, we have investigated the optical and electrical properties of the GaNAs/GaAs MQWs p–i–n junctions by comparing the results of EL and PL measurements.

2. Experiment

The GaNAs/GaAs MQWs p–i–n junctions were grown on (001) n-doped GaAs substrates by radio frequency molecular beam epitaxy (RF-MBE) using the modulated nitrogen radical beam source method [16] where the parameters, such as nitrogen gas flow, RF power, ignition of nitrogen plasma, and beam shutter were sequentially controlled by computer. By this method, we can fabricate GaNAs/GaAs hetero structures with thickness controlled in the scale of atomic layers [16–18].

Fig. 1 shows a schematic of the GaNAs/GaAs MQWs p–i–n junction. We used Mg doped GaAs as a p-layer, Si doped GaAs as

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an n-layer, and undoped GaNAs/GaAs MQW as an i-layer. The thickness of GaNAs and GaAs layers were 1 ML and 50 ML, respectively. The stacking number of GaNAs quantum wells was varied as $n=10$, 20, and 30. The growth temperature of substrate was held at 500 °C. The K-cell temperatures of Ga, As, Mg and Si were 1050, 350, 400 and 1200 °C, respectively. The electrical and optical properties of the samples were characterized by current–voltage (*I–V*), PL and EL measurements. In PL measurements, the samples were excited by the DPSS laser (532 nm) at 77 K. In EL measurement, the samples (3 mm × 3 mm) with In(Zn) contacts both top and bottom sides were mounted on circuit boards with traces of Au wires at 77 K. Both EL and PL measurements were carried out simultaneously by collecting the luminescent light by the same optical analyzer and detector. We also have made room temperature EL measurements for $[GaNAs_{1\ ML}/GaAs_{50\ ML}]_{20}$ p–i–n junction.

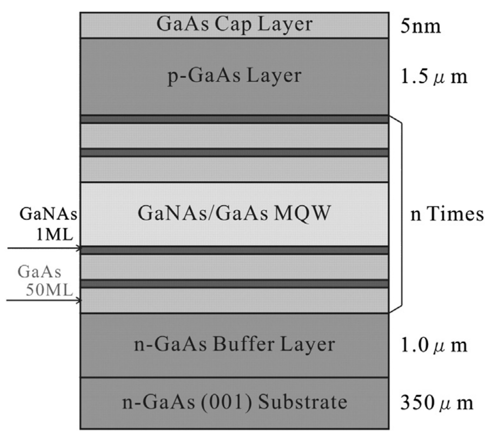

Fig. 1. A schematic of GaNAs/GaAs MQWs p–i–n junction. The thicknesses of n-GaAs layer and p-GaAs layer are 1.0 and 1.5 μm, respectively. Structures of the MQW i-layers are $[GaNAs_{1\ ML}/GaAs_{50\ ML}]_n$ where *n* is 10, 20 or 30.

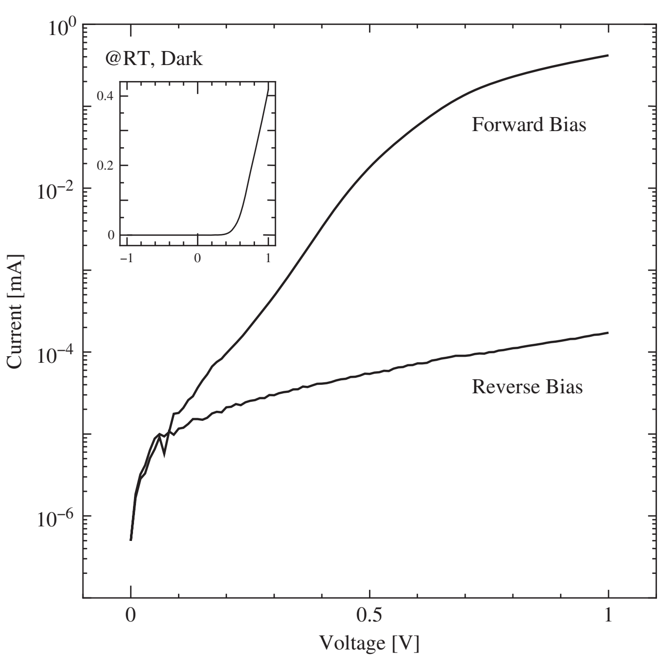

Fig. 2. Log *I–V* curves of $[GaNAs_{1\ ML}/GaAs_{50\ ML}]_{20}$ p–i–n junction at room temperature without illumination. The inset shows an *I–V* curve in liner scale of the same sample.

3. Results and discussions

From results of the *I–V* measurements at 300 K as shown in Fig. 2, rectifying characteristic was clearly observed in the GaNAs MQW p–i–n junction of $n=20$. In this sample, photovoltaic effect was also observed with illumination by a sun light simulator at room temperature [9].

Fig. 3 shows EL spectra of the p–i–n junction ($n=20$), that the EL intensity was increased with increasing current magnitude.

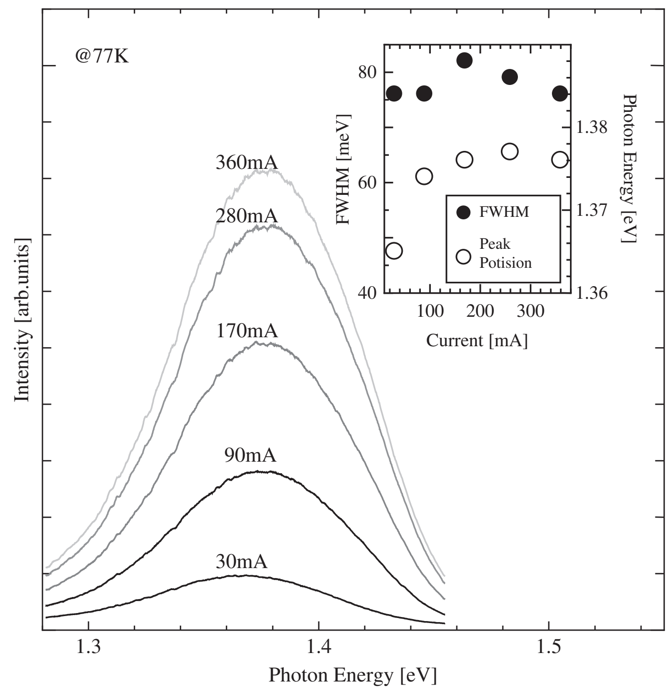

Fig. 3. Current dependence of EL spectra of $[GaNAs_{1\ ML}/GaAs_{50\ ML}]_{20}$ p–i–n junction at 77 K. The inset shows the FWHM (as shown as close circle) and photon peak energy (as shown as open circle) as functions of currents.

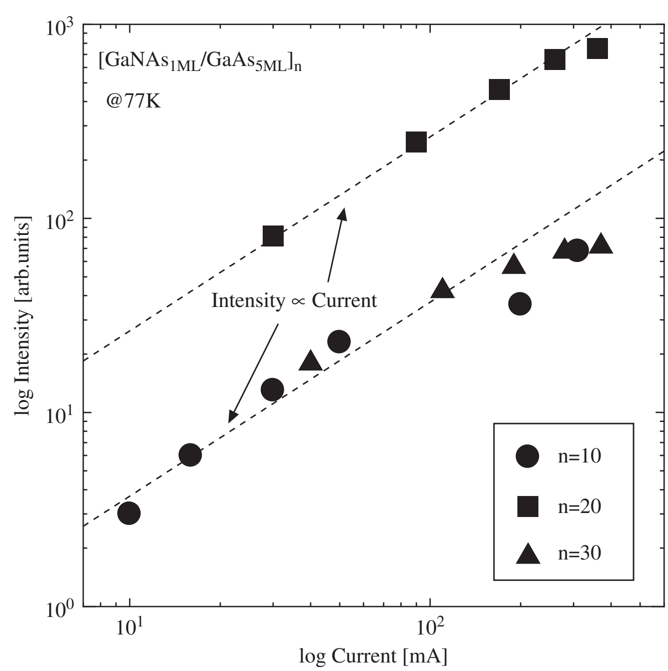

Fig. 4. Log current dependence of EL intensities of GaNAs/GaAs p–i–n junctions ($n=10$, 20, 30) measured at 77 K.