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Photo- and contactless electro-reflectance spectroscopies of step-like GaInNAs/Ga(In)NAs/GaAs quantum wells

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Abstract

Step-like GaInNAs/Ga(In)NAs/GaAs double quantum well (DQW) structures tailored at 1.3 μm have been studied in photoreflectance (PR) and contactless electroreflectance (CER) spectroscopies. Spectral features related to absorption in the active part of the step-like DQW structure, i.e. GaInNAs/Ga(In)NAs QW, as well as features related to absorption between states confined above the step-like barrier (SLB) and in GaAs barriers have been observed. It has been shown that these two techniques give information about the same optical transitions. However, due to some differences in the mechanism of band bending modulation, PR and CER spectra are not exactly the same especially for the layer which is under significant internal electric field. It has been shown that Franz–Keldysh oscillations related to GaAs cap layer are clearly observed in CER and disappear in PR at strong modulation conditions due to an effective flattering of the surface band bending during PR measurements.

Keywords: Photoreflectance; Modulation spectroscopy; Photoluminescence

1. Introduction

Semiconductor lasers operating at 1.3 and 1.55 μm wavelengths are very important light sources for fiber telecommunication. Recently, a novel GaAs-based material system (i.e. GaInNAs/GaAs QW) has been proposed for this application [1,2]. GaAs-based lasers offer a number of advantages, as compared to conventional InP-based structures, including higher temperature insensitivity of the laser threshold and output, which could allow for uncooled operation of the devices. However, with an increasing nitrogen mole fraction in GaInNAs compound, the optical quality of the material usually deteriorates significantly, resulting in a higher threshold current density of lasers. For these reasons, other approaches were developed to redshift the emission wavelength and to keep good optical quality for GaInNAs-based systems [3]. One of them is to introduce strain compensated layers to this GaInNAs/GaAs QW structure [4–9], thus the active region of such a laser structure is a step-like QW.

The step-like GaInNAs/Ga(In)NAs/GaAs QW structures make it possible to achieve 1.3 and 1.55 μm emission at a lower nitrogen and/or indium content. So far, the optical properties of such step-like QWs have been mainly investigated in photoluminescence (PL) spectroscopy. Modulation spectroscopy (MS) like photoreflectance (PR) and contactless electroreflectance (CER) [9,10] enables observation of a large number of sharp spectral features including those related to excited state transitions in low-dimensional structures, in contrast to common PL spectroscopy, which usually probes only the ground state. MS spectroscopy is very sensitive at room temperature which is a very important aspect of material characterization since devices normally operate around room temperature. Moreover, PR and CER spectroscopies are very useful because they can be performed in contactless mode that is non-destructive for samples. For the two techniques, the internal electric field is the parameter which is modulated during measurements. However, the modulation mechanism is not the same for the two techniques [10–12].

In this paper PR and CER spectroscopies have been applied to study the step-like GaInNAs/Ga(In)NAs/GaAs DQW structures tailored at 1.3 μm. We have compared

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these two techniques and discussed their similarities and differences as well as advantages and disadvantages.

2. Experiment

Structures were grown on a 500 μm thick (001)-oriented unintentionally doped GaAs substrate by solid source molecular beam epitaxy (MBE) using an *EIKO 100S* MBE system. Standard effusion cells were used for As, Ga, and In. An *Applied Epi* UNI-Bulb™ radio frequency (RF) plasma source operating at 13.56 MHz was used to generate nitrogen radicals from high-purity (6N) N_2 gas. The whole structure was grown without any interruptions. The N-plasma source was driven at an RF-power of approximately 230 W with the background pressure of the plasma-chamber being below 2×10^{-5} Torr. During growth, the background pressure in the growth-chamber was better than 5×10^{-6} Torr. The buffer and cap layer were grown at 590 °C and Ga(In)NAs QW layers at approximately 440 °C. To determine the nitrogen and indium contents, both high resolution X-ray diffraction and pre-calibrated PL investigations of the samples have been preformed.

Fig. 1 shows schematic structure of the step-like GaInNAs/Ga(In)NAs/GaAs DQW samples. The structures is composed of a 500 nm thick GaAs buffer layer, step-like tensile strained Ga(In)NAs barriers, compressive strained GaInNAs QWs, and a 100 nm thick GaAs cap layer. Two samples tailored at 1.3 μm have been selected to this paper. For the first sample (i.e. the GaInNAs/GaNAs/GaAs DQW structure) the content of GaNAs step-like barriers (SLBs), and GaInNAs QW layers is ∼1.5% N, and 34% In and ∼1% N, respectively. For the second sample (i.e. the GaInNAs/GaInNAs/GaAs DQW structure) the content of GaInNAs SLBs, and GaInNAs QW layers is 3.6% In and ∼1.4% N, and 36% In and ∼1% N, respectively.

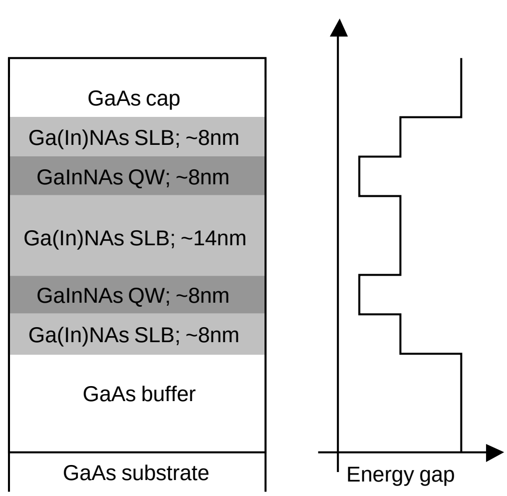

Fig. 1. Schematic structure of the step-like GaInNAs/Ga(In)NAs/GaAs double quantum well samples.

A conventional experimental set-up with a tungsten halogen lamp (150 W) as a probe light source, a 0.55 m monochromator and InGaAs *pin* photodiode was applied for obtaining the PR and CER spectra. For PR, a YAG laser with 532 nm emission was used as the pump beam. The probe and pump beams were defocused to the diameter of 2 mm and the power of modulated beam was about 15 mW. In the CER experiment, the top electrode consisted of a transparent conducting ATO layer on quartz, which was kept at a distance of 0.1 mm from the sample surface while the sample itself was fixed on the bottom cuprum electrode. A maximum peak-to-peak alternating voltage of 0.9 kV was applied. Phase sensitive detection of the PR and CER signals was made using a lock-in amplifier. Other relevant details of the experimental set-up have been described in Refs. [10–12].

3. Results and discussion

Figs. 2 and 3 show a comparison of PL, PR and CER spectra recorded at room temperature for the step-like GaInNAs/GaNAs/GaAs and GaInNAs/GaInNAs/GaAs DQW structures, respectively. In the case of PL spectra, only one peak related to the fundamental transition is observed. The line shape of this peak is asymmetric with a tail at high energy side, which is a typical of free carrier recombination at room temperature [13,14]. In the case of PR and CER spectra, besides the ground state transition, a lot of features related to excited states in the GaInNAs/

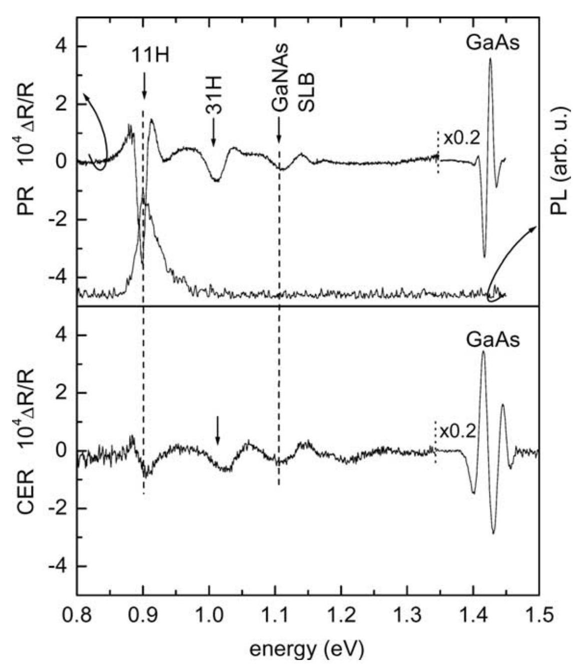

Fig. 2. Room temperature photoluminescence, photoreflectance, and contactless electroreflectance spectra of the step-like GaInNAs/GaNAs/GaAs double quantum well structure.