Optica Applicata, Vol. XXX, No. 1, 2000

Optical characterisation of strained-layer $In_xGa_{1-x}As/GaAs$ MQW LED grown by MOVPE

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We present the use of photoreflectance (PR) spectroscopy combined with the standard photoluminescence (PL) and electroluminescence (EL) for the room temperature optical investigation of strained-layer multiple quantum well (MQW) $In_xGa_{1-x}As/GaAs$ light emitting diode (LED) for 1040 nm. In the PR spectra, except the fundamental transition observed also in the emission spectra, two extra features related to the active region of the device have been seen. The presence of these two excited state transitions allowed the band structure to be analysed and the correctness of the device performance to be checked. We repeated the measurements after the top *p*-doped GaAs cladding layer had been etched off and discussed the changes of the built-in electric field.

1. Introduction

The nondestructive characterisation and qualification of complex semiconductor multilayer structures is a crucial step in the fabrication of semiconductor devices. The fabrication of present-day electronic, optical and opto-electronic devices involves a number of complicated procedures, ranging from the actual epitaxial growth of thin layers to pattern definition and transfer. Developmental efforts in the design of such devices tend towards more compact structures. This trend places ever increasing demands on device parameters and hence evaluation procedures in order to upgrade performance and yield.

Rapid progress in strained-layer $In_xGa_{1-x}As/GaAs$ structures technology has led to the wide acceptance of $In_xGa_{1-x}As$ lasers, emitting in the 1 μm wavelength range, as pumping sources for infrared optical fiber amplifiers (*e.g.*, Er^{3+}-doped 1.5 μm or Pr^{3+}-doped 1.3 μm) and solid state lasers (*e.g.*, Ng:YAG laser). In this paper, we present investigations of light emitting diode emitting at 1040 nm as an alternative to laser pumping source. The advantages of LED arrays in comparison to lasers are the following: LED technology is much simpler than VCSEL (vertical cavity surface emitting laser) or Fabry–Perot laser technology and LEDs use the same active region as lasers, *i.e.*, MQW (multiple quantum wells) which work with high quantum efficiency. Light emitting diodes are characterized by spontaneous emission, so they have a zero threshold current and can be more efficient than lasers in low power applications. Through the use of an optical resonant cavity, the spontaneous emission spectrum of LEDs is drastically altered and more of the spontaneous radiation can be coupled into a narrow wavelength band. Because the emission mechanism of the LED is determined only by the external cavity, the electroluminescence full width at half maximum (FWHM) wavelength is independent of the forward bias over a broad range.

For application purposes optical characterisation techniques should be simple, inexpensive, compact, rapid and informative as much as possible. Another valuable aspect is the ability to perform measurements in a contactless manner at room (or even at elevated) temperature using wafer-sized samples. The contactless electromodulation methods like photoreflectance are ideally suited for this purpose [1]–[3]. Recent works have clearly demonstrated its considerable potential for evaluating important parameters of semiconductor laser structures [4]–[10].

In this paper, we report on a room temperature optical study (photoreflectance combined with a standard photoluminescence and electroluminescence) of $In_{0.2}Ga_{0.8}As/GaAs$ MQW LED structure. Photoreflectance spectroscopy is a kind of electromodulation technique in which modulation is provided by a chopped laser pump beam. This causes changes in the sample dielectric function and thus reflectance, yielding sharp derivative-like features in the modulated reflectance spectrum ($\Delta R/R$), which can be related to quantum well excitonic transitions or Franz–Kieldysh oscillations of the bulk-like parts of the structure.

2. Experimental details

The sample used in this study was grown by metal-organic vapour-phase epitaxy on a GaAs (100) Te-doped (10^{18} cm^{-3}) substrate. The basic unit of the structure consists of five, 10 nm thick, pseudomorphic $In_{0.2}Ga_{0.8}As$ quantum wells separated by 100 nm thick GaAs barriers and sandwiched between two 500 nm thick GaAs layers. The bottom one was of *n*-type (Si-doped $2 \cdot 10^{17}$ cm^{-3}) and top one of *p*-type (Zn-doped $2.5 \cdot 10^{18}$ cm^{-3}). The whole structure was capped with 200 nm of Zn-doped ($7 \cdot 10^{18}$ cm^{-3}) GaAs layer. Further details of the growth conditions have been described elsewhere [11].

The PR set-up used in this study was a conventional one, as described in [3] and [12]. The modulating He-Ne laser beam was chopped at 120 Hz and the power density used for these experiments was 1 mW/cm^2. The probe light beam came from a 150 W tungsten halogen lamp dispersed through a GDM1000 monochromator. The PR signal was detected by a Si photodiode.

In the photoluminescence experiments the 488 nm line of an Ar$^+$ laser was applied as the excitation source and a liquid nitrogen cooled Ge photodiode was used as a detector.

To measure the electroluminescence we applied standard contacts for GaAs -based *p-i-n* structure, *i.e.*, AuGe/Ni/Au for the *n*-doped substrate and Cr/Au for the *p*-doped cap layer in the configuration of the surface emitting diode. The LEDs were driven by current pulses of 5.5 mA amplitude and frequency of 120 Hz from a pulse generator. The LED was biased from a DC current source. The emitted light was fed into the multimode optical fiber coupled to the chip surface.

The etching of the sample was carried out in the solution of H_2SO_4:H_2O_2:H_2O with the ratio of: 12:1:1.

3. Results and discussion

In Figure 1, the PR spectra of as-grown and etched (650 nm from the top of the sample) LED sample are shown. Except the GaAs band gap oscillatory feature (Franz–Kieldysh effect) there are three resonances related to the MQW system. The derivative nature of the spectra made it possible to easily determine the position of the features with accuracy of about 1 nm at room temperature. The transition energies were obtained from the fitting procedure according to the first derivative of Gaussian line shape (FDGL), the most appropriate form of the PR resonance in the case of confined transitions at room temperature [1]–[3]. By

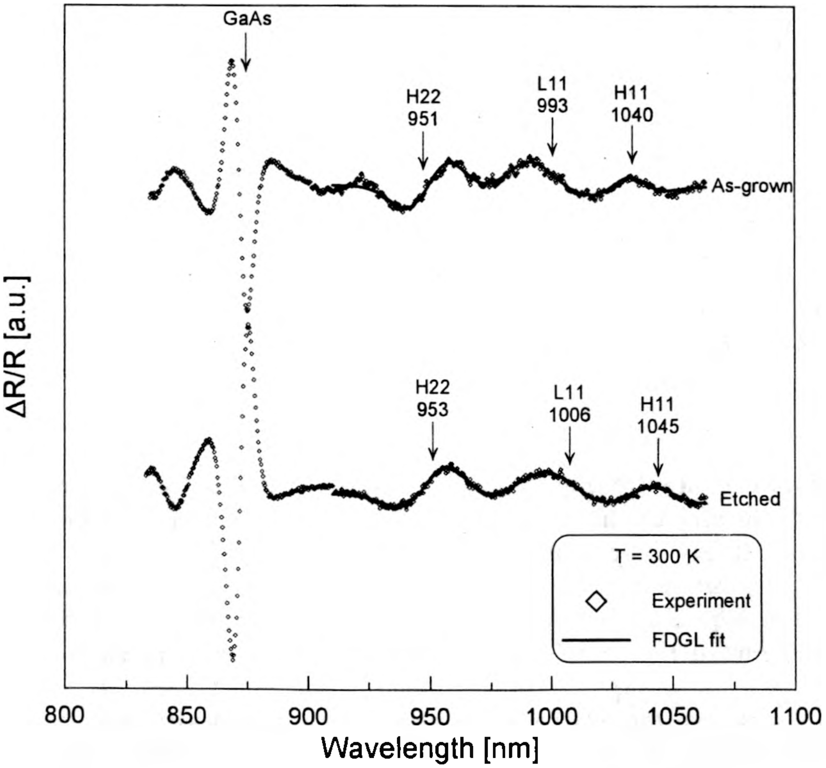

Fig. 1. Room temperature photoreflectance spectra of the $In_{0.2}Ga_{0.8}As$/GaAs MQW LED structure for as-grown and etched sample. For description of the optical transitions see the text.

energies of these MQW features with the results of an envelope function calculation [13], including the effects of strain, the transitions were identified as H11, L11 and H22, assuming decoupled wells due to the very thick (100 nm) GaAs barriers. The H(L)*nm* notation stands for the transition between the *m*-th conduction and *n*-th valence subbands in the quantum well. The exciton binding energies were taken after papers [14], [15]. Any small shifts of the transition energy related to the quantum confined Stark effect, due to the built-in electric field, were not taken into account. The calculation allowed also the evaluation of the In composition and width of quantum wells in the structure. These results are in good agreement with the ones from the growth conditions and X-ray diffraction measurements.

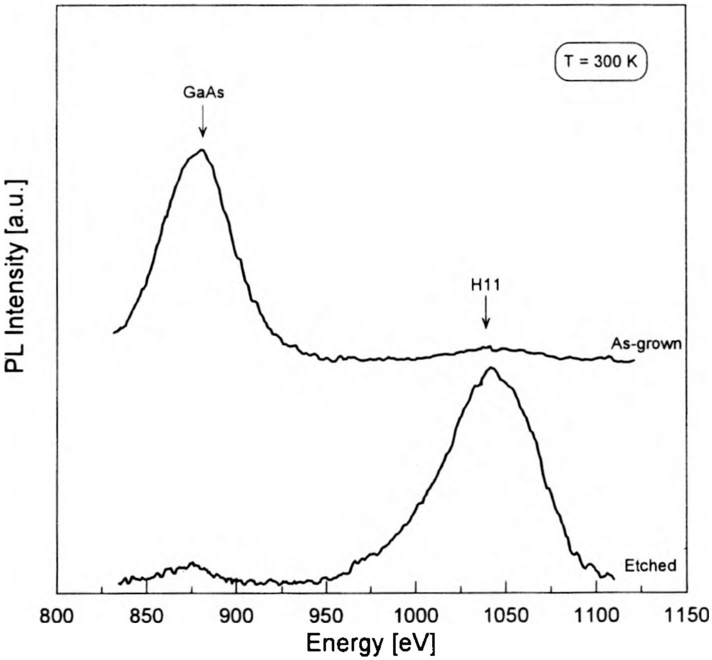

Fig. 2. Photoluminescence of the $In_{0.2}Ga_{0.8}As/GaAs$ MQW LED structure.

The photoluminescence spectra (Fig. 2) show two peaks related to the GaAs band gap bulk-like transition and to the fundamental, confined transition between the ground electron and heavy hole states in the $In_xGa_{1-x}As/GaAs$ MQW. The energy of the latter transition agrees very well with that from the PR measurements and calculation. The observation of the luminescence from the active region being buried at 700 nm in the sample demonstrates a very good quality of the structure.

It can be clearly seen that the relative intensities of these two peaks observed in PL change after the etching procedure. For the case of unetched sample the MQW transition is weaker than the GaAs-related one, whereas in the case of the etched sample the MQW-related peak is much stronger than the GaAs one. Simply, after the top GaAs layer was etched off the distance from the surface to the active region became smaller and hence the excitation in this region was more effective resulting in an increase of the PL intensity from the $In_xGa_{1-x}As$ quantum wells. The intensity of the GaAs related peak decreased due to surface trap states generated by the etching procedure producing an additional concentration of the surface recombination centers.

It is necessary to comment on the small red shift of the MQW-related features visible in the PR and PL spectra after etching procedure. We connect this with the changes of the built-in electric field in the active region. In the as-grown sample the Fermi level is pinned at the Si donor level at the bottom, and at the Zn acceptor level at the top of the sample giving the *p-i-n* structure. After the top *p*-type layers are almost etched off the surface electric field connected with the surface depletion region adds to the *p-i-n* junction field and the internal electric field increases. The higher field causes the red shift of the transition energies between the subbands of the valence band and those of the conduction band of the MQW. This is known as the quantum confined Stark effect [16].

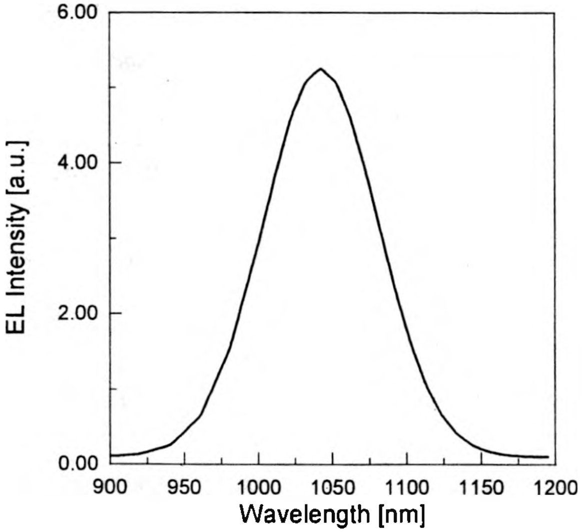

Fig. 3. Electroluminescence spectrum of the emission line of the full (with contacts) $In_{0.2}Ga_{0.8}As/GaAs$ MQW LED.

We also present the EL spectrum of the full LED structure (Fig. 3). The EL spectrum shows an emission peak at the wavelength of 1040 nm and the linewidth FWHM of about 100 nm which is a typical value for light emitting diodes. We also analysed the dependence of the intensity of electroluminescence emission versus the current and obtained the best efficiency of the device for currents ranging from 0.3 to 0.4 A.

4. Conclusions

We have presented the room temperature photoreflectance, photoluminescence and electroluminescence study of the $In_{0.2}Ga_{0.8}As/GaAs$ MQW LED structure being a good pumping source in the fiber optics and solid state lasers applications. From all the measurements we determined the energy of the fundamental optical transition in the active region of the device which is responsible for the emission line of the LED. The room temperature luminescence showed a good quality of the structure. The PR spectra, showing the presence of the excited state transitions, allowed us to analyse the band structure of the MQW and the correctness of the device performance. We also investigated the sample after etching off the top *p*-type part of the structure and discussed the influence of changes in the built-in electric field on the optical transitions.

Acknowledgements — This work was partly supported by the Centre for Advanced Materials and Nanotechnology, Wrocław University of Technology.

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Received December 11, 1999