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Yu. Yakovlev, A. Baranov, A. Imendov, A. Popov, V. Sherstnev. Tunable diode lasers based on quaternary III-V alloys in the spectral range of 2-4 μm for laser spectroscopy applications. Journal de Physique IV Proceedings, 1994, 04 (C4), pp.C4-671-C4-676. 10.1051/jp4:19944177 . jpa-00252636

HAL Id: jpa-00252636

<https://hal.science/jpa-00252636>

Submitted on 1 Jan 1994

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Tunable diode lasers based on quaternary III-V alloys in the spectral range of 2-4 μm for laser spectroscopy applications

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ABSTRACT

The structures and electroluminescence characteristics of new two types of single mode A^3B^5 semiconductor tunable lasers in the 1.8-3.9 μm spectral range have been demonstrated. The first type of tunable diode laser based on quaternary solid solutions GaInAsSb and GaAlAsSb lattice matched to GaSb substrate covers 1.8-2.4 μm spectral range. Such tunable 1.8-2.4 μm lasers have single mode or quasi- single mode operation in the wide temperature range from 1.6 to 300K. The second type of tunable diode laser based on multiple component InPAsSb/InAsSb lattice matched or mismatched to InAs substrate covers 2.8-3.9 μm spectral range, which was not available for diode laser spectroscopy until nowadays. Such tunable 2.8-3.9 μm lasers have CW single mode operation up to 100K and pulse operation up to 180K. These lasers can be the key devices for diode laser spectroscopy and sensitive detection of pollutants.

2. INTRODUCTION

The diode laser spectroscopy (DLS) is one of the most accurate methods of spectral analysis, which can be applied both for fundamental investigation and for practical using, for example, in environmental monitoring. Near infrared spectral range GaAlAs/GaAs and InGaAsP/InP laser diodes is available for DLS up to wavelength of about 1.7 μm [1].

The semiconductor diode lasers based on A^3B^5 multiple component GaInAsSb and InAsSb solid solutions cover spectral range of molecular overtone and vibrational bands of important pollutant gases and are the key devices for mid-infrared (1.8-3.6 μm) tunable diode laser spectroscopy. Recently, the first experimental demonstration of application of these devices to the ultra-sensitive detection of pollutants such as carbon dioxide CO_2 (00⁰-20⁰ band, $\lambda=1.97 \mu\text{m}$) [2] and methane CH_4 (R-branch of ν_3 band, $\lambda=3.24 \mu\text{m}$) [3] have been made. The high speed p-i-n photodetectors [4] were created for this spectral range.

In this communication we report about the InGaAsSb laser for the 1.8-2.4 μm and the InAsSbP laser for the 2.8-3.6 μm spectral range, which was not available for DLS until recently.

1.8-2.4 μm LASERS

Structures of these types we used for fabricating of the 1.8-2.4 μm lasers (Fig.1). The first one was a conventional DH structure, where 0.2-2 μm thick narrow-gap GaInAsSb active layer was enclosed between the wide-gap GaAlAsSb layers and GaSb top was grown to provide good Ohmic contact (Fig.1a). One or two GaSb

Fig. 1 : Band gap profile of the laser structures. 1 - GaSb; 2 - GaAlSbAs; 3 - GaInSbAs

Fig. 2 : Design of the lasers.

layers were introduced into waveguide region of structures of type II and III respectively. A staggered-lineup heterojunction with the GaInAsSb active layer are formed [5]. The laser structures (Fig.2a) were prepared by Liquid-Phase Epitaxy on an GaSb substrate oriented in (100) plane.

The structures of three types were used to fabricate broad contact lasers (Fig.2a), mesa-stripe (Fig.2b) and substrate-channel buried lasers (Fig.3c). The resonator length was in 200-300 μm range.

The broad contact lasers are multi-mode (Fig.3a), threshold currents are high (1-3 A), but output optical power is about 0.2-1.0 W. For the mesa-stripe (Fig.2b) and buried (Fig.2c) lasers there are usually 1-3 modes in the emission spectra and these lasers are more favorable for the laser diode spectroscopy. Threshold current is in the range 200-600 mA and output optical power is essentially lower and reaches 0.2-1 mW. These values of threshold currents are presented for room temperature. Electroluminescence characteristics of the lasers depended on the internal structure of the devices. The introduction of the staggered-line up heterojunction into the waveguide region resulted in lowering the threshold current I_{th} and made the dependence of I_{th} on the active region thickness weaker (Fig.4). The threshold current was two times lower in these devices comparing with the DH lasers of the same active layer thickness. A unique property of these lasers is the record low threshold current at $T=80\text{K}$. These effects are due to the change in prevailing mechanism of radiative recombination from the bulk to the recombination via

quantum states of the staggered-line up heterojunction.

The important question for many spectroscopy applications is a possibility of CW operating of diode laser at room temperature. We have realized CW operation at room temperature using the structure shown in Fig.1 and the design shown in Fig.2c [6].

The diode laser quality as a coherent light source is quite essential for application in DLS installations. We have measured a linewidth of the GaInAsSb laser operating at 1.8-2.2 μm region [2]. The technique is based on using CO_2 absorption line as a frequency discriminator. The linewidth of the lasers varied from 3 to 60 MHz (see Table 1).

Table 1. The linewidth of the 1.8-2.2 μm lasers.

N	Sample	Design	T, K	I, mA	P, mW	$\Delta\nu$, MHz
1	D307-184	Channeled, buried, Fig.2c	250	120	0.8	66
			120	56	1.1	11
2	S-61-11	mesa-stripe, Fig.2b	90	175	4.0	3.3

This study is the first linewidth measurements of GaInAsSb diode lasers. The study shows that the 1.8-2.4 μm lasers are suitable for high resolution molecular spectroscopy.

2.8-3.6 μm Lasers

In previous publications concerning InPAsSb lasers [7-9] the single mode regime of operation and data of tuning were not reported. In this communication we report about the InPAsSb lasers for the spectral range of 2.8-3.1 μm , which was not available for DLS until recently.

The InPAsSb laser structures were fabricated by LPE on InAs substrates and consisted of two cladding layers of InPAsSb with InP mole fraction 0.25-0.3 and an active layer enclosed between them (Fig.3). The active layer was made either of the InPAsSb solid solution with a lower band-gap or of the InGaAsSb solid solution with a composition closed to InAs. The active layer and the n-type cladding layer were undoped, the p-type cladding layer was doped with Zn. The thickness of the wide-gap layers was about 2 μm and for the active layer it was varied in the range between 0.5-2 μm .

The laser diodes of deep mesa geometry (Fig.2b) were fabricated with a 30 μm mesa width. Cavity length of the lasers L varied from 50 to 900 μm . The threshold current was measured in 77-180K temperature range. At 77K the measurements were made with DC and at higher temperatures with 100 ns current pulses at repetition rate of 5 kHz.

The threshold current of the lasers I_{th} showed typical values 50-300 mA at 77K. Peak emission wavelength varied from 2.8 to 3.6 μm at this temperature in accordance with the composition of the active layer.

The coherent emission spectra of the lasers for a current near the threshold at 77K and 82K are shown in Fig.3b. The lasing usually occurred near the peak of the spontaneous band. The inset

FIG. 3. a) Laser structure and layer profile of the band gap E_g ; b) spectrum of the laser emission for 77 K, and c) oscilloscope traces of the pulses of its radiation passing through air (1) and through a Fabry-Perot resonator (2) for an initial temperature of 80 K.

Fig 4 Output optical power versus current.

Fig 5 Dependence of the Fabry-Perot mode position on current.

(Fig.3b) demonstrates the two modes of lasing. It can be seen that the intensity of the radiation transmitted through an external Fabry- Perot resonator varies sinusoidally with time and that the mode is stable during the more than 300 μ s of the pulse duration with the wavelength λ varying because of heating during the pulse.

The output optical power of the lasers at 82K heatsink temperature was measured by using of the RK-5710 radiometer. Typical dependence of the measured output power (calculated for two facets) is represented in Fig.4. The measurements were carried out without collimating optics in pulsed regime (pulse width: 155 ms, repetition rate: 129 Hz). Taking into account possible radiation losses one can obtain internal quantum efficiency 12-15% for this laser. For CW regime the quantum efficiency was 1.5-2 times lower because of overheating of the devices.

The important parameter for DLS is the shift of a longitudinal mode position with current and temperature. In Fig.5 the moves of the main lasing mode with current is shown for pulsed (pulse width: 200 ms, repetition rate: 129 Hz) and CW regimes. For CW operation, above the threshold the mode position moves continuously to the long wavelength side, in pulsed regime the mode shifts to shorter wavelengths even above the threshold and only at higher currents it moves to the correct long wavelengths side. For the same laser in the short pulses regime (300 ns pulse width) at 220 mA current the modes shifts to the long wavelength side with a rate 0.6 A/K in the heatsink temperature range 82-95K.

First experiments showed that the lasers can be successfully used for DLS and we expect that their parameters will be improved by optimization of the structure and geometry of the devices.

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