SPECTRAL INVESTIGATION OF LASER STRUCTURES USING NSOM EXPERIMENT

Dušan Pudiš[a], Ivan Martinček[a], Jaroslav Kováč jr.[b], Jaroslav Kováč[b,c], Volker Gottschalch[d]

[a] *University of Žilina, Department of Physics, Veľký diel, SK 010 26 Žilina, Slovakia*
[b] *Slovak Technical University, Department of Microelectronics, Ilkovičova 3, SK 812 19 Bratislava, Slovakia*
[c] *International Laser Center, Ilkovičova 3, SK 812 19 Bratislava, Slovakia*
[d] *Fakultät für Chemie und Physik, Universität Leipzig, Linnéstrasse 3-5, 04103 Leipzig, Germany*

Summary We present for the first time the local spectral analysis of quantum well laser devices recorded in the near-field region. The distribution of mode spectra along and across active region was scanned using near-field scanning optical microscopy (NSOM). This experimental technique in combination with the near-field analysis of optical field could be effective optical tool for the final diagnostic of optical waveguide and laser device.

1. INTRODUCTION

Near-field scanning optical microscopy (NSOM) is an exciting class of optical microscopies, which can provide optical resolution better than the diffraction limit [1, 2, 3]. One realization of NSOM uses optical fiber-tip with an aperture that is much smaller than the wavelength λ of the detected light. Typically, an optical fiber is pulled to a small tip (eventually metal coated) with an aperture in the range of 100 nm. This fiber-tip is then placed very close (in order of 10-100 nm) to the sample surface. The application of near-field imaging in combination with spectroscopy to optoelectronic devices and laser diodes provides subwavelength information on a device structure, performance and their output properties.

The emission profile is obtained by coupling the emitted radiation into the fiber-tip moving along the investigated emitter (collection mode). The fiber-tip can be used also as a local tunable optical source exciting (excitation mode) a photocurrent in the near-field region of an investigated structure – near-field optical beam induced current (NOBIC) [1, 2]. The emitted optical field from the front laser facet can be determined using collection mode. When the fiber-tip is placed close (in order of 10-100nm) to the front laser facet the near-field profile of laser diode could be obtained.

Laser devices based on multiquantum well structures became attractive in last decade because of their excellent optical properties. We present here the characterization of multiquatum well laser structure based on GaAs material with InAs monolayers. The spectral mode spectra of laser devices based on this structure as well as band calculations were published in [4]. In this paper we focus on local spectral characterization of InAs/GaAs MQW laser device using near-field scanning optical microscopy as well as the near-field shape. Using of experimental setup based on collection mode the profile of optical field of laser diodes based on multiquantum well structures with InAs monolayers in GaAs in active region was investigated [4].

2. EXPERIMENTAL METHODS

In experiment the optical field of the stripe semiconductor laser diode has been investigated. The quantum well laser diodes based on GaAs material in active region with InAs monolayers were used. The electrical and optical confinement of these diodes consists of p,n-doped $Al_{0.35}Ga_{0.65}As$ layers. On the bottom of the structure the vertical AlAs/GaAs resonator was processed to improve optical properties of laser device. The spectral region of operation of these quantum well laser diodes is in the range of 910-930 nm and FWHM of mode is ~0.2nm [4].

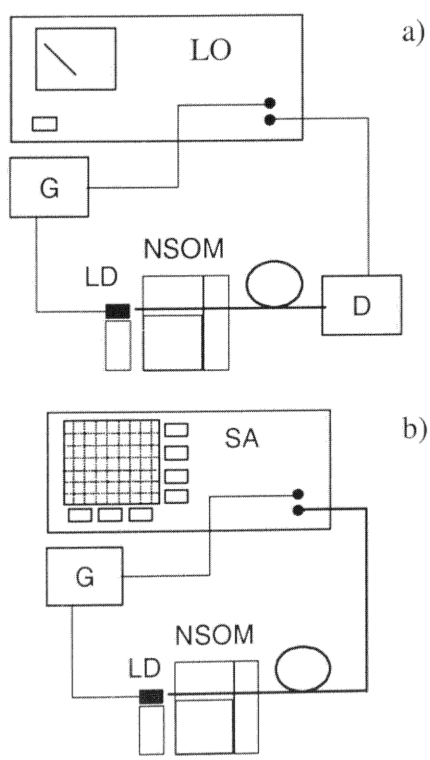

Fig.1 Schema of experiment: a) for near-field shape measurement, b) for spectral analysis. G-pulse generator, NSOM –near-field scanning optical microscopy arrangement, LD-laser diode, LO-Lock- in amplifier, SA-spectral analyzer

The optical near field of laser diode was recorded using optical fiber-tip mounted on 3D mechanical positioning stage (Near-field scanning optical microscopy – NSOM) with step 50nm. The fiber-tip diameter used for field detection was better than 200nm [4]. The fiber-tip was placed <50nm close to the front laser facet. Two experimental setups were used to analyze the near-field shape of laser device and the laser emission spectra:

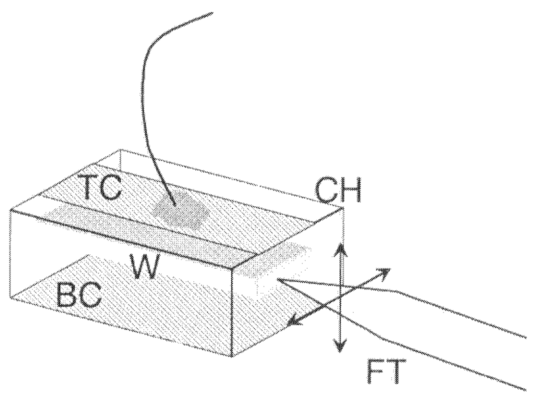

Fig.2 Detail of NSOM experiment on front laser facet. CH –laser diode chip, FT – fibre-tip, TC – top contact, BC – bottom contact, W – gain guided waveguide

i) For the near-field shape investigations of laser diode the experimental arrangement with Si-detector has been used (Fig. 1a).
ii) The spectral analysis measurements were investigated using the spectral analyzer Anritsu HS 9710B with spectral range 0.6-1.7μm (Fig. 1b).
The spectral analysis using NSOM experiment at different positions of fiber-tip on the front laser facet was determined as is shown on detail scheme of experiment (Fig. 2). The laser mode spectrum has been recorded at different driving currents in stimulated emission. For the spectral analysis using NSOM the following advances were used:
i) Mode laser spectrum has been recorded at different vertical positions of the NSOM fiber-tip from the front laser facet. Vertical step of experiment was set to 300nm. Horizontal position fiber-tip was set to get the maximal intensity.
ii) Spectral analysis at different driving currents has been taken at defined vertical positions of fiber-tip.

3. EXPERIMENTAL RESULTS

From dependence of optical power vs. driving current the threshold current I_{th}=40mA has been determined (Fig. 3). The resonator parameters of laser diode are: stripe length d=235μm, stripe width w=22μm.
The mode spectrum as well the near-field shape of stripe laser diode has been investigated using NSOM

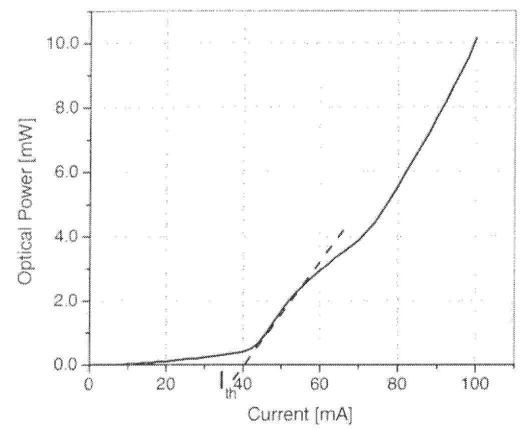

Fig.3 Dependence of optical power vs. driving current with estimated threshold current value I_{th}=40mA

diagnostic and spectral analyzer with spectral resolution 0.07 nm. The measured mode spectrum of laser diode in different vertical position of fiber-tip on the front laser facet with step of record 300 nm is shown in Fig. 4a. For these vertical measurements the horizontal position of fiber-tip was set to obtain the maximum intensity of signal. The corresponding density image of mode spectrum distribution scanned vertically across active region is shown in Fig. 4b.
The peaks in laser mode spectra correspond to longitudinal modes in the Fabry-Perot resonator. Their wavelength separation could be determined from simple approach for Fabry-Perot resonator:

$$\Delta\lambda = \frac{\lambda^2}{2nd}, \tag{1}$$

where λ is the wavelength one of adjacent modes, n is refractive index and d is resonator length (in stripe laser diode d is stripe length). The mode separation of the investigated laser diode for adjacent modes (maximum at wavelength λ=919.8 nm) was determined from measured spectra $\Delta\lambda$=0.5nm. This experimental result corresponds to theoretical calculation $\Delta\lambda$=0.507 nm, following equation (1) and taking into account the waveguide parameters of laser diode stripe (length d=235μm and refractive index of active region $n_{(GaAs)}$=3,55).

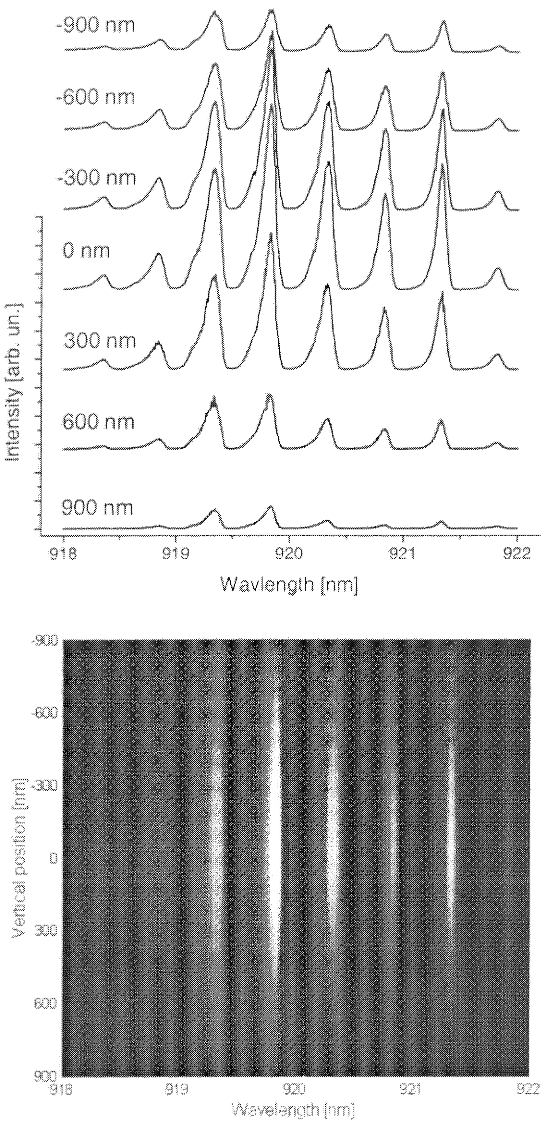

Fig.4 a) Laser mode spectrum at different vertical positions of fibre-tip at driving current I=50mA and vertical step 300nm, b) interpolated density image. Note, zero vertical position doesn't correspond to the middle of active region.

In all range of vertical scanning only longitudinal modes corresponding to Fabry-Perot wavelengths were observed. From these spectral dependencies scanned along vertical axis of active region the near-field profile was calculated as a simple integration in the wavelength range 915-925 nm in all vertical positions. The calculated near-field profile was compared with measured data scanned in vertical direction using Si-detector. Good agreement of near-field profiles obtained using both of methods is shown in Fig. 5. The weak shoulders on solid curve reflect the fiber-tip surface inhomogeneities originated from the technological imperfections of fiber-tip preparation [5].

In all vertical positions the current dependencies of laser mode spectra were measured. Corresponding current dependencies in vertical position +300nm

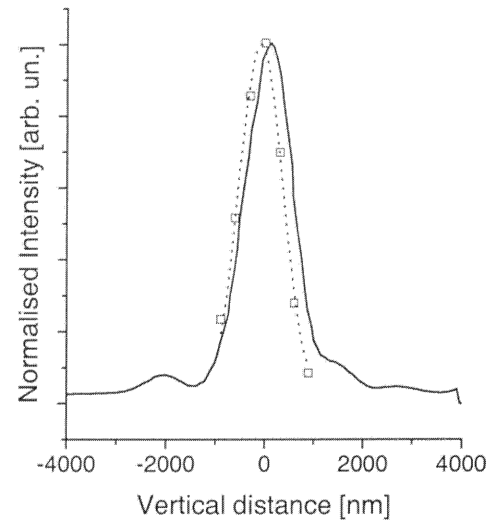

Fig.5 Measured near- field profile of laser diode in vertical direction (solid line) and iIntegrated near-field profile from measured spectral dependencies approximated with Gaussian curve (dash line).

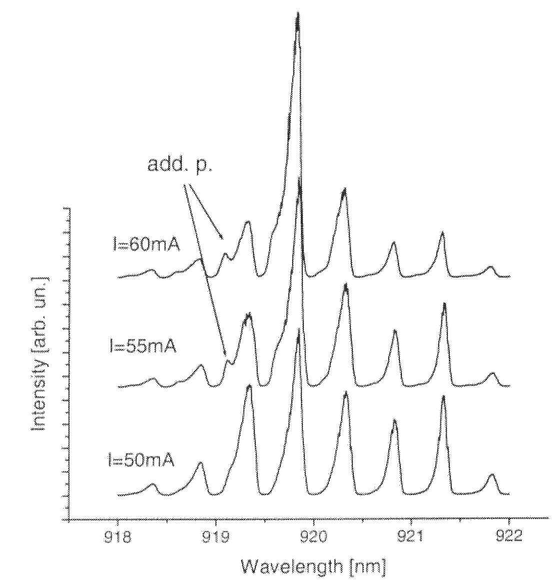

Fig.6 Laser mode spectrum at different driving currents recorded at vertical position +300nm. Additional peaks (add.p.) in spectra are shown.

are shown in Fig. 6. By increasing the driving current the intensity of the longitudinal mode at 919.8 nm increases while the intensity of other modes lightly declines. In these current dependencies the additional peaks (add.p.) have been observed. Their positions in spectral dependencies do not correspond to the longitudinal Fabry-Perot resonator wavelengths. Their behavior as well as their origin will be subject of forthcoming investigations. We suppose their relation with lateral modes of planar waveguide. We believe, that the spectral analysis using NSOM diagnostic in the horizontal direction could reveal more about their origin.

4. CONCLUSION

To our knowledge we employed the local spectral analysis with NSOM diagnostic for the first time as the optical tool for the near-field characterization of laser devices. This method shows the intensity as well as the spectral distribution in different positions of the NSOM fiber-tip in the laser near-field. These results could reveal the longitudinal and lateral modes behavior and could give the complex waveguide characterization in the stripe laser device.

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