Study of Near-Field Emission of Semiconductor Laser

K.P.Gaikovich, **V.F.Dryakhlushin, V.V.Levichev*, V.P.Mishkin***

Institute for Physics of Microstructures RAS, Nizhny Novgorod,GSP-105,

Russia, 603950. E-mail: gai@ipm.sci-nnov.ru; phone: (8312)675037; fax: (8312)675553

***Nizhny Novgorod State University**

Results of the study a thin near-field structure of semiconductor laser emission using near-field optical microscopy (SNOM) are presented. In contrast to papers in this area [1-3] we have achieved a higher resolution that makes it possible to observe details with sizes of about 50 nm, which are most likely related to nano-scale inhomogeneities of emitting laser surface. To achieve such a resolution a small-aperture probe [4] has been used in a SNOM system. The microscope resolution is determined by the size of the probe aperture (~50-100 nm), which is much smaller than the wavelength of light. To obtain yet better resolution, measurements results have been processed further taking into account the probe transfer function.

This processing used results of our previous work [5], where image deconvolution method has been developed to restore SNOM images distorted by the probe transfer function influence. Under this influence the smoothing of the real picture takes place. If the transfer function is known (even approximately), it is possible to consider the inverse problem of the image rectification. This problem consists of the solution of integral Fredholm equation of the 1-st kind of 2-D convolution type, which is known as ill-posed problem. In [5] an algorithm based on Tikhonov's method of generalized discrepancy has been worked out. If a 2-D distribution of SNOM signal is measured, then it can be (at least, approximately) expressed as 2-D convolution of true distribution and probe transfer function:

$$z_{\mathrm{m}}(x,y)=\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}K(x-s,y-t)\mathrm{z}(s,t)\,dsdt \qquad (1)$$

where the kernel $K(w,W)$ is the transfer function, $z_{\mathrm{m}}(x,y)$ is the measured signal, $z(s,t)$ is the true distribution to be found. The solution of (1) relative to $z(s,t)$ make it possible to retrieve the surface image with a higher resolution.

The key part of the approach developed in [5] is a method of determination of the transfer function in (1) from the image of a structure that contains small (much less than the size of aperture) details. These details can be considered as δ-function, so one has from (1) $z_m(x,y) = K(x,y)$. The probe transfer function has been determined from the analysis of a test structure (thin vanadium film (<10 nm) on the quartz partially etched to the substrate), and it was obtained that the corresponding kernel can be well approximated by the 2-D Gauss distribution with half-width parameters $\sigma_x = \sigma_y = \sigma \cong 70$ nm. The achieved (after the deconvolution) resolution $\sigma_r \cong 20$ nm has been determined by the smallest details of the retrieved image, or about 0.045 of the SNOM wavelength.

Using SNOM microscopy and image deconvolution the semiconductor injection laser with quantum walls has been studied. It has a current threshold of 0.5 A, quantum efficiency of 27% at power of 0.2 W on the wavelength λ=961 nm. The laser scheme is shown in Fig.1.

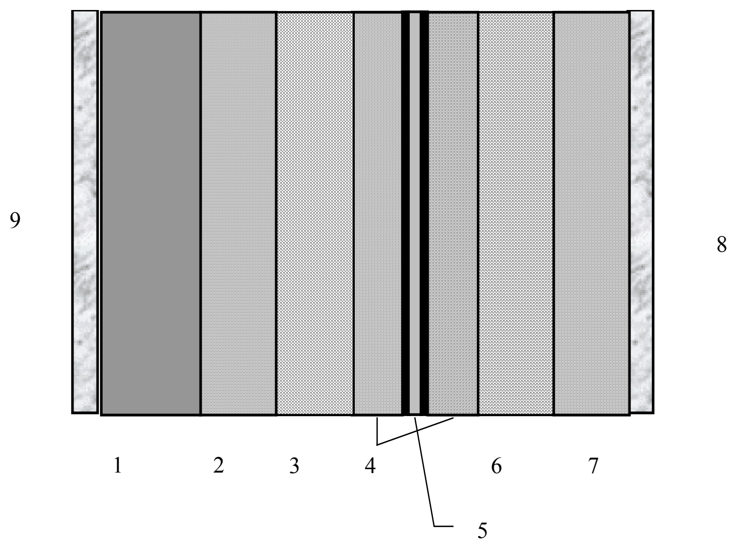

Fig.1. Structure of the laser. 1 – substrate n^+ - GaAs, 2 – buffer layer GaAs (550 nm), 3- bounding layer n - InGaP (500 nm), 4 – waveguide layers GaAs (300 nm), 5 – active region consisting of two quantum walls InAs (8 nm) and separating layer GaAs (80 nm), 6 – bounding layer p – InGaP (500 nm), 7 – contact layer p^+ - GaAs, 8,9 – ohmic Au contacts to n and p – type of GaAs respectively.

The InGaAs/GaAs/InGaP structure of laser has been grown by hybrid MOC epitaxy at atmospheric pressure on GaAs substrate directed along the crystal plane (100). After the growth, using the photolithography method, the mask was deposited in the form of strips of 100 μm width with a period of 400 μm directed along the crystal direction ($1\bar{1}1$). Outside the stripes, the contact layer of GaAs was etched, then these regions were isolated using implantation method of H^+ ions at energy about 100 keV. Thus, the working width of the active region of the laser consisted 100 μm. Afterwards, the mask was removed, and, using the method of vacuum sputtering, Au contacts were created. The plate was split into bars of 500-100 μm in width in the direction (100) transversely to the strips. The split off edges were then in use as resonator's mirrors. These mirrors were covered, using the electron-emitting sputtering in vacuum (one edge - by a multi-layered reflective cover with the reflection coefficient R_1>95 %; another – by quarter-wave film with R_2 = 5%). The bars were divided to separate laser chips, each of them giving only one active stripe.

Results of SNOM measurements in collection mode of the near-field (the probe-surface distance $h \leq 5$ nm $<< \lambda$) laser emission are shown in Fig.2 (left). There are small (practically invisible) spatial variations in this image, but taking into account the averaging over the probe transfer function footprint, after the image deconvolution, we have obtained the true emission distribution shown in Fig.2 (right). The variation in this reconstructed image are much more pronounced (about 3-4%). The size of the spatial variation of the laser emission is about 50 nm and these variations are most likely related to nano-scale inhomogeneities of the emitting surface

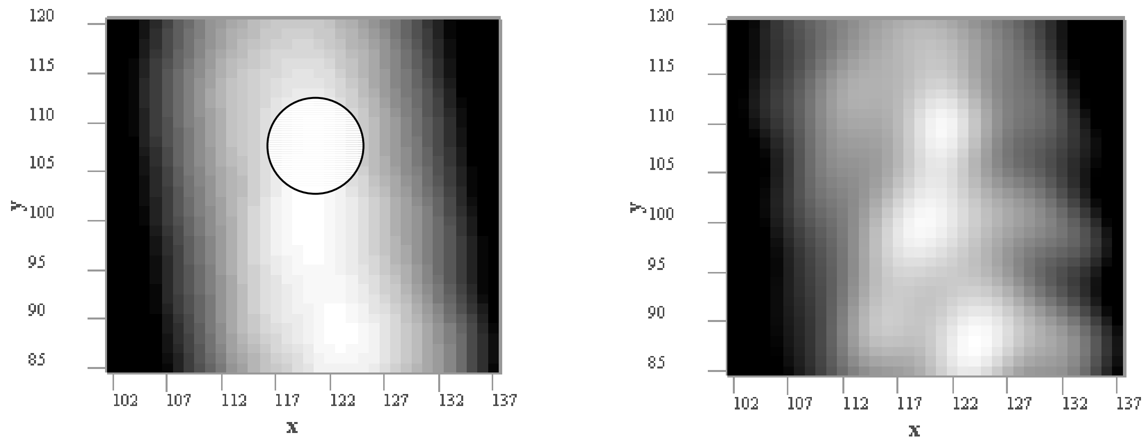

Fig.2. Initial (left) and reconstructed (right) SNOM-images of near-field laser emission. Circle in the initial image marks the probe pattern footprint. The pixel size is 16 nm.

This work was supported by the RFBR, grant *No*. 03-02-17321.

References

1. J.Kim, J.T.Boyd, H.E.Jackson, K.D.Choquette. Near-field spectroscopy of selectively oxidized vertical cavity surface emitting lasers. Applied Physics Letters, 2000, vol.76, *No*.5, pp.526-528.
2. D.K.Young, M.P.Mack, A.C.Abare, and al. Near-field scanning optical microscopy of indium gallium nitride multiple-quantum-well laser diodes. Applied Physics Letters, 1999, vol.74, *No*.16, pp.2349-2351.
3. J.Kim, D.E.Pride, J.T.Boyd, and H.E.Jackson. Spectrally-resolved near-field investigation of proton implanted vertical cavity surface emitting lasers. Applied Physics Letters, 1998, vol.72, *No*.24, pp.3112-2351.
4. V.F.Dryakhlushin, A.Yu.Klimov, V.V.Rogov, and S.A.Gusev, A probe for a near-field scanning optical microscope. Instruments and experimental techniques, vol.41, No.2, pp.139-139, 1998.
5. Gaikovich K.P., Dryakhlushin V.F., Kruglov A.V., and Zhilin A.V. Rectification of SNOM-images taking into account the probe transfer function. Physics of Low-Dimensional Structures, 2002, vol.5/6, pp.93-98.