Near-field Analysis of Beam Properties of InGaAs Ridge Lasers

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We report mode structure and beam propagation analysis of high power strained (In,Ga)As quantum well lasers using the super-resolution capabilities of near-field scanning optical microscopy (NSOM). We are able to directly measure the optical beam waist and astigmatism by imaging the output of the laser diode at various heights above the device facet. In the near-field we observe spatial shifts in the position of the optical field between different spectral components of the laser diode emission.

Near-field scanning optical microscopy and spectroscopy (NSOM) is a recent technique [1], where an aluminum coated tapered optical fiber probe is placed within a fraction of a wavelength of a sample and scanned over the surface [2]. The tapered single-mode optical fiber provides a tiny aperture through which the light is coupled providing a spatial resolution slightly less than tip size (∼100 nm). In collection mode spectra can be obtained by coupling the collected signal to a monochromator. The fiber tip, used in excitation mode, provides a local optical source allowing for near-field optical beam induced current (NOBIC) measurements. The application of near-field spectroscopy and imaging to laser diodes provides sub-wavelength information on device structure, performance, and beam properties [3,4].

In our measurement setup, the laser diode is mounted facet up on a piezo actuated flexure stage and scanned in the $\hat{x} - \hat{y}$ plane beneath the probe tip which is at the focal point of a reflecting objective on a metallurgical microscope. Simultaneous shear-force topography is used to control the tip height $z \sim 10$nm in both excitation and collection modes.

We studied high power strained (In,Ga)As graded-index separate confinement heterojunction (GRIN-SCH) laser diodes [5] These devices emit at 980 nm and are designed to pump Erbium doped fiber amplifiers. The structure consists of a single InGaAs quantum well sandwiched in a symmetrical waveguide of graded AlGaAs cladding layers. The cavity facets are dielectric coated for front and rear reflectivities of 0.1 and 0.9, respectively.

Figure 1 shows an image of the sample topography and the laser emission as measured in the near-field. The laser mode intensity is plotted as contours superimposed on the topographical image of the laser facet and mesa structure. The metal contact on top of the mesa slightly protrudes over the facet of the device. This image is typical of the mode structure of the device up to 200 mA. The laser emission profile is centered under the mesa and over the active region as determined by NOBIC measurements [4]. Slight distortion at the edge of the emmision profile is believed to be due to the deep mesa etch.

Figure 2 is a series of images of the laser mode intensity collected with the near-field probe at various heights above the laser diode facet. The first image was taken in the near-field ($z \sim 10$nm). Each successive image is 1μm further from the facet with the last image at 7μm from the surface. From this series of scans we measure the variation of the spot size of the mode along the optical axis. Figure 3 shows the spot size measurements (where the intensity has dropped to 1/e of the maximum value) as determined by fitting the intensity profile with Gaussians in both lateral and vertical dimensions as shown by circles and squares, respectively. On the same figure, solid lines show the fits of the spot size variation along the optical axis to a propagating Gaussian beam. The fit for the vertical axis makes use of a beam waist derived from the asymptotic divergence angle of the optical field [illegible] nimum waist

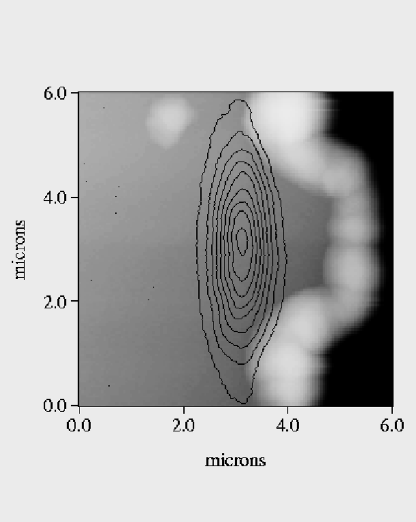

Fig. 1. Near-field collection mode image of the GRINSCH laser diode emission intensity (contours) superimposed on the topographical shear-force image (grayscale).

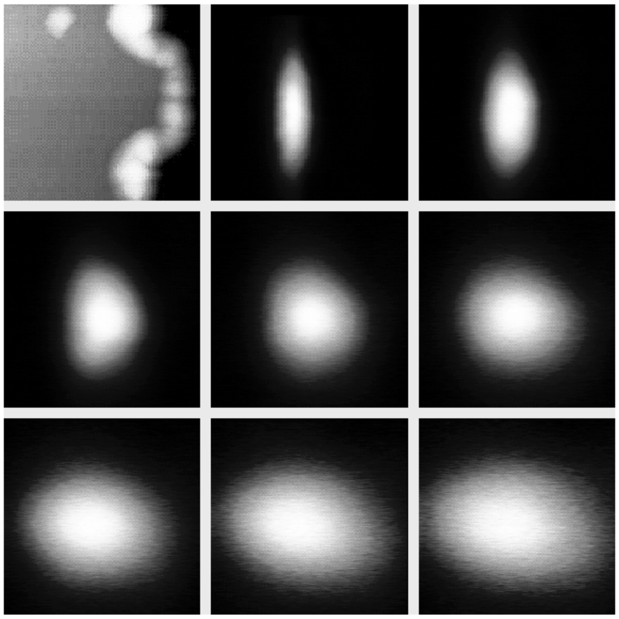

Fig. 2. Image of the mesa structure as recorded by shear-force and images of the beam propagation from the near-field to 7μm from the laser diode.

position and the confocal parameter are the parameters. The derived confocal parameter matches closely with that expected from the beam waist for a Gaussian beam. For the lateral dimension, the beam waist, its position, and the confocal parameter are the variables. We observe a monotonically diverging beam along the vertical dimension. The position of the vertical beam waist is extrapolated to be approximately 0.5μm below the facet. The beam profile in the lateral dimension (in the plane of the layer structure), however, exhibits a minimum in the waist diameter at approximately 3μm from the facet. The derived values for the lateral beam waist and the confocal parameter suggest a non-Gaussian profile as observed in the near-field. This measurement of the beam waist represents, to the best of our knowledge, the first direct measurement of laser diode astigmatism by NSOM.

We have also carried out spectral measurements on these laser diodes. At high currents (> 200 mA), we observe longitudinal modes in several groups. These sets of longitudinal modes are believed to correpond to different transverse modes [4]. Near-field analysis of the spatial distribution of these spectral features reveals $\mathrm{TEM}_{0,0}$–like mode shapes for each of these spectral components. While all of the components of the lasing spectrum have similar profiles, a spatial shift of the peak position of these modes is clearly observed. Figure 4 shows the lateral profiles of three simultaneously lasing components.

In conclusion, we demonstrate a direct method for measuring the beam propagation and waveguiding properties of high power ridge laser diodes. Beam waist and astigmatism measurements are made by imaging the beam from the laser facet in the near-field and at multiple points along the optical axis outside the laser cavity. In the near-field, spatial shifts in the location of the lateral position of the mode are measured for multiple spectral features.

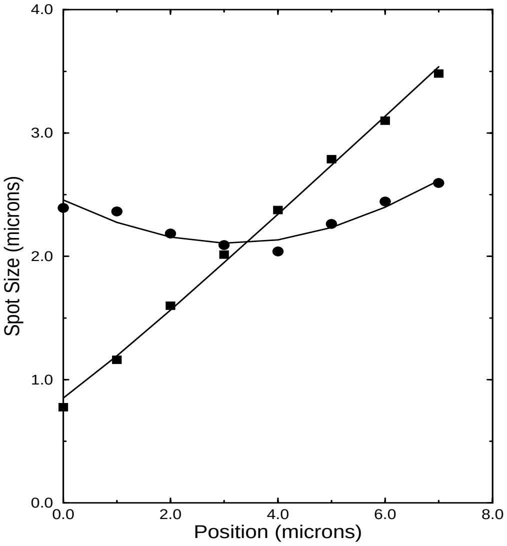

Fig. 3. Experimental measurements of the lateral (circles) and vertical (squares) spot size dependence on position. The solid lines represent fits to the data assuming Gaussian beams.

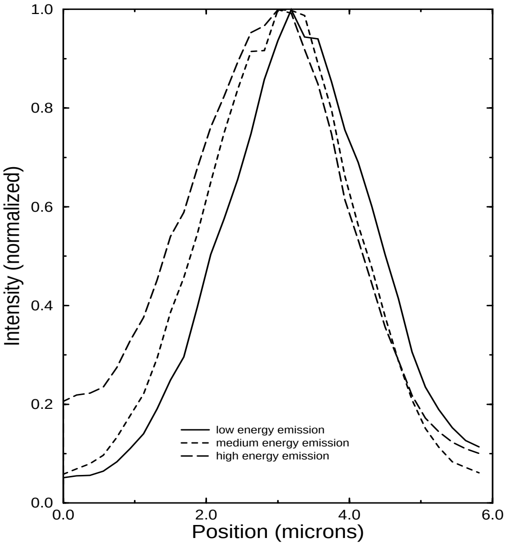

Fig. 4. Lateral profiles of simulataneously lasing components obtained by integrating the spectra over three different wavelength regions at every spatial point. A shift in the peak position is clearly observed for different spectral components.

References

[1] U. Durig, D. W. Pohl and F. Rohner, *J. Appl. Phys.,* vol. 59, p. 3318, (1986)

[2] E. Betzig and J. K. Trautman, *Science,* vol. 257, p. 189, (1992)

[3] M. Isaacson et al., *J. Vac. Sci. Technol.,* B 9, p. 3103, (1991)

[4] B. B. Goldberg et al., *IEEE J. Select. Topics in Quantum Electron.,* vol. 1, p. 1073, (1995)

[5] G. Hunziker et al., *Applied Optics,* vol. 34, p. 6118, (1995)