# Layer Composition and Mode Structure Analysis of Heterojunction Laser Diodes by Near Field Scanning Optical Microscopy

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We report mode structure and layer composition analysis of high power strained (In,Ga)As lasers using the super-resolution capabilities of near field scanning optical microscopy (NSOM). The lasers are designed to pump Erbium doped fiber amplifiers in a configuration optimized for a single transverse laser mode. At high current levels, coupling efficiency decreases due to broadening of the spot size and the onset of multiple transverse modes. Sub-micron collection mode imaging and spectroscopic mapping of the emission mode structure as a function of laser pulse length and current easily identify a regime of operation where multiple transverse modes are observed. The evolution of multiple transverse modes coincides with a kink observed in the L-I curve. Near field microscopy enables the mode profile and spectral image to be correlated with the layer structure of the device with 100 nm resolution.

NSOM is a recent technique [1] where a tapered optical fiber probe of aperture size $a$ <100 nm is controlled in close proximity ($z \sim 10$ nm) to a sample and scanned over the surface. Characterization of materials can also be performed by near field optical beam induced current (NOBIC) measurements where the tip provides local excitation. In collection mode, the laser diode is driven with a pulse generator and the emission collected in the near field by the tip. In NOBIC, a tunable laser provides excitation through the tip and the diode is reverse-biased to monitor the photocurrent. Topological imaging and height control are achieved by shear-force techniques. These images enable the spatial alignment of NOBIC, mode profile, and spectroscopic scans for the correlation of the compositional layer structure with the intensity and spectral profile of the laser emission.

We studied strained (In,Ga)As graded-index separate confinement heterojunction (GRINSCH) laser diodes. NOBIC is used to identify the active region and surrounding mesa structure and the collection mode emission profile can then be correlated to the actual device structure. At low current levels, the emission profile indicates a single transverse mode that peaks in the active region and is centered under the mesa. Spectra of the laser diode emission for the low current levels shows multiple longitudinal modes around 976 nm. When the power is increased (I=260mA) a kink in the L-I curve is observed along with the appearance of a second transverse mode in the spectra at lower energy (~980 nm). The near field images of the mode profile for varying current levels clearly show the broadening of the spot size and deformation of the Gaussian shape corresponding to the onset of multiple transverse modes. We have also determined the dependence of NSOM resolution on excitation wavelength and its limitations for studying heterostructure optoelectronic devices.

In conclusion, NSOM is able to correlate layer composition directly with local optical properties and thereby provides a valuable diagnostic and analytical tool for laser diodes. Further studies involving spectral imaging to identify the profile of individual transverse modes will provide detailed information of the mechanisms of multi-mode operation.

[1] E. Betzig, J. K. Trautman, T. D. Harris, J. S. Weiner and R. L. Kostelak, *Science*, 251, p. 1468, (1991)

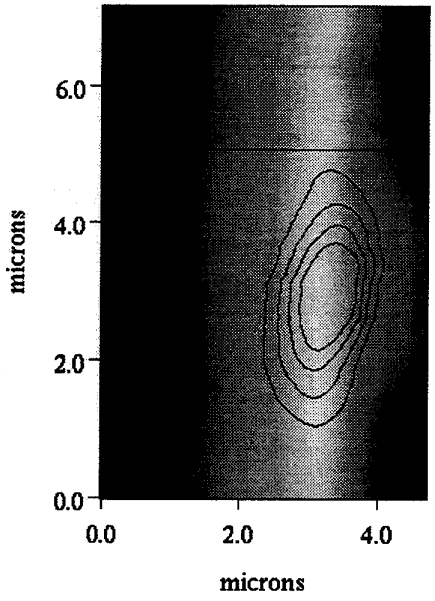


Fig. 1. Collection mode emission profile superimposed as contour lines on near field optical beam induced current (NOBIC) image. Substrate is to the left, and the mesa (to the right) can be seen since the GaAs cap layer responds weakly to the excitation.

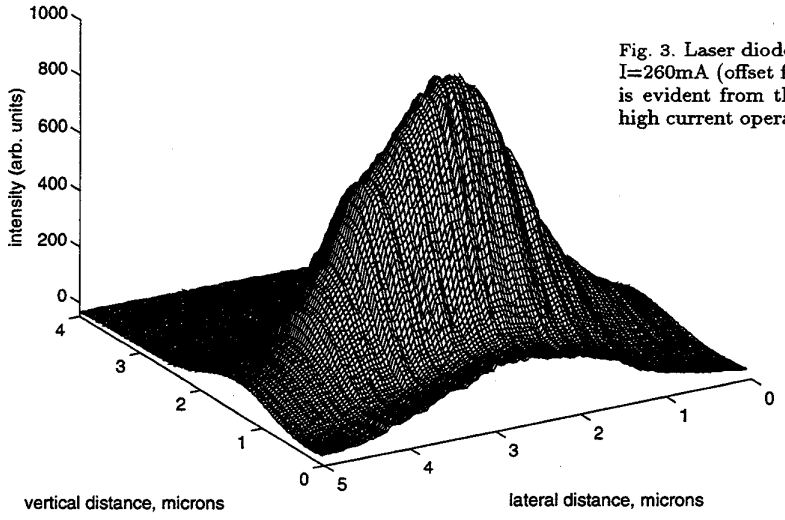


Fig. 2. 3-D image of the laser diode mode profile at high power. Vertical distance is measured from the substrate to the epi-surface, and horizontal distance is along the device mesa. The intensity profile is deformed from the Gaussian shape observed at low power providing evidence and information on higher order transverse modes. We also observe mode leakage into the substrate.

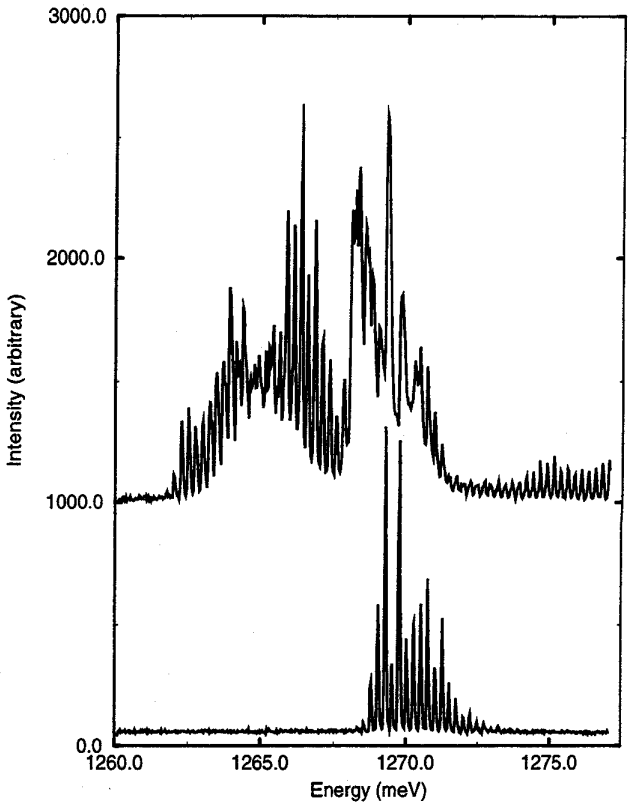


Fig. 3. Laser diode emission spectra for (bottom) I=30mA and (top) I=260mA (offset for clarity). The second transverse mode operation is evident from the low energy collection of longitudinal modes in high current operation.

This research was supported by the National Science Foundation under the grant Nos. ECS-9309607 and DMR91-58097, and by ONR grant No. N00014-93-1-1186.