Optical near-field probe action in microdisk laser with 0.12\(\lambda\) resolution

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Near-field probe action in a 1.55\(\mu\)m GaInAsP/InP microdisk injection laser is demonstrated. A high spatial resolution of 190nm was determined by using a sharp Pt-Ir needle as a target object. It was nearly 0.12 times the lasing wavelength.

The optical near-field probe sensor has attracted much attention since it allows the fluorescence spectroscopy of nanometre objects such as quantum dots, genes, etc., with resolution unlimited by optical diffraction\[1\]. Its use as a read/write head in an optical memory with ultra-high density storage of the order of Tbit/inch\(^2\) is also envisaged. A sharpened singlemode fibre is used as a probe; the fibre is coated with a metal film having an aperture smaller than the wavelength of light. The fabrication technique of such fibre probes has been well established\[2\] and the probe sensor system is now commercially available. However, this technology still has the problems of low signal-to-noise ratio and difficulty with high speed sensing and/or scanning. The parallel sensing by arrayed probes is effective for improving the speed. However, fibre probes are difficult to integrate. An integrated probe composed of arrayed holes on a silicon substrate has been proposed and its probe action has been experimentally demonstrated\[3\]. However, the integration of light sources and detectors seem to be difficult for this structure. To solve these problems, we have proposed an active near-field probe for which a semiconductor microdisk laser is directly used as a probe tip\[4\]. The microdisk laser is a kind of whispering gallery (WG) mode laser, which allows useful reductions of size and threshold\[5\]. It is well known that the WG mode spreads the evanescent field out of the disk edge. If the evanescent field is scattered by a neighbouring object, then the threshold current is increased and thus the amount of laser light is decreased even with a constant injection current. The probe function originates from the laser light modulated according to the shape of the object. The resolution of the disk probe was theoretically estimated to be 0.17\(\lambda\), in the direction normal to the disk plane, where \(\lambda\) is the lasing wavelength\[4\]. In this study, we have experimentally confirmed this probe action and estimated a high resolution almost comparable or even superior to the theoretical value.

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and detected by the fibre. This increase will be suppressed by detecting the light just behind the disk against the needle.

Fig. 2b shows the response against the needle with a tip radius of 50nm. The FWHM was as small as 160nm. This value is almost comparable or slightly superior to the theoretical value 220nm, as shown by the thick curve. It is seen from theoretical calculations that the probe resolution according to Rayleigh’s definition is 1.20 times the FWHM of the response. Applying this relation to the observed FWHM, we estimated the probe resolution to be 190nm. This value is 0.12 times the lasing wavelength of 1.547μm.

We considered reasons why the resolution was greater than the diffraction limit. An obvious reason is that the equivalent refractive index of the laser mode is nearly 2.65, which simply reduces the wavelength in the cavity. In a similar way, the solid immersion lens gains a resolution higher than the diffraction limit. However, it was already taken into account in the theory. Another reason is the dynamic change of the orbital length of the laser mode in the disk, which was not taken into account. We observed the blue-shift in lasing wavelength when the needle was moved towards the disk. The shift is almost proportional to the decrease in laser mode intensity, as shown in Fig. 3. This indicates that the orbital length is dynamically changed by the needle. We expect that this effect sharpened the response and further improved the resolution.

In conclusion, we have experimentally demonstrated optical near-field probe action in a microdisk laser, for the first time, with a resolution of 0.12λ. If we fabricate such a laser using a 400nm-InGaN/AlGaN material system, the probe resolution will be nearly 50nm. Another method for improving the resolution is to coat the disk with insulator and metal films and open a small aperture, as is usually done for fibre probes. We expect this kind of probe to be used in ultra-high speed sensing, since it can easily be integrated at the edge of the substrate in the array configuration.

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References