Near-field Scanning Optical Microscopic Studies of Micro-ring Resonators

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Abstract **– Near-field Scanning Optical Microscopy has been used to measure internal optical modes in channel waveguides and ring resonators. The period of the observed standing modes is a direct measure of the effective index.**

Keywords **– integrated optics, near-field scanning optical microscopy, channel drop filter, ring resonator**

In the near future, large scale integrated optical systems with densely packed simple optical components will constitute the building blocks of optical communications networks and signal processing circuits. These all-optical circuits are faster, more scalable, and potentially less expensive than their hybrid electrical/optical analogs since there is no need to perform optical to electrical conversion. Precise modeling and exacting fabrication of dielectric structures are necessary to build the next generation of integrated optical systems. Also essential are new techniques for accurate characterization of such optical systems, from the most basic building blocks like simple channel waveguides to novel structures such as micro-ring resonators for wavelength division multiplexing.

Transmission measurements give global information about the entire device and as such are very suitable for determining qualitative device performance. Unfortunately, transmission and reflectivity measurements are not very effective for diagnostic purposes, since the cause of most device problems are local and microscopic within the device. It is therefore essential to develop a way of probing internal spatial modes within these guided-wave devices. In this paper, we will show that near-field scanning optical microscopy can be used to measure internal optical intensity within both basic and novel guided-wave structures. We will show that this method has a number of advantages over other methods, including the ability to distinguish scattered from guided light and determine the vectoral components of the wavevector, all with a minimum amount of perturbation.

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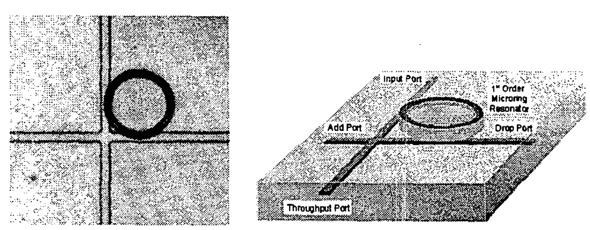
Near-field scanning optical microscopy[1,2] (NSOM) raster scans a tapered single-mode fiber optic[3] serially, building up a high-resolution image of a sample. The aperture in the tapered fiber is much less than the wavelength of light, and therefore, when scanned in close proximity to the sample, yields an image with resolution better than the diffraction limit. The earlier development of NSOM has targeted applications where ultra-high spatial resolution was required. More recently, NSOM has been recognized as a tool to study evanescent fields to obtain otherwise inaccessible information about guided-wave optical systems. NSOM studies of waveguides have demonstrated evanescent field decay[4], standing modes[5,6], and recently observed a modulation in the propagation direction[7] due to the Tien effect. Studied of more complicated devices have included directional couplers[8] and star couplers[7]. We have demonstrated the first modal characterization of single mode optical waveguides with direct measurements of propagation vector components and standing wave structures[6].

The device studied here, shown in Fig. 1, is unique in that the ring resonator is vertically coupled to the bus waveguides.[9] The devices employ cross-bus waveguides, which provides for easy cascading in a 1xN or NxN geometry in a very small wafer area.[10] Lastly, these microring resonators are fabricated in a low-index material system, which is better matched to silica fibers and is more forgiving of sidewall roughness.

A schematic of our setup is shown in Fig. 2. A lensed fiber is used to launch light from a tunable external cavity laser into the guided-wave device under study. Transmitted light at the exit facet is imaged onto both a CCD for optimizing coupling and a Ge photodiode for qualitative measurements.



(a) (b)

Fig. 1. (a) Optical Micrograph of a glass micro-ring resonator and buried crossed bus waveguides. (b) Schematic of device structure showing the buried waveguides and identifying the various ports.

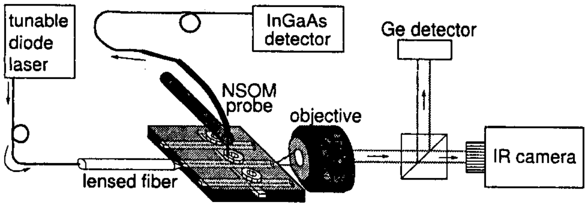


Fig. 2. Experimental setup used for characterizing internal optical fields inside guided-wave devices. Light from tunable laser is launched into the device under test, and the transmitted light is analyzed. The NSOM probe is scanned over the surface of the device, measuring topography and sampling the evanescent field.

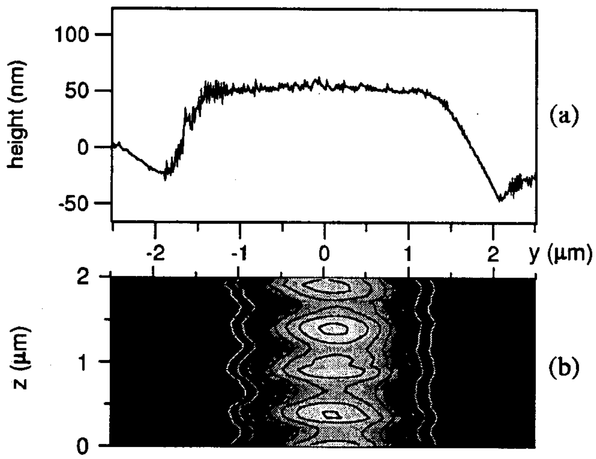


Fig. 3. (a) Line-scan of the surface topography across the waveguide, showing ridge at surface due to buried waveguide. (b) Optical image obtained at the surface of the waveguide when TM modes are excited. The period variation in the *z*-direction is a standing mode due to the cavity forms in the waveguide. A line-cut for *y=0* exhibits almost pure sinusoidal behavior, with a peak-to-valley ratio of 1.2.

In Fig. 3(a), a slight ridge in the surface of the waveguide is observed due to the buried waveguide. When TM modes are excited by controlling the input polarization, we obtain the image shown in Fig. 3(b). The dependence along y of the measured optical intensity is consistant with a single mode waveguide. The periodic variation in the z-direction is a standing wave due to the cavity formed between the entrance and exit facets of the waveguide. The period if the standing mode is given by $\lambda_0 / 2\ n_{eff}$, where λ_0 is the vacuum wavelength and n_{eff} is the effective index for the guided optical mode. The measured $n_{eff} = 1.458$ compares very favorably with simulations which yield $n_{eff} = 1.473$.

To study the ring resonator itself, we use a multimode large core fiber to collect light coming out of the drop port. This allows us to monitor both the thru and drop port simultaneously with the NSOM scans. Fig. 4 shows normalized transmission spectra from these two ports.

We will show new NSOM data of the ring resonator, showing standing modes in the ring, which is unexpected considering the travelling-wave nature of the device. However, we will show that these standing modes are, in fact, easily explained, and are due to the standing mode in the waveguides that are used to couple light into the ring. We will show this using a new standing wave spectroscopy technique, which identifies reflectivties within guided-wave strucutres by studying the behavior of the standing modes as a function of wavelength.

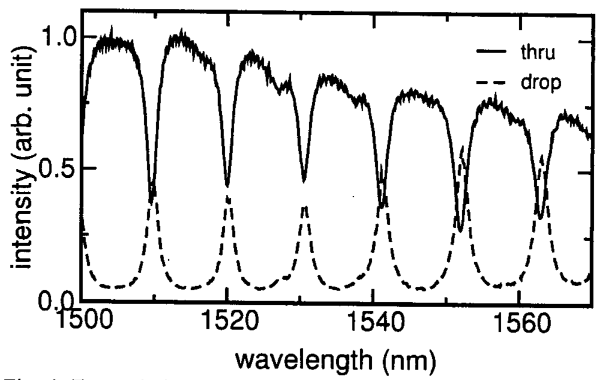


Fig. 4. Transmission spectra through the ring resonator, showing signal at the thru port (solid) and the drop port (dotted) when light is launched into the input port. The slight drop in the transmission at longer wavelengths is due to the lower responsivity of the Ge detector used.

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