ULTRA-HIGH FINESSE POLARIZATION-MAINTAINING FIBER RESONATOR

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ABSTRACT

Recent measurement of a previously described fiber optic resonator using a new technique yielded significantly higher finesse values than were previously thought. The resonator is a spliceless, lapped optically contact bonded type, fabricated with polarization-maintaining fiber. Using a highly coherent laser source, and FM spectroscopy techniques with closed-loop laser and ring stabilization, accurate line width and free spectral range values may be obtained. The theory of the technique is described, and the experimental setup is used to measure finesse of several resonators. Using this technique, finesse of one of the resonators was measured to be in excess of 1000.

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ABSTRACT

In development of the fiber optics resonant ring gyro it is important to measure the fiber ring linewidth to high accuracy. This short paper introduces a fast and accurate method for measuring of the resonator linewidth and its free spectral range. Using this technique polarization preserving fiber resonator with finesse of 1045 was measured.

INTRODUCTION

The fiber optic ring resonator is an important component for the fiber resonant ring gyro development. It is made of a resonant ring, wound of optical polarization preserving fiber and a high coupling ratio coupler as illustrated in Figure 1. The fiber endfaces are polished at an angle to minimize backreflections, which would form a Fabry-Perot cavity and unwanted modulation.

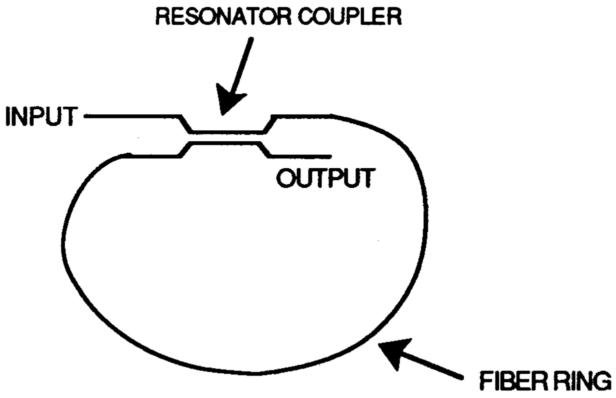

Figure 1. Polarization Holding Fiber Resonant Ring

The fiber type used for the fiber ring fabrication was Hitachi polarization preserving single mode fiber operating at 1.55 µm. The fiber ring coil was wound on a 3 inch diameter spool.

FIBER RESONANT RING

The resonator coupler was fabricated by refining the lapped block method[1]. The optical fiber resonator is fabricated by imbedding the pigtails of a 20 meter fiber coil into special glass blocks. The blocks on opposite ends of an optical fiber are configured after lapping such that the nearly 100 % coupling is achieved between the two fibers resulting in a spliceless resonator.

In order to fabricate the resonator from the polarization holding fiber or any other high birefringent fiber it is necessary to align the principal axes of the coupled fibers. The principal axes of the birefringent fiber are aligned to the surface of the block before bonding in the groove. The polarization alignment system, depending on the fiber, is capable of axis alignment to better then 0.5 degree which is demonstrated by couplers made with low polarization cross coupling (-40 dB). It is important that the selection of fiber and subsequent processing is done such that there is minimum principal axes rotation during fiber-block structure polishing. As the blocks (coupler halves) are polished, successive oil drop tests[2] are performed to determine the distance between the fiber core and the polished surface. When the oil drop test indicate ≈15 dB loss the two coupler halves are polished to the proper distance from the fiber core giving specific coupling.

The optical coupling between the two fibers is set such that the optimum resonant condition is achieved. This is achieved when the (fiber and coupler) insertion losses are matched with the coupling ratio of the coupler. At resonance the amplitude of the optical wave recirculating in the ring builds up because its phase is matched to that of the coherent ring input wave. The output from the coupler is near zero at resonance, since the noncoupled wave and recirculating wave are of opposite phase and destructively combine, effectively canceling each other. In an off resonance condition the output from the ring coupler is at maximum; the recirculating wave and ring input wave have relative phase that prevents the recirculating wave from building up.

When the proper coupling ratios are achieved on each coupler half they are ready for bonding. Optical-contact-bonding, widely used in the attachment of ring laser gyro mirrors and other optical components, occurs when two similar surfaces are brought into intimate contact with one another. If surface flatness, roughness, and cleanliness are sufficient, Van der Waals and other surface molecular forces draw the blocks together forming essentially one piece, resulting in a negligible index layer between the two optical fiber waveguides. This is very rugged, hermetic bonding method.

MEASUREMENT TECHNIQUE

In order to accurately and repeatedly measure a fiber optic ring resonator performance, a technique is used that is referenced to an accurate standard. The optical source used for this measurement was an externally stabilized HeNe gas laser operating at 1.52 μm with low 1/f noise measured by self-heterodyne technique (linewidth less then 5 kHz). The optical source provides a coherent optical beam to an integrated optical chip (IOC) phase modulator via an optical isolator (-50 dB) as illustrated in the Figure 2.

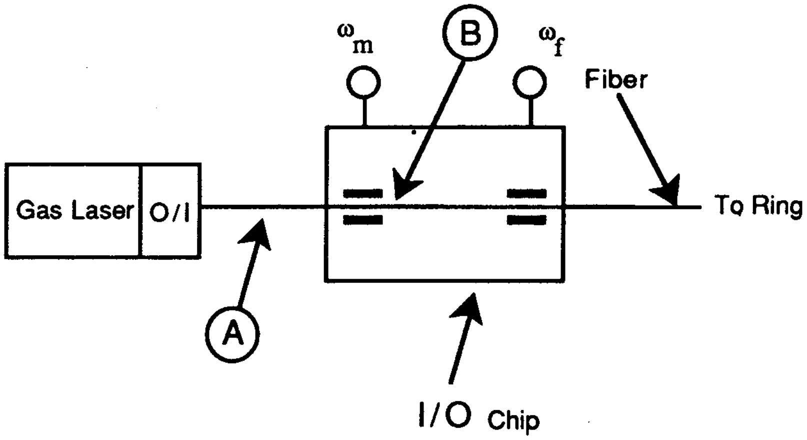

Figure 2. Probe Generation Optics

The coherent laser beam at reference point A is phase modulated at frequency ω_m (which is approximately 1/10 of the free spectral range of the fiber ring cavity) at an amplitude value such that the $J_0 J_1$ product is maximized[3] as illustrated at the reference point B of the ring probe signal. The signal is then launched into the fiber optic resonator input port. The relationship between the probe signal and the fiber ring signal is illustrated in Figure 3.

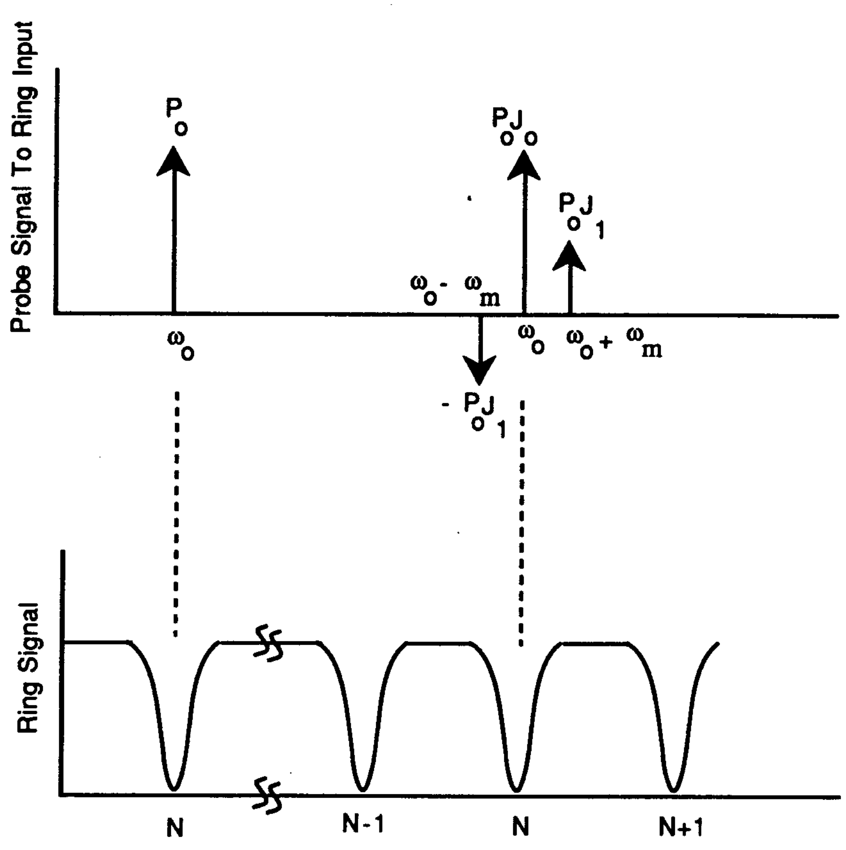

Figure 3. Probe versus ring signal relation.

The resonator linewidth is determined by sweeping the gas laser through the resonances and demodulating the transmission intensity at frequency ω_m. The frequency discriminant obtained is then used for determination of the fiber ring linewidth. The first step in the resonator linewidth measurement is to measure the fiber resonant ring free spectral range (FSR) to high precision. The modulation frequency of the I/O chip phase modulator port ω_f is incremented until the discriminant generated is exactly overlapping with the discriminant induced by ω_m modulation frequency. Reading the synthesizer frequency gives the FSR of the fiber ring resonator.

The next step in the fiber ring linewidth measurement process is to use the frequency of the ω_m I/O port with the discriminator picture generated by the demodulation electronics on a storage scope and calculate the fiber ring linewidth. Figure 4 illustrates a typical discriminant and parameters necessary for determination of the fiber resonant ring linewidth.

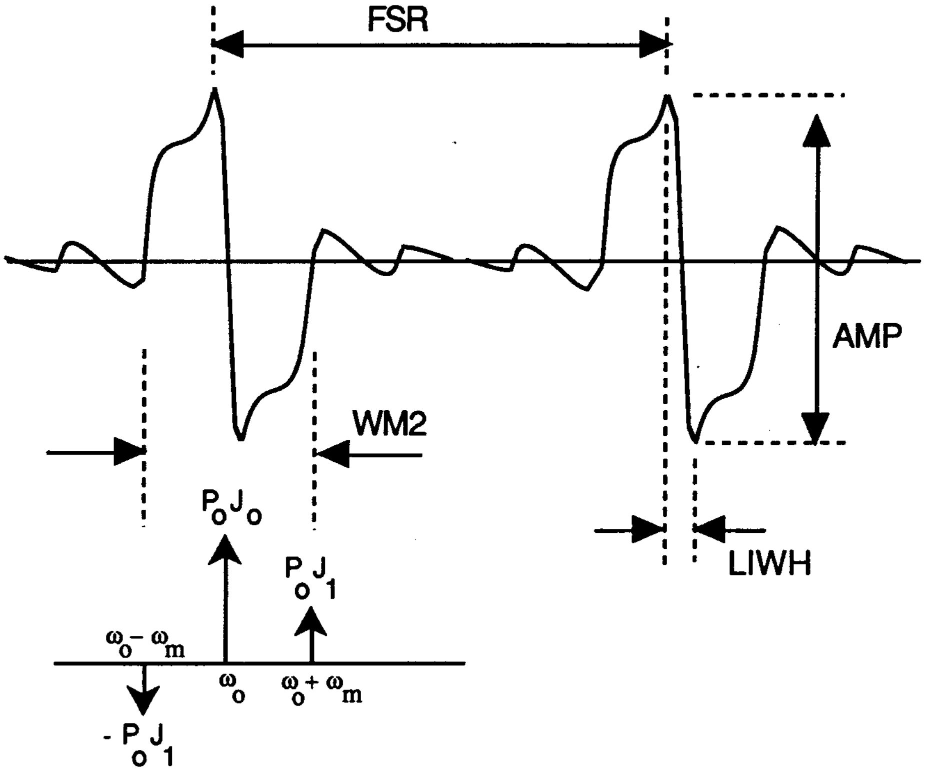

Figure 4. Discriminator generated by the demodulation electronics.

In Figure 4 the FSR is expressed in units of time and if divided by previous measurement a scale factor for a frequency vs. time is obtained. It is also possible to check the accuracy of the scale factor by utilizing the WM2 parameter and the knowledge that this value is exactly equal to the twice the modulation frequency ω_m. The final step in fiber resonant ring linewidth measurement is to divide the scale factor by the LIWH parameter value and invert the result. Using this process a fiber resonant ring linewidth is rapidly determined with high accuracy and repeatability. For example, characterization of a resonator fabricated by Honeywell Inc. will be described.

RESULTS

The ring resonator tested by direct examination of the resonant dips was previously reported to have a finesse of 160, measured with an unstabilized HeNe 1.52 μm laser[4] . When retested using the new technique, a discriminant was obtained like that in Figure 5. Using the measured FSR of 10.2563 MHz the fiber resonant ring finesse was determined to be 1045, corresponding to a linewidth of 9.8 KHz. The orthogonal polarization dip was <-30 dB down from the main dip. To our knowledge this is the highest finesse reported for a PM fiber resonator at 1.3 μm wavelength.

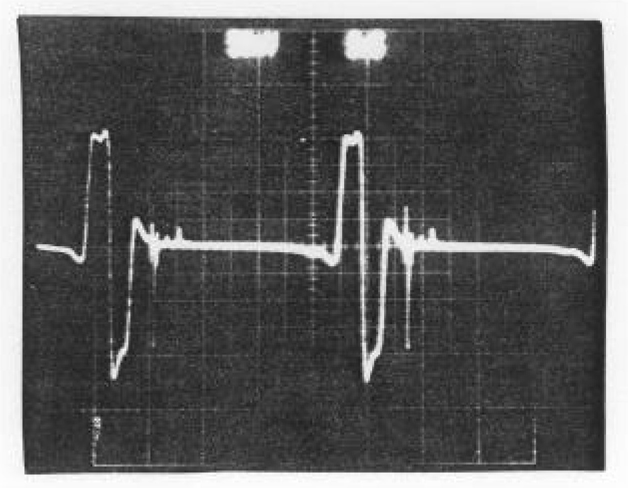

Figure 5. Typical Fiber Resonant Ring Discriminant.

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[2] M. Digonnet, J. Feth, and L. Stokes Optics Letters, Vol. 10, No. 9, (1985).

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