In-Line Fiber Fabry-Perot Interferometer with High-Reflectance Internal Mirrors

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Operation of fiber Fabry-Perot interferometer (FFPI) temperature sensors from -200^0C to $+1050^0$C has been demonstrated [1]. These sensors used internal mirrors produced by a fusion splicing technique. Internal-mirror FFPIs have been embedded in graphite-epoxy composites and polymers, where they were used to sense temperature [2] and ultrasonic pressure [3].

Previous work on internal mirror fiber devices has utilized single-layer dielectric mirrors, with maximum reflectances of less than 10% for the individual reflectors. In this paper, the use of multilayer films to obtain mirror reflectances of greater than 85% in a FFPI is reported, and data for a thermally tuned interferometer are compared with model calculations. Enhancement of sensor sensitivity through the use of high-finesse interferometers is discussed, as are potential applications of internal mirror FFPIs in communications.

The experimental arrangement for testing a FFPI is shown in Fig. 1. Light from a fiber-pigtailed 1.3 μm distributed feedback laser is coupled into an input port of a fiber directional coupler through an in-line Faraday isolator. The FFPI is spliced to one output port of the coupler. Transmittance and reflectance of the FFPI are monitored using power meters. Reflections from fiber ends are suppressed using index matching gel.

Internal mirrors for the FFPI were produced by a fusion splicing technique [1] in Corning single-mode silica fiber. Multilayer films for the mirrors were deposited in a dc planar magnetron sputtering system. A seven-layer quarter-wave TiO_2/SiO_2 stack on a cleaved fiber end gave a reflectance of 93%. The first mirror for the FFPI was produced by splicing a coated fiber end to the cleaved end of a

0-8194-0715-1/91/$4.00

second, uncoated fiber. The mirror reflectance after splicing had decreased to 86%. Next, the fiber was cleaved a distance beyond the mirror corresponding to the desired interferometer cavity length. Another coated fiber was then spliced to the cleaved fiber end to produce the second mirror.

The dependence of the reflectance and transmittance of the FFPI on phase shift in the interferometer was characterized by thermal tuning. The FPPI and a thermocouple were inserted in a quartz tube, which was positioned in a hole in a copper block with embedded heating elements. The reflected and transmitted optical power and the thermocouple reading were recorded as the assembly was slowly heated. The refractive index of the fiber mode is, to a good approximation, a linear function of temperature in the 120^0 - 140^0C range where the measurements were made [1]. Thus, the thermal tuning response curves give the dependence of reflected and transmitted power on round-trip phase shift in the interferometer. The results are shown in Fig. 2 for a 9.5 mm long interferometer. The calculated curves [4] in Fig. 2 utilize values for the the mirror reflectance R = 86% and the mirror excess loss A = 7.2%. The reflectance value used in the calculations was determined from the observed value of 21 for the finesse.

An alternative way of testing FPPIs makes use of thermal tuning of the frequency during a laser pulse to produce a spectral response curve. Fig. 3 shows the reflectance vs. time of the FFPI in response to a 20 mA, 750 nsec square pulse superimposed upon a dc bias of 25 mA for the DFB laser. The response peaks are farther apart near the end of the laser pulse because the chirp rate is a decreasing function of time.

Much better sensitivity to changes in temperature, pressure, strain, or other parameters of interest can be obtained in high-finesse FFPIs than in sensors with low-reflectance internal mirrors reported earlier [1-3]. To achieve high sensitivity, the sensor must be operated near the maximum slope of the R_{FP} vs. phase-shift curve. To achieve maximum sensitivity in practice, the laser frequency can be thermally tuned by changing the bias current. Our calculations indicate that, in comparison with an interferoemter with mirror reflectances of 2% reported earlier [1], the high-finesse interferometer increases the maximum sensitivity to temperature or other parameters of interest by a factor of about 25.

In line fiber Fabry-Perot interferometers are also of interest for use as filters and discriminators in frequency-shift-key fiber communications systems [5]. A finesse as high as 500 was reported for an FFPI in which multilayer dielectric mirrors were epoxied to the ends of a polished fiber [6]. The internal mirror FFPIs can also be used in this manner, with a piezoelectric fiber stretcher for tuning. However, higher mirror reflectance values (to give a higher finesse) and lower mirror excess loss (to reduce the insertion loss of the FFPI) will be needed before the internal mirror devices can be competitive in this application.

In conclusion, internal fiber mirrors with high reflectance (86%) and moderate excess loss (7.2%, or 0.33 dB) have been produced by a fusion splicing technique. The mirrors consist of a 7-layer TiO_2/SiO_2 stack deposited in a magnetron sputtering system. A finesse of 21 was observed in a Fabry-Perot interferometer using these mirrors. The data agree well with model calculations. A sensitivity enhancement by a factor of 25 over earlier sensors using low-reflectance internal mirrors is calculated.

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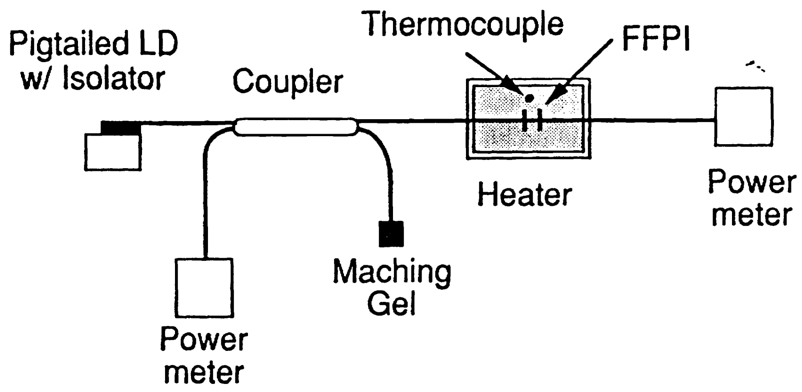

Fig. 1 Experimental Arrangement.

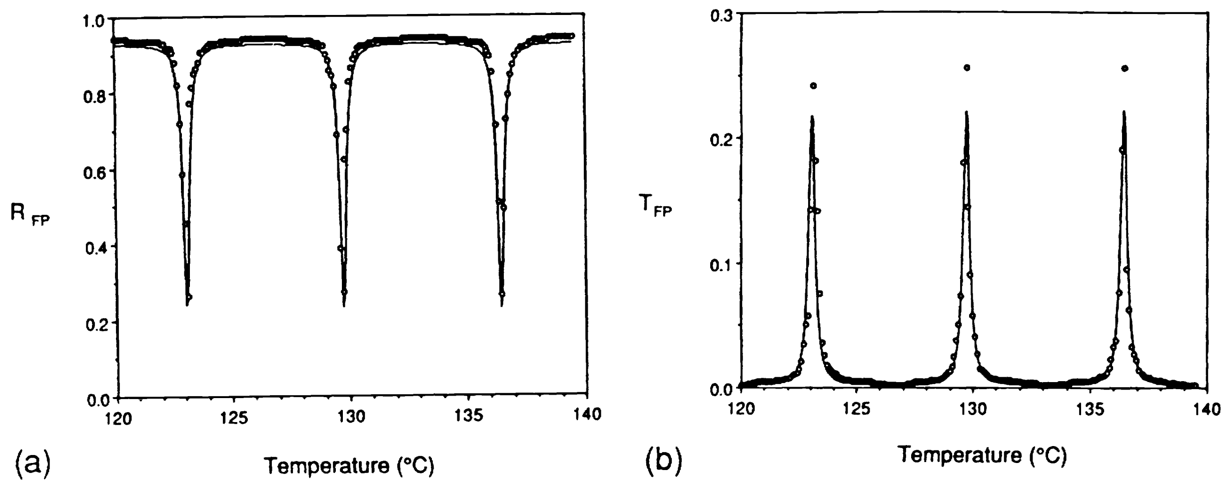

Fig. 2 Temperature dependence of (a) reflectance and (b) transmittance of internal mirror FFPI. Solid and dotted line indicate the calculated and measured data respectively.

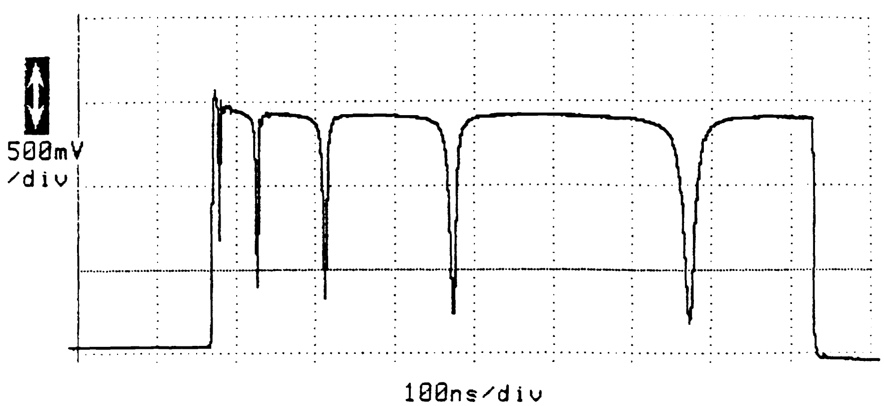

Fig. 3 Oscilloscope trace showing temporal response of FFPI reflectance to a chirped laser pulse.