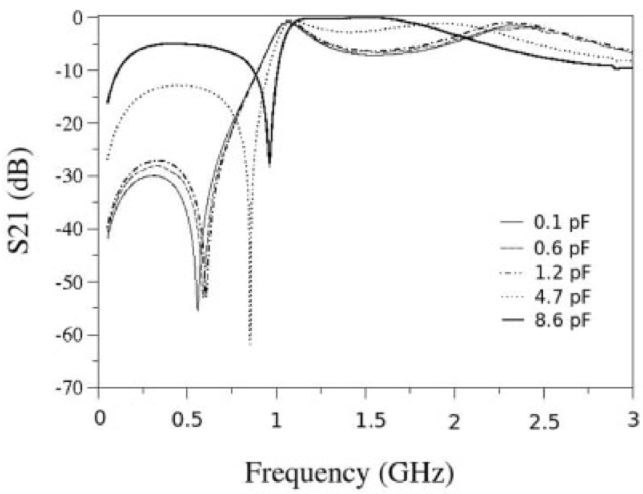

Figure 4 Measured insertion losses in the structure of Fig. 1(a) with different values of the series capacitance

4. CONCLUSIONS

It is concluded that by tuning the series capacitance of CSRR-based metamaterial transmission lines, a significant variation in the transmission characteristics, including the possibility of balancing or quasi-balancing the lines, is obtained. By varying this capacitance, the transmission zero of the structure is also modified. This has been interpreted from the influence of such capacitance on the shunt impedance of the equivalent T-circuit model of the structure. The results of this work indicate that reconfigurable metamaterial transmission lines based on CSRRs and varactor diodes can be realized. Work is in progress in this direction.

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A SIMPLE METHOD FOR SIMULTANEOUS MEASUREMENT OF THE TILT ANGLE AND TEMPERATURE

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ABSTRACT: *A simple and compact sensor for simultaneous measurement of the tilt angle and temperature is presented. The sensor is composed of a fiber taper and a fiber Bragg grating. The tilt angle is measured by monitoring the tilt-induced loss of the taper. The grating is used for enhancing the tilt angle sensitivity as well as monitoring the wavelength shift induced by the temperature variation.* © 2007 Wiley Periodicals, Inc. Microwave Opt Technol Lett 49: 2248–2250, 2007; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.22701

Key words: *optical sensor; fiber grating; optical fiber*

1. INTRODUCTION

Fiber tapers have been successfully used in directional couplers [1] and beam expanders [2] because of their merits: easy for fabrication and tailor [3], and consequently low cost. Recently, fiber taper-based devices have been applied in biochemical sensing [4, 5] and strain sensing [6] in view of the advantages of optical fibers (such as suitability for remote sensing and electromagnetic immunity). A fiber taper is made by stretching a heated fiber, which can be realized by flame or a pair of electrodes. Fiber gratings have also been widely used in sensing, e.g., temperature, strain, pressure [7], acceleration [8], and ultrasound detection [9].

In this article, we present a sensor, which is composed of a fiber taper and a fiber Bragg grating (FBG) for simultaneous measurement of the tilt angle and temperature. The magnitude of the tilt angle can be obtained by monitoring the tilt-induced loss (bending loss) of the taper and the FBG is used not only for monitoring the wavelength shift induced by the temperature variation of the surrounding but also for enhancing the measurement sensitivity of the tilt angle. The present sensing head is compact.

2. PRINCIPLES AND EXPERIMENTS

It is well known that a loss will be induced when a single mode fiber (SMF) is bent or tilted at a certain point. Measurement of the tilt angle from the bending loss of a tapered fiber was proposed in

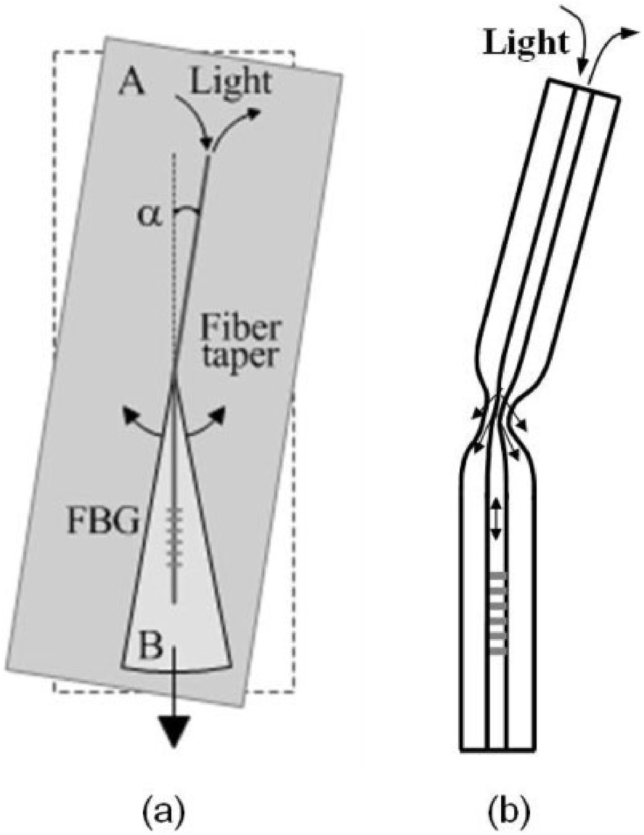

Figure 1 Diagram of the tilt senor (a) and the detailed diagram of the sensing head (b)

[10]. When the bending radius is large, the tilt-induced loss has some oscillation due to a so-called whispering gallery mode [11]. Oscillation will destroy the monotonous behavior of the measured loss for sensing. Unlike [10], we eliminate this oscillation by reducing the bending radius in the present article. The loss is too small for sensing when the tilt angle is less than several degrees. Tapering (i.e., reduction of the core diameter) will increase the core-mode field diameter and consequently the tilt-induced loss (good for sensing). However, tapering can also introduce some oscillation in the loss due the mode transition from the core mode to cladding modes [10] when the normalized frequency (V) decreases under a critical value defined as [12]:

$$V_c = \sqrt{\frac{2}{\ln(S)}} \times \left(1 + \frac{0.26}{\ln(S)}\right)^{-\frac{1}{2}} \tag{1}$$

where S is the ratio of cladding to core radii. In the present article, we eliminate this oscillation (which exists in [11]) by keeping V parameter slightly larger than the critical value V_c.

The schematic diagram of the present sensor is shown in Figure 1. We fixed one end of the fiber (for both input and output) on a fixed plate A, while the other end connected with a FBG is fixed on a rotatable plate B [shown in Fig. 1(a)], which can tilt around the axis passing through the center of the fiber taper. When the sensor is inclined away from the vertical position at a certain angle α (e.g., the fixed plate A is away from the vertical position while the rotatable plate B is still in the vertical position due to the gravity), the fiber taper will be tilted around the axis, and consequently introduce a loss of the output power. To reduce the bending radius, we control the taper length within hundreds of micrometers, which is useful for increasing the tilt loss and thus improving the sensitivity.

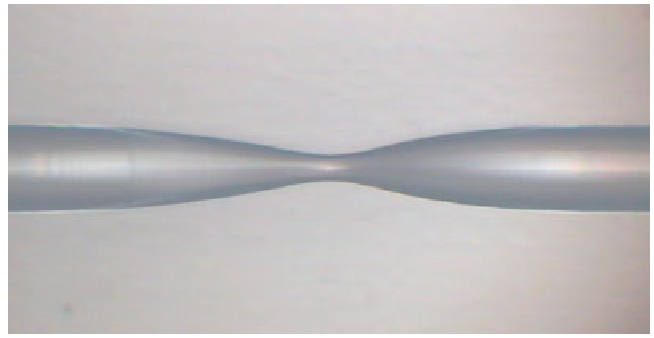

Figure 2 Photograph of the fiber taper. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

The fiber used for taper fabrication is SMF-28 fiber with an initial cladding diameter of 125 μm, core diameter of 8.2 μm, and a V-parameter of about 2.33. We can obtain V_c of ~0.819 from formula (1). We adopted the electrodes of the Fitel fusion splicer to produce the taper to minimize the taper length since the electrodes have narrow arc discharging area. The resultant structure of the fiber taper is shown in Figure 2. With the assistance of microscope, we can see that the fiber diameter decreases to 47 μm and thus the normalized frequency V parameter is about ~0.876 (assuming that the ratio of the cladding to core radii and the refractive indices of the core and cladding keep constant during the tapering process), which is slightly larger than $V_c \approx 0.819$. The length of the total taper is about ~720 μm, and the length of the taper waist is about ~70 μm. The insertion loss induced by the taper processing is about 2.1 dB, which is acceptable for sensing.

This sensor operates in the reflection mode since the FBG reflects the input power at the Bragg wavelength, which is sensitive to the temperature and can be characterized as a temperature measurement. The light passing through the taper is reflected by the FBG, and the reflected wavelength is determined by the FBG, which is sensitive to the temperature variation. When the light is finally collected by the power meter, the output light actually passes through the taper twice and thus the sensitivity of the tilt angle is enhanced. The FBG was fabricated in the photosensitive fiber with a phase mask using KrF excimer laser. The transmission spectrum with 15 dB transmission was shown in Figure 3.

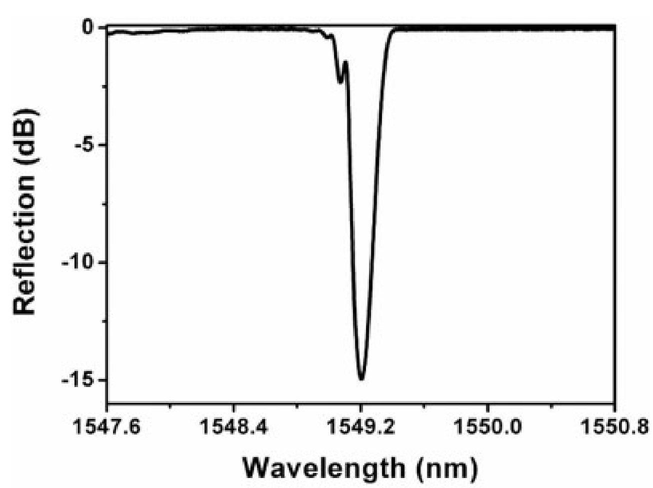

Figure 3 The measured transmission spectrum of the FBG

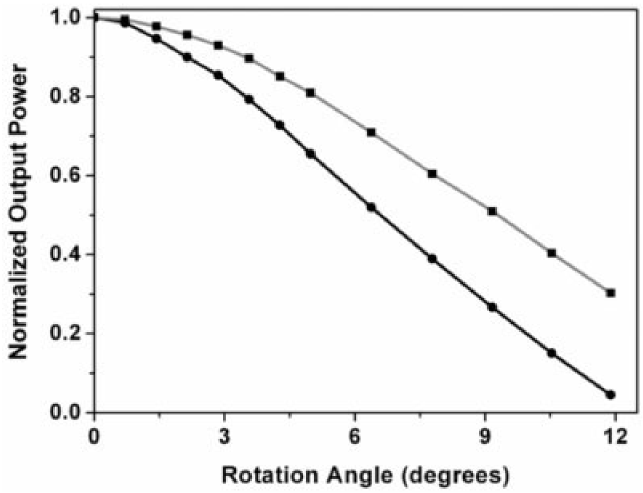

Figure 4 Measured normalized output power as a function of the tilt angle

3. RESULTS AND DISCUSSION

Figure 4 shows the normalized output power against the tilt angle with FBG (squares). The normalized output power shows a monotonic decrement against the tilt angle, as expected. For comparison, the normalized output power against the tilt angle without FBG was also measured, and the results are given in Figure 4 (circles). From the results, we can see that the FBG can effectively enhance the tilt angle sensitivity of the sensor.

The Bragg wavelength shift of the FBG with temperature was directly recorded by monitoring the wavelength shift using an optical spectrum analyzer. The resolution of the optical spectrum analyzer is limited (0.01 nm). The temperature response of the senor is shown in Figure 5. A sensitivity of about 0.0121 nm/°C was obtained. The temperature sensitivity of the sensor can be enhanced by packaging with a material with higher temperature sensitivity.

4. CONCLUSION

A sensor based on a fiber taper and an FBG for simultaneous measurement of the tilt angle and temperature has been presented. The sensor is operated in the reflection mode. The magnitude of the tilt angle can be obtained by monitoring the tilt-induced loss of the light that passes the taper and is reflected by the FBG. The fiber grating can not only enhance the tilt angle sensitivity but also measure the surrounding temperature by the wavelength shift. The sensor is simple and compact.

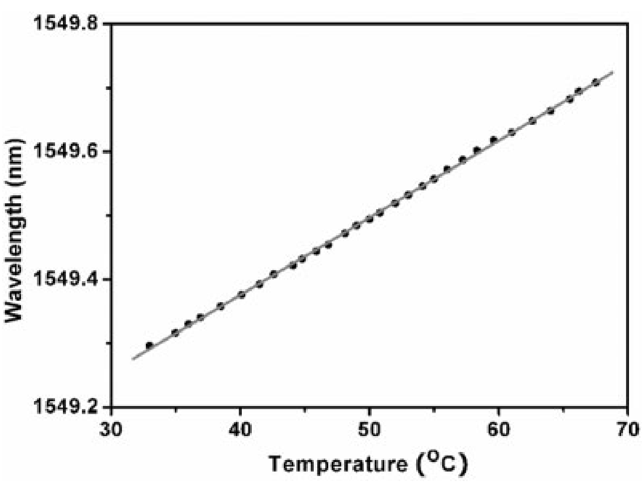

Figure 5 Measured wavelength shift as the surrounding temperature varies

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SURFACE-MOUNT LOOP ANTENNA FOR AMPS/GSM/DCS/PCS OPERATION IN THE PDA PHONE

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ABSTRACT: *A surface-mount loop antenna very suitable for application in the mobile devices such as the PDA (Personal Digital Assistant) phone for quad-band operation is presented. The antenna comprises of a loop metal pattern for generating two wideband resonant modes at about 900 and 1800 MHz to cover the AMPS/GSM/DCS/PCS bands and a central coupling stub as the feed structure. Although quad-band operation is obtained, the antenna occupies a small volume of $7 \times 8 \times 60$ mm^3 or about 3.4 cm^3 only and is easy to be embedded inside the PDA phone as an internal antenna. Details of the proposed surface-mount*