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Simultaneous measurement of the temperature and force using a steel cantilever soldered with a partially nickel coated in-fibre Bragg grating

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ABSTRACT

A method for the simultaneous, independent measurement of temperature and force using a single in-fiber Bragg grating (FBG) sensors was proposed and demonstrated. The FBGs were partially metallized using a partial nickel coating method. A Bragg reflex peak was successfully divided into two reflex peaks during the partial nickel plating process. The metallized part of the FBG was soldered on a steel cantilever, and the non-metallized part hanged in air. Using a structure that is composed of the steel cantilever soldered with a dual-wavelength FBG, the temperature and pressure can be simultaneously measured and discriminated. The metallized part of the FBG is highly temperature-sensitive (about 26.1 pm/°C), and for the non-metallized part the original Bragg wavelength of the FBG remains unchanged. The force sensitivity of the metallized part which soldered on the cantilever remained at 82 pm/N from 30 to 90 °C.

1. Introduction

Fiber Bragg grating (FBG) sensors have undergone a rapid development in recent years due to their advantages over traditional sensors, for example, immunity to electromagnetic interference, remote sensing, ease in handling, low cost, small size and light weight. By monitoring the Bragg grating wavelength shift many measurands can be calibrated, such as temperature, strain, displacement, force and acceleration [1–6]. However, normal FBG is highly sensitive to both strain and temperature so that it is difficult to distinguish them from the response of the sensor. In order to solve the problem of cross-sensitivity between temperature and strain, researchers proposed various methods. (i) Utilizing two (or more) different gratings in which each has a different responsivity to the temperature and strain, i.e., using a reference grating [7], hybrid fiber gratings [8], dual-wavelength fiber grating [9], different-diameter fiber gratings [10] and special geometry designed gratings [11]. Most of them are based on the measurement of two characteristic wavelength shifts which are associated with two different gratings. However, the use of more than one fiber element increases the system cost and complicates the fabrication of the sensor head. (ii) Utilizing a single grating in which a certain property (strain or temperature sensitivity) of one half is different from that of the other, such as using fiber gratings that are partially embedded in glass or metal tubes [12,13] or partially mounting the FBG on a cantilever[14], and using a polarization properties analysis method [15].

In our previous work the fiber and in fiber Bragg grating were metallized following a two step plating method [16], and the temperature sensitivity of FBG was enhanced. The metal coated fibers and FBGs have been embedded in steel parts and an aluminum foil successfully [17,18]. In the plating process, an interesting phenomenon was noticed where the Bragg peak wavelength shifted down significantly after plating and embedding process due to the contraction stress [18,19]. In this paper the single mode fibers and in fiber Bragg gratings were partially metalized by the nickel plating method. In the plating process the Bragg peak was divided into two peaks with different wavelengths. The metalized part has a lower Bragg wavelength and for the other part the original Bragg wavelength remains. Therefore a partially metalized FBG with dual-wavelength was acquired. This sensor was then soldered on the surface of a steel cantilever and subsequently the temperature and force changes were simultaneously measured successfully.

2. Partial metal coating of the FBG

2.1. Experimental procedure

In the previous work, a two-step method was presented for metallization of the fiber and in-fiber Bragg grating[16]. Using this method, the FBG can be protected well and the length and the

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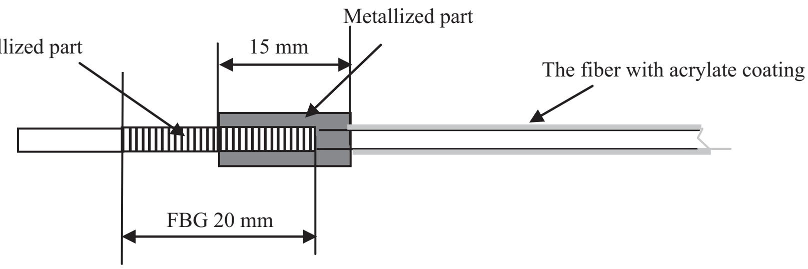

Fig. 1. Sketch of the partial metal coating FBG.

Table 1
Central wavelength (nm) of the FBGs and associated wavelength shift (nm) after nickel coating (about 30 °C).

No.	Original	After nickel coating
1	1532.089	1530.262 (−1.827)
2	1531.796	1530.089 (−1.707)
3	1532.376	1529.015 (−3.361)

thickness of the metal coating can be controlled easily. In this paper, the FBGs were partially metallized using this method.

The partial metal coating process includes two steps: chemical plating and electroplating of nickel, which are similar to the process presented in the previous work [16]. However, differences do exist: after chemical nickel plating the fiber and FBG were coated with a nickel coating; the nickel coating was partially removed by a pair of special scissors (which is usually used to remove the organic coating of optical fiber) with the chemical coating part remaining of about 15 mm. Subsequently the chemical plating nickel coat was used as a conductive interlayer, based on which electroplating proceeded. Fig. 1 shows the sketch of the structure of the partial nickel coated FBG.

2.2. FBG wavelength shift during nickel plating process

The chemical plating nickel coating was used as a conductive interlayer with a thickness of only about 2–5 μm. The FBG wavelength change was not monitored in the chemical plating process. During the electroplating process, in order to determine the wavelength change of the FBG the Bragg wavelength shift was recorded using an FBG Network Analyzer (Model FONT-2004B, Shanghai SynetOptics Technology Corporation, the wavelength resolution is 0.001 nm). During the development of the partial coating method, several fibers with in fiber Bragg gratings were used. Table 1 presents some of the original central wavelengths and associated dual-wavelength of the FBGs after nickel coating.

Fig. 2 shows the curve of a typical FBG (No. 1 in Table 1) wavelength change during the nickel electroplating process. It can be seen that there are two Bragg wavelengths of the FBG: the lower one represents the nickel coated part and the higher one is associated with the non-metallized part. During the electroplating process, the wavelength of the non-metallized part shows the temperature change of the surroundings and the wavelength of the metallized part decreased gradually due to the contraction stress of the electroplating deposition. The wavelength difference increased gradually during the electroplating process. Fig. 3 shows the wavelengths of the two parts after nickel plating: the FBG reflective peak was divided into two distinct ones, and a dual-wavelength FBG was then acquired.

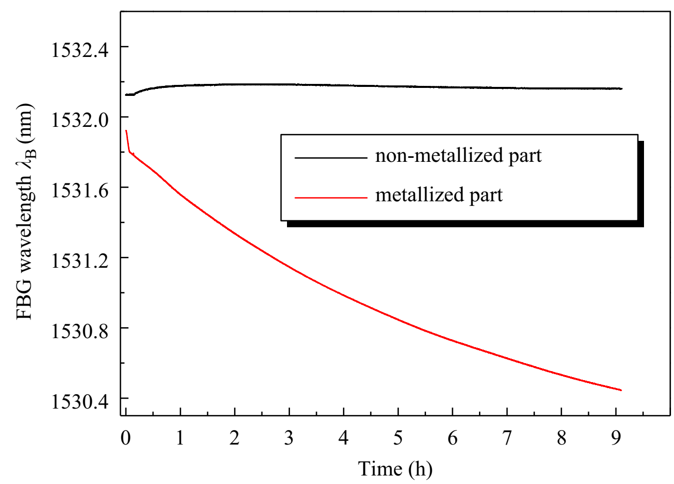

Fig. 2. Curve of FBG wavelength change during nickel plating process.

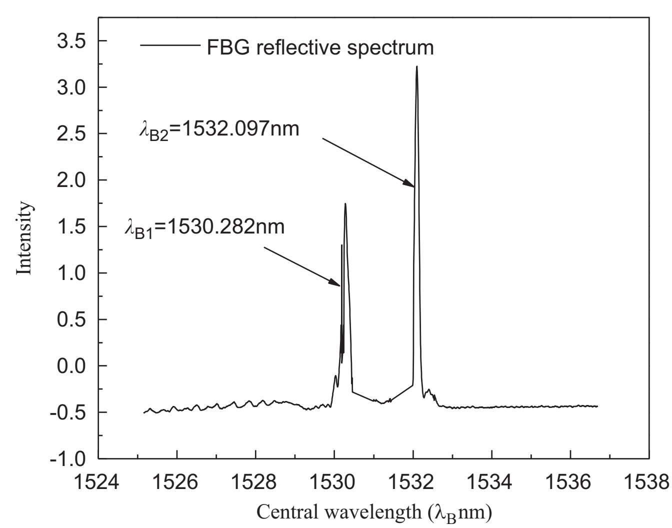

Fig. 3. Spectrum of the FBG, showing the wavelengths reflective peak was divided into two different ones after plating (surrounding temperature about 30.5 °C).

3. Soldering of the dual-wavelength FBG on the cantilever

A dual-wavelength FBG was acquired after partial metal coating, and this type of grating can be used in multichannel OADMs, multiwavelength filters, and multiwavelength fiber lasers and for solving the problem of the temperature–strain cross sensitivity of FBG sensors [20]. In this paper, it was used to determine the temperature and force change of the cantilever. Several papers concern the topic of simultaneous measurement of strain (or force/displacement) and temperature; the fiber sensors were