Optical Fiber Bragg Grating Sensors

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This paper presents the utilization of fiber Bragg gratings (devices which reflect a narrow band of the optical spectrum) in the development of sensors. A discussion about the advantages of its use and possible parameters to be measured precedes the presentation of preliminary results obtained with a strain gage and a thermometer.

Neste trabalho é discutida a utilização de redes de Bragg em fibras ópticas (dispositivos capazes de refletir faixas estreitas do espectro óptico) no desenvolvimento de sensores. Uma discussão sobre as vantagens apresentadas por estes sensores e sobre os parâmetros envolvidos no sensoriamento precede a apresentação de resultados preliminares obtidos com um extensômetro e um termômetro.

Introduction

In 1978 the first in-fiber devices, capable of reflecting narrow bands of the light spectrum were demonstrated [1]. These so-called Bragg gratings are obtained by the periodic modulation of the optical fiber refractive index along its axis. Light reflected at each period will suffer constructive interference only if its wavelength satisfies the Bragg condition for normal incidence:

$$m\lambda_m = 2n\Lambda \qquad m = 1, 2, 3, ...$$

where λ_m is the reflected wavelength at order m (usually $m = 1$), n is the average refractive index, and Λ is the spatial period of the grating.

The modification of the refractive index in germanium doped silica fibers is obtained with the incidence of UV radiation near 240 nm. This effect can also be obtained with radiation near 480 nm, where a two photon process takes place. The index modulation is obtained by the interference of two beams of coherent UV radiation on the fiber. By varying the angle made by the beams and the fiber it is possible to set Λ to the desired value. This method is known as external writing method [2].

The reflected spectral band is in the range of picometers to nanometers. This width depends on the number of effective modulations and thus, on the length of the grating (typically of mm or cm). The reflectivity can vary from 0 to 100% depending on the grating length and the intensity of the refractive index modulations. Bragg grating are generally written at 1.55 or 1.30 μm, where the transmission windows used in telecommunications are located, but can also be written at any wavelength longer than the writing UV. Gratings used on multiplexed telecommunications systems must present high reflectivity and narrow width, but the ideal characteristics for sensing applications can vary, and will be discussed latter in this paper.

Bragg gratings presenting 20 % reflectivity and spectral width of about 1 nm are written in the Physics Department of PUC-Rio, where the UV radiation used is the fourth harmonic of a 1.06 μm Nd:YAG laser [3] at 266 nm.

Advantages of Bragg Grating Sensors

The wavelength reflected by the gratings depends on the conditions to which the fiber is submitted. Changes in the period Λ or in the fiber refractive index directly affect the Bragg wavelength. These modifications can be caused by temperature or length variations in the grating region. Thus, the basis of the Bragg Grating sensing relies on the determination of the reflected or transmitted spectrum obtained as a function of the parameter of interest.

The possibility of addressing multiple parameters with the same technology is one of the advantages, although it becomes a crucial issue separating the physical reason behind any Bragg wavelength change. The ease of multiplexing these sensors and fact that the information is spectrally encoded are also important. Apart from these characteristics, Bragg grating sensors have all the attractiveness of all fiber sensors, namely, no EMI, light weight and remote measurement capability, among others. In this paper we present preliminary results on strain and temperature measurements.

Applications

At constant temperature, a longitudinal strain is related to changes in Bragg wavelength through [4]:

$$\Delta\lambda/\lambda = (1 - p)\Delta L/L$$

where p is the photoelastic constant of the fiber (approximately 0.22), and L the original length of the strain region. For commercial fibers the maximum strain which can be safely measured is on the order of 0.5%. The resolution in strain measurements depend on the accuracy in determining the Bragg wavelength. Typically a few pm is achievable, corresponding to $\sim 10^{-6}$ strain for a grating at 1.5 μm wavelength.

The main effect of temperature on a Bragg grating is via a refractive index change. Although the temperature sensitivity varies from fiber to fiber, a shift of 10 pm/°C is typical. The temperature range is limited by the grating stability, which depends on the fabrication method. The more common gratings are stable up to 200°C but it is possible to write gratings to work beyond 500°C.

Many methods have been proposed to achieve the desired wavelength resolution. An optimum option should be fast, easy to implement, capable of reading many gratings and should not cost too much. In the following section we present results obtained with two possible approaches which we are investigating.

Results

The strain gage consists of a Bragg grating reflecting at 1550 nm with 1 nm spectral width, as shown in figure 1. It is connected to a pigtailed LED which provides 10μW of broadband CW light. The region of the fiber containing the grating was carefully glued to a metal ruler side by side with a conventional electric strain gage. The ruler was then strained and the reflection spectrum measured with a optical spectrum analyzer OSA (Ando AQ-6315A).

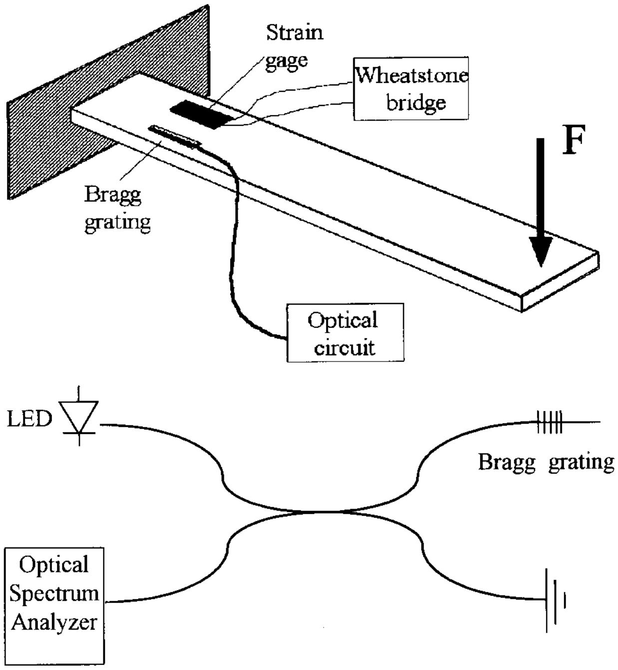

Figure 1. Strain measurements, (a) experimental setup for calibration and (b) optical circuit.

The maximum spectral resolution of the of OSA is 50 pm which, in principle, limits the accuracy in strain determination to 4×10^{-5}. In practice, the signal to noise limited this figure even further. Our solution was to use a parabolic fit near the top of the reflection peak and assume the analytical curve as the actual spectrum. Figure 2 is an example of this procedure. This approach improved the resolution by an order of magnitude giving a final resolution of 4×10^{-6} strain. The calibration up to 4.5×10^{-4} strain is shown in figure 3. This result gives a value of 0.23 to the photoelastic constant of the fiber.

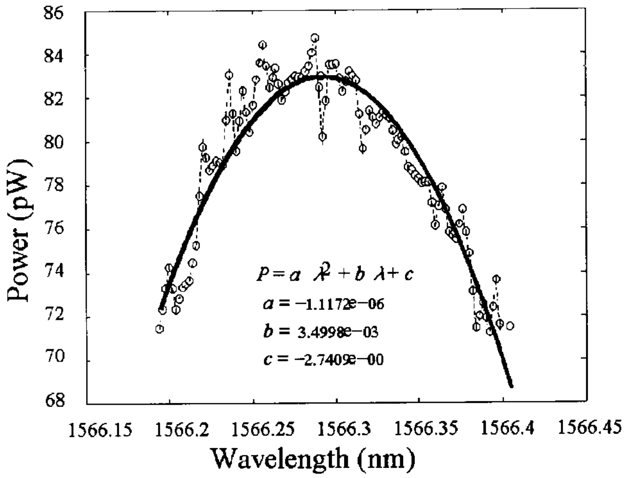

Figure 2. Parabolic fit of reflection peak.

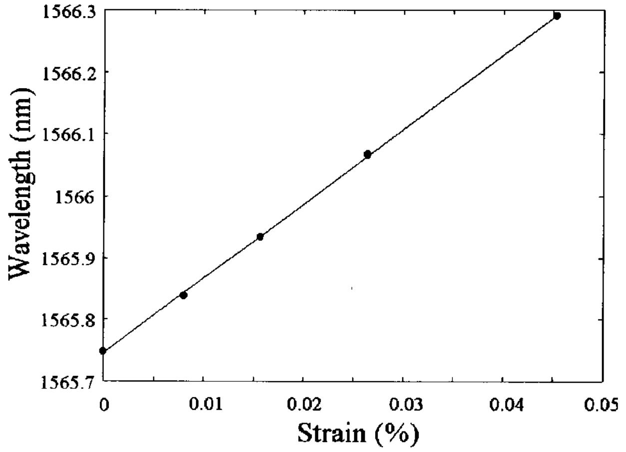

Figure 3. Calibration of reflection peak with strain.

In order to avoid the use of the OSA, which is an expensive multipurpose equipment, a second approach was tried. In this case an tunable optical band-pass filter (1nm), followed by a optical powermeter replaced the OSA. As the reflected spectrum changes due to strain, the total power transmitted trough the filter will also change. The calibration of optical power with strain was repeated for five different filter positions and the result is shown in figure 4. These results show that in the best filter position a resolution of 10^{-5} strain could be achieved. By improving the peak reflectivity of the grating and using higher power LED further improvements are expected.

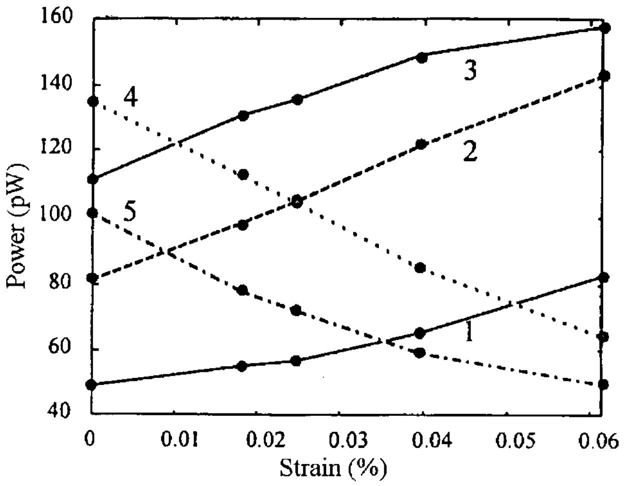

Figure 4. Transmitted power with strain.

Temperature measurements were also tested using a similar setup. The grating and a thermocouple were immersed on oil and placed on a hot plate. A calibration of peak position with temperature was performed from 20°C to 80°C. The OSA was used and the data processed in a similar way to that used in the strain measurements. The curve in figure 5 indicates that a +/- 1°C resolution can be achieved.

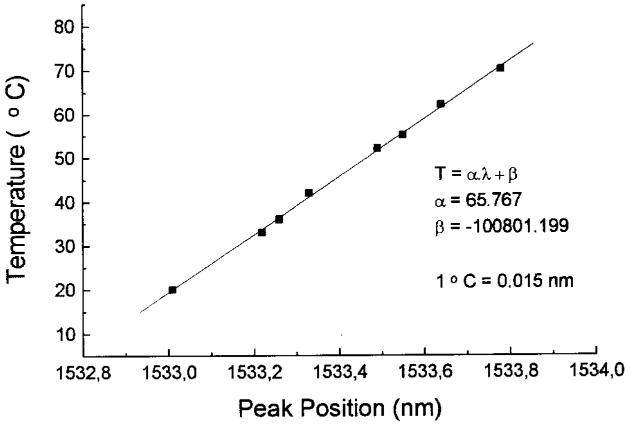

Figure 5. Peak position with temperature.

Conclusions

Our preliminary results confirm the potential of fiber Bragg grating sensors. Work is under way to improve accuracy while keeping costs low. The optical filter is being replaced by a second properly designed grating. Both techniques described here are adequate for multiplexing up to ten gratings written at different wavelengths. We are also working on means of separating the influences of temperature and strain, which necessary for field applications. We also intend to look at indirect measurements of other parameters such as electric and magnetic fields, which can be accomplished associating the gratings to electrostrictive and magnetostrictive materials.

References

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