Mechanically induced cascaded long-period grating structure for reflectometric strain and temperature sensing

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Introduction

Fiber-optic gratings have had a considerable impact on sensing devices and systems [1]. One of such gratings is a long-period grating (LPG) [1,2], which typically has a period in the range from 100 μm to 1 mm. An LPG promotes coupling between the propagating core mode and co-propagating cladding modes. The transmitted light has a spectrum containing a series of attenuation bands centered at discrete wavelengths, which correspond to different cladding modes. As these wavelengths are dependent on applied strain and ambient temperature, LPG-transmitted spectra can be used to develop strain and temperature sensors.

To enhance the measurement accuracy (i.e., to narrow the bandwidth of the spectral dips), a cascaded LPG structure has been developed [3,4,5]. When a high-speed sensing technique based on spectral slope power is employed, this structure also leads to enhanced strain (or vibration) and temperature sensitivities because of its steeper slope [5,6]. However, ultraviolet (UV) inscription of two identical LPGs in a silica single-mode fiber (SMF) is not beneficial from an economic viewpoint.

In this work, to reduce the cost, we develop a reflectometric configuration of the cascaded LPG structure exploiting the Fresnel reflection at the sensing fiber end. This structure involves merely a single LPG mechanically induced in the fiber; in addition, the sensing fiber length can be doubly shortened.

Principle

A cascaded LPG structure forms an in-fiber Mach-Zehnder interferometer of the core mode and cladding modes, resulting in a periodically channeled transmitted spectrum. The bandwidth of each dip is much narrower than that of a single LPG, leading to a higher accuracy of strain and temperature measurement [5,6]. While cascaded LPG structures previously reported have two identical LPGs in the system, here we newly develop a refrectometric configuration involving only one LPG by folding the structure by exploiting the Fresnel reflection at the open end of the sensing fiber. It is well known that an LPG can be mechanically induced by applying pressure periodically along a fiber, because the core refractive index is periodically modulated owing to a photoelastic effect [7].

Experiments

Fig. 1 shows the experimental setup of the reflectometric cascaded LPG structure for strain and temperature sensing. All the fibers in the system were silica SMFs (core diameter: 8 μm). Amplified spontaneous emission was used as a wideband light source, which was injected into the cascaded LPG structure. Then, the spectrum of the reflected light was observed using an optical spectrum analyzer. The end of the sensing fiber was perpendicularly cleaved to maximize the Fresnel reflection. The fiber length between the distal end of the LPG and the fiber end was 70 mm. The sensing part was placed in a thermostatic chamber, and its temperature dependence of the reflected light spectrum was investigated.

As depicted in **Fig. 2**, the LPG was mechanically induced by pressing the bare SMF sandwiched between 35-mm-long periodically grooved plate (depth: 35 mm) and a flat plate. The pressure was varied by loads placed on the grooved plate. The grating pitch was 600 μm, which was selected so that the coupling wavelengths of lower cladding modes appeared around 1550 nm [7].

The reflected light spectra at different loads from 0.1 to 10.0 N are shown in **Fig. 3**. When a load was applied, several spectral dips appeared; with increasing load, the depth of each dip increased. This result indicates that an LPG was successfully induced mechanically and that the cascaded LPG structure properly operated in the reflectometric configuration.

Subsequently, we measured the temperature dependence of the spectral dip (at 1554.5 nm at 30°C). As shown in **Fig. 4(a)**, with increasing temperature, the dip shifted to a longer wavelength. **Fig. 4(b)** shows the dip wavelength dependence on

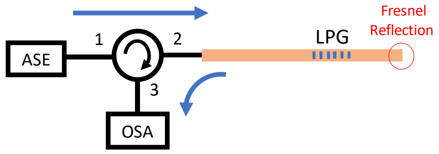

Fig. 1 Schematic setup of the cascaded LPG structure for strain and temperature sensing. ASE: amplified spontaneous emission, OSA: optical spectrum analyzer.

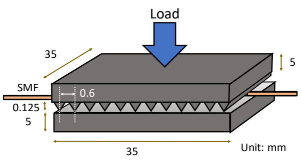

Fig. 2 Method for mechanically inducing a long-period grating.

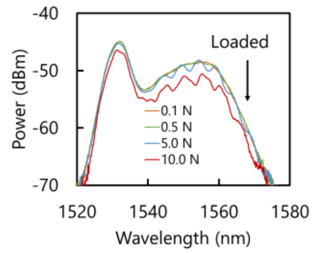

Fig. 3 Load dependencies of the reflected spectrum.

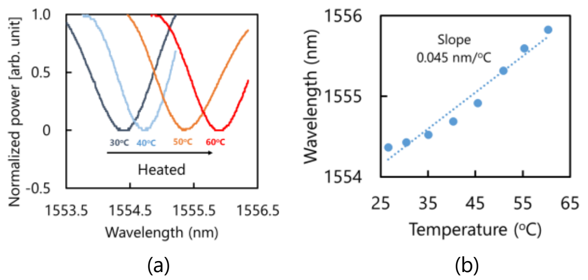

Fig. 4 Temperature dependences of **(a)** the spectral dip and **(b)** its wavelength. The dotted line is a linear fit.

temperature. The dependence was not completely linear in this measurement, but its linear fitting roughly yielded a dependence coefficient of 0.045 nm/°C. This value is 4.3 times smaller than that of the transmissive configuration [8], though this comparison is not fair as a number of experimental conditions are different. However, the short length of the sensing fiber is an absolute merit of this reflectometric configuration along with its lower cost.

Conclusion

We demonstrated reflectometric strain and temperature sensing based on a mechanically induced cascaded LPG structure (the strain dependence will be presented at the conference). Compared to conventional UV-inscribed cascaded LPG sensors, our system has two advantages: lower cost and halved length of the sensing fiber. Our future tasks include optimization of the LPG-inducing method, grooved length, grating pitch, load (or pressure), and sensing fiber length as well as demonstration of high-speed vibration (or acoustic) sensing.

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