ALL-FIBER HYBRID FIBER BRAGG GRATINGS CAVITY FOR SENSING APPLICATIONS

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Abstract. By now, fiber Bragg gratings (FBGs) represent a well assessed technology in sensing field. Unfortunately, to make FBGs sensitive to surrounding refractive index, hosting fiber structuring is needed. In last years, also tilted FBGs (TFBGs) have been proposed as promising technological platform for sensing applications. However, complex spectral features limit the practical exploitation of this technology. It would be extremely useful to merge the peculiar spectral characteristics of both grating types. To address this issue, here, we propose a hybrid cavity involving two unbalanced uniform FBGs written at both sides of a TFBG. The proposed configuration provides a wavelength gated reflection signal. Such a structure preserves uniform FBG advantages in terms of interrogation methods and allows the possibility to contemporarily measure multiple parameters.

1. Introduction

Over the last decade, fiber Bragg gratings (FBGs) have been utilized as optical sensors to measure a wide range of physical parameters including temperature and strain [1]. Their wavelength encoding, flexibility of design, and relative low cost make FBGs ideal devices for a multitude of different sensing applications. However, to make them sensitive to the surrounding refractive index (SRI), hosting fiber structuring is needed with consequent weakening of the grating structure [2]. In contrast, tilted FBGs (TFBGs) – refractive index modulation blazed with respect to the fiber axis – are intrinsically SRI sensitive [3]. In TFBGs, a core and several cladding mode resonances appear simultaneously in their transmission spectrum [4]. This has several advantages: the cladding mode resonances are sensitive to external perturbations (SRI, bending, etc.) while the core mode resonance is only sensitive to temperature and mechanical strain. Up to now, two main types of techniques have been proposed to demodulate the transmitted spectrum of a TFBG subject to an external perturbation: global monitoring of the area delimited by the cladding modes [3] and local monitoring of selected cladding mode resonance shifts [5]. To correctly operate, spectral measurements on a few tens of nanometers are required, severely complicating

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the demodulation technique of such sensing elements. It would be extremely useful to opportunely combine uniform FBGs and TFBGs in a single in-fiber structure to obtain strain, temperature, bending, and SRI sensitivity for multi-parametric measurements maintaining the advantages of FBG interrogation. To this aim, here we demonstrate that a hybrid cavity – involving two unbalanced FBGs and an interposed TFBG – can be used for sensing purposes, offering simple multi-parametric measurements working in reflection mode.

2. Device description

The proposed hybrid cavity is made by an unbalanced interferometer composed of two uniform FBGs in the middle of which a weakly TFBG is inscribed. The lateral FBGs are 0.5 mm long, but they have a different maximum reflectivity: about 30% and 100%, respectively. Experimental results concerning two different cavities will be reported: one involves a 4 mm long 4° TFBG, while the other one a 3 mm long 2° TFBG. The uniform FBGs are approximately centred at 1,577.7 and 1,574.7 nm, respectively. A schematic diagram of the investigated structure is reported in Fig. 1a. Such an interferometric cavity can be interrogated in reflection from the non-strong FBG side. The experimental spectral response of the cavity involving the 2° TFBG is shown in Fig. 1b. The reflected spectrum is given by interference fringes due to the Fabry-Pérot cavity formed by the two uniform FBGs with superimposed the attenuation bands – only those overlapping with the Bragg mirrors spectra – due to the cladding modes resonances of the TFBG within the cavity. This way, the hybrid interferometric cavity preserves the versatility of uniform FBGs with respect to measurements in reflection for strain and temperature sensing applications In addition, compared to a single TFBG, the structure preserves the spectral SRI and bending sensitivities, but strongly reduces the useful signal bandwidth.

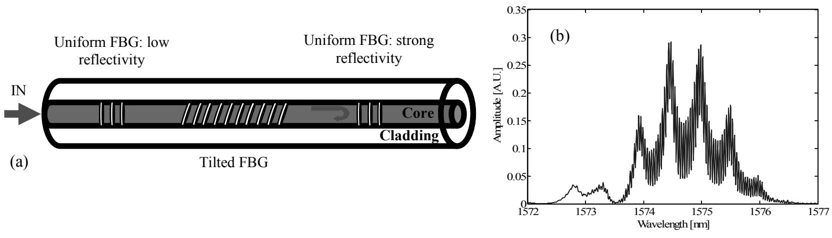

Figure 1. (**a**) Scheme of the all-fiber hybrid cavity; (**b**) reflected spectrum by the 2° TFBG cavity.

3. Experimental results

To demonstrate the device multi-parametric sensitivity and discrimination, SRI, bending, temperature, and strain characterizations have been carried out.

3.1. *SRI and bending characterization*

Figure 2a shows the spectrum of the 4° TFBG hybrid cavity for different SRIs. As well known [3], as the SRI increases the cladding mode resonances red shift due to the increase in the mode effective indices. In addition, approaching their cut-off condition, the attenuation bands progressively disappear starting from the ones at lower wavelengths (higher order cladding modes) and are gradually replaced by a broadband low level attenuation due to the coupling with a continuum of radiation modes. The same spectral effects can be observed for the cladding mode resonances involved in the cavity spectra reported in Fig. 2a. As direct consequence, the total reflected power progressively decreases. This suggests a simple demodulation technique based on reflected power monitoring. Figure 2b shows the reflectance changes – normalized to the reflectance in air ($\Delta R/R_{air}$). Note that the cut-off condition depends on the modes order, and thus it is possible to design the cavity in order to work within the desired SRI range. Similarly, reflected power decrease has been also pointed out for increasing bending along the cavity. In particular, Fig. 2c shows the spectrum of the 2° TFBG hybrid cavity subject to different curvature radii. Figure 2d, instead, shows the correspondent normalized (to the free bending state) reflectance changes. As observable from the reported spectra, no experimental wavelength shift has been observed during SRI and bending characterizations.

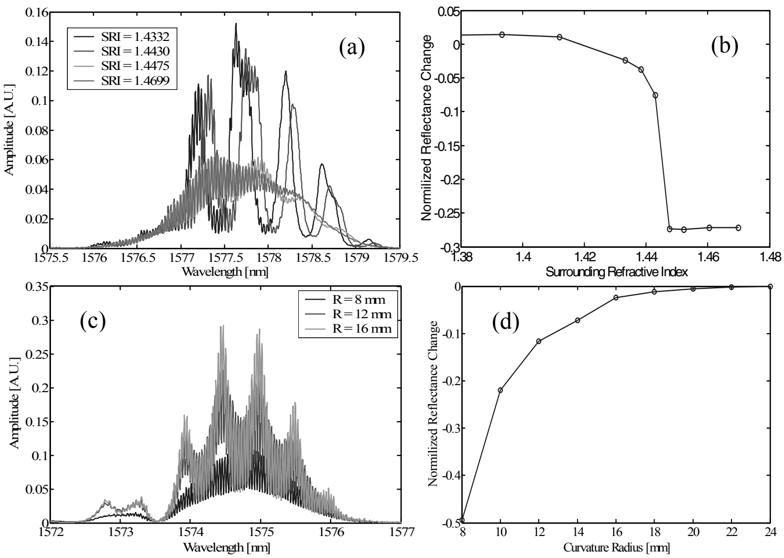

Figure 2. Cavity spectra (**a**) and normalized reflectance change (**b**) for different SRIs; Cavity spectra (**c**) and normalized reflectance change (**d**) for different bending states.

3.2. *Temperature and strain characterization*

Figure 3a shows the hybrid cavity spectrum (4° TFBG) as the temperature changes. As observable, temperature increases only red shift the reflected spectrum. As consequence, uniform FBGs demodulation technique based on wavelength shift monitoring could be adopted. In particular, Fig. 3b shows the cavity central wavelength versus temperature, revealing sensitivity of 9.5 pm/C. Very similar spectral behavior has been registered versus strain (applied mass to tension the fiber structure). Figure 3c shows the spectra of the same hybrid cavity for different applied masses, whereas Fig. 3d shows the correspondent cavity central wavelength – sensitivity of 8.5 pm/g. Note that no reflectance changes have been registered versus temperature and strain.

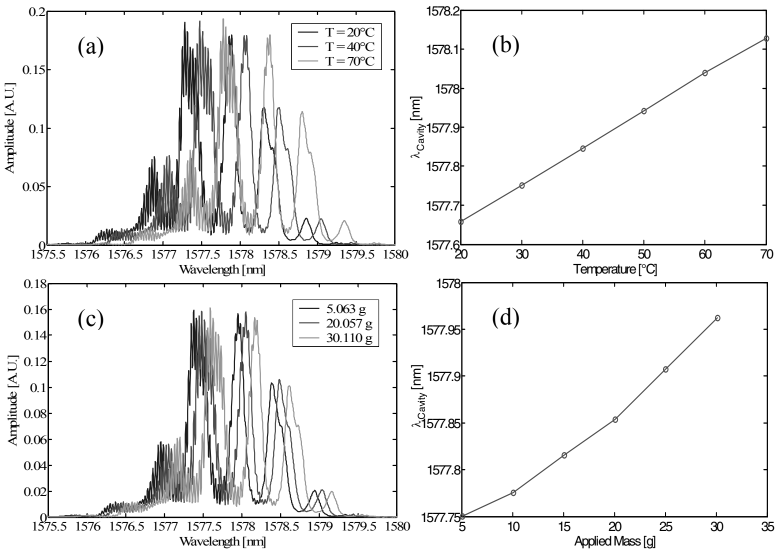

Figure 3. Cavity spectra (**a**) and cavity central wavelength (**b**) for different temperatures; Cavity spectra (**c**) and cavity central wavelength (**d**) for different strain states.

4. Discussion and Conclusions

The results demonstrate simultaneous SRI, bending, temperature, and strain sensitivity. In particular, standard FBG interrogation methods could detect temperature and strain changes independently on SRI and bending variations, while intensity based measurements could detect external SRI and bending changes independently on temperature and strain variations. In addition, the narrow reflected signal could easily allow the multiplexing of several of these cavity structures by wavelength division multiplexing.

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