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Power-referenced and self-calibrated PM-FBG vibroscope

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Abstract: A compact vibration sensing probe, in which a short section of polarization-maintained (PM) fiber stub containing a normal straight fiber Bragg grating (FBG) is spliced to another single-mode fiber without any lateral offset, is proposed and experimentally demonstrated. Two groups of well-defined resonances with ~ 7 nm wavelength separation have been achieved in reflection. Among them, the recoupled cladding modes at short wavelength side are extremely sensitive to fiber bending and provide the real-time vibration information by cost-effective power detection. Meanwhile, the unwanted power fluctuations and temperature perturbations can be referenced out by monitoring the core mode resonances at the longest wavelength.

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I. Introduction

Over the last two decades, intensive research on fiber-optic vibration sensor has been carried out and reported which is motivated by the broad applications of structure health monitor, industry process monitoring, homeland security etc. In these sensors, the recovery of the signal information is accomplished by the detection of the strain-induced wavelength changes of a FBG element. In order to simplify and reduce the cost of the interrogation scheme, some intensity-based studies have been performed for vibration measurement [1-3]. Meanwhile, it should be noted that, power-referenced sensing schemes usually suffer from light source power fluctuations and therefore an additional power reference is necessary for calibration. And finally, a compact sensing configuration (i.e., a fiber-tip probe) is really desired for the applications of small space sensing, like the “embedding” measurement.

Different form our recent papers on single mode fiber (SMF) or multi-mode fiber (MMF) based tilted fiber Bragg grating (TFBG) [4,5], which are typically characterized by recoupling the backward transmitted low-order cladding modes (ghost modes) to the upstream fiber core, here in this paper, we used a normal straight FBG inscribed in a polarization-maintained (PM) fiber to achieve the high-sensitive power-referenced vibration measurement, combining with a power-self-calibration ability. Meanwhile, an obvious spectral difference from the original reports is that, two groups of well-defined resonances with ~7 nm wavelength separation (~2 nm in the TFBG case) have been achieved in reflection, indicating these recoupled cladding modes (achieved at the PMF-SMF splicing point) are not the well known “ghost” modes. The proposed PMF-SMG-FBG sensing configuration takes the advantages of easy fabrication of grating without tilt, automated fiber splicing without any lateral offset, and strong polarization dependence which potentially can be used for orientation-recognized vibration measurement.

II. Principle and Experimental Results

We selected the high birefringence PM fibers, named “Bow Tie” PM fibers, and a pulsed ArF excimer laser with apodized scanning and the phase-mask technique for grating fabrication. A 6 mm long segment of PM fiber containing a normal straight FBG was spliced back to a 1 m long piece of SMF using a commercial Corning compact fusion splicer. The SMF-PMF-FBG sensing probe was lighted by a broadband source (BBS) and its reflection spectrum was monitored by an optical spectrum analyzer (OSA) with a resolution of 0.02 nm.

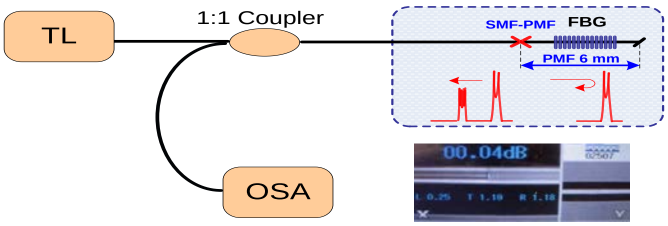

Fig. 1 Experimental setup of vibration sensing system. Inset shows the photography of a low loss SMF-PMF splicing point.

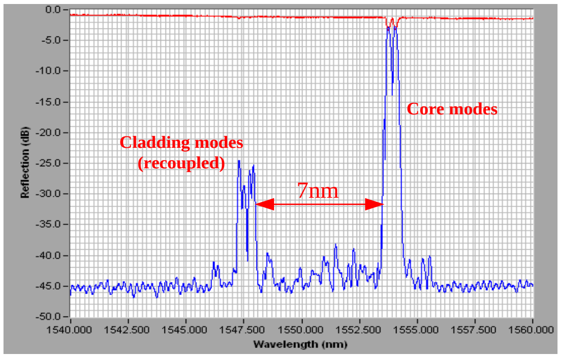

Fig. 2 Transmission & reflection spectra of SMF-PM-FBG sensing probe.

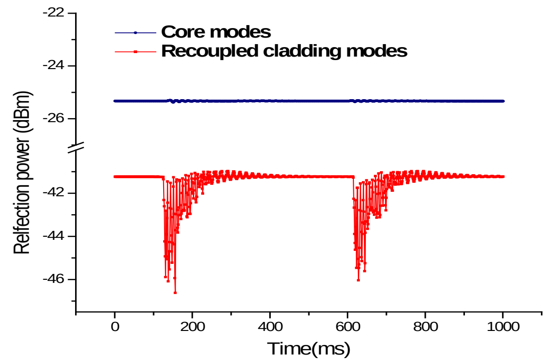

Fig.3 Real-time power output of SMF-PM-FBG sensing probe following period impulse excitations.

Fig.1 shows the experimental setup of vibration sensing system, in which the blue-dashed frame describes the configuration of SMF-PMF-FBG sensing probe and the inset shows the photography of the low loss SMF-PMF splicing point. The spectral response of proposed sensor are shown in Fig.2, as the blue line stands for reflection spectrum and the red line stands for transmission spectrum. In the reflection, we clearly see there are two groups of resonances which include a group of cladding modes on the left and two core modes on the right. As PM-FBG has different refractive index modulation along its two orthogonal directions, therefore we can get two core resonances in reflection by using one phase mask (equal to writing two gratings along "fast" and "low" axis, respectively). The wavelength gap between two core resonances is dominated by the original birefringence of the fiber (here 0.4 nm).

The most interesting thing is that there are a very strong group of cladding resonances appears at shorter wavelength side of the core resonances with a band gap about ~7 nm. Clearly, they are not the "ghost" modes defined in the early reports because there are much larger band gap and no tilt induced as grating inscription. Experimentally tests show that these cladding modes are recoupled at the SMF-PMF splicing point (which cannot be found by directly interrogating the reflection via PM fiber without splicing) and they show an extremely high sensitivity to slight fiber bending, as the red line shown in Fig. 3. More important, another power reflection (i.e. core modes reflection) is immune to any fiber bending and provides a stable reference to cancel out any fluctuations induced by light source and transmission line, as the blue line shown in Fig.3. The recoupled cladding modes also show strong polarization dependence due to they are excited by the grating in a PM fiber, which potentially can be used for orientation-recognized vibration measurement.

III. CONCLUSIONS

The feasibility of a novel vibration sensor based on SMF-PMF-FBG configuration has been demonstrated. Two independent power information can be achieved in which one is used for real-time vibration detection and another is used for self-calibration. The compact size (tip reflection), cost effective interrogation (power detection) enable the proposed sensor to good potentials for in-field applications.

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