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Fiber-optic In-line Mach-Zehnder Modal Interferometer for Breathing Monitoring Application

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***Abstract*—A simple fiber-optic in-line Mach-Zehnder modal interferometer is fabricated and studied for monitoring human being's breathing rate, which is one of the most important vital signs. The sensing structure is simply fabricated by a couple of up-tapers manufactured in the common telecommunication single mode fiber (SMF) by a commercial splicer. Sensing performances with different distances between the dual up-tapers are addressed. The whole setup only contains one laser source, one photo-detector and one section of SMF with dual up-tapers. It can real-timely monitor people's respiration rhythm without complex signal processing and the scheme is simple and low-cost.**

Keywords—Mach-Zehnder; modal interferometer; breathing monitoring; optical fiber sensor

I. INTRODUCTION

As modern society develops, people are more and more concerned with their health conditions. Meanwhile, diseases like obstructive sleep apnea syndrome may influence patients' sleeping, even threat their lives. Therefore, breath monitoring devices are required to detect people's health condition, finding latent illnesses in advance. Current breath monitoring devices based on polysomnography (PSG) [1-2] require the patient to sleep in the sleeping room overnight to record data from whole night monitoring. Recorded data includes eye movement, blood oxygen, chest movement and other dozens of physiological indicators. However, the sensors are attached directly to the skin of the user, which is invasive and uncomfortable. In addition, these traditional electrical breath monitoring devices are susceptible to electro-magnetic interference (EMI).

To overcome these drawbacks, the fiber-based miniaturized modal interferometer is a potential approach to simplify the whole system and avoid invasive touch. Favero et al. proposed a structure, where the photonic crystal fiber (PCF) is sandwiched between two single mode fibers (SMFs) [3]. It can successfully detect users' respiratory. However, PCF is relatively expensive.

In this paper, to our best knowledge, this is the first time that a simple non-invasive fiber-optic SMF-based Mach-Zehnder modal interferometer is proposed and investigated to monitor human being's breathing rate. It is constructed by two cascaded up-tapers with a 20cm interval The fabrication is simple and the cost is low because only SMF and a commercial splicer are needed. When someone lies on it, it can effectively monitor the breath rhythms.

II. THEORETICAL SIMULATIONS

The proposed dual up-tapers structure (DUTS) is shown in Fig. 1 and the picture below shows the photograph of the typical fiber up-taper. The two up-taper fibers are simulated with a waist diameter of 160-μm on a same SMF whose refractive indexes (RIs) of the fiber core and fiber cladding are set as 1.452 and 1.447 respectively.

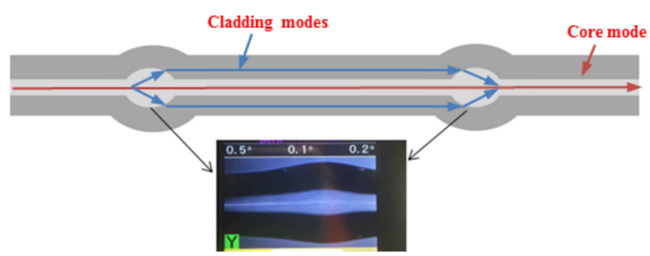

Fig. 1. Schematic structure of DUTS and the micro structure of up-taper fibers

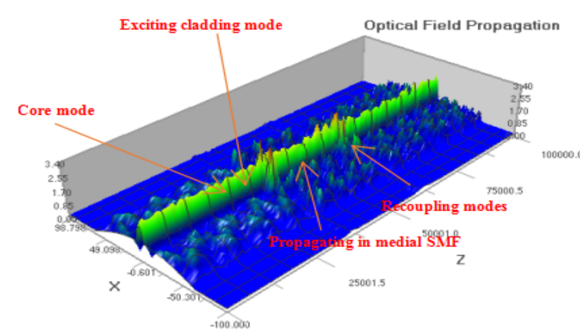

Fig. 2. Optical field propagation of DUTS

As is shown in Fig. 2, when the light propagates through the first fiber up-taper, because the mismatch of mode field diameter, the core mode are excited and parts of the inject light split into the cladding. Recoupling and interference occur when the core and cladding modes meet at the second up-taper.

III. PRINCIPLE

Assume I_{out} is the output light intensity of the DUTS, and can be given by

$$I_{out} = I_{cl} + I_{co} + 2\sqrt{I_{cl}I_{co}}\cos\Delta\varphi. \qquad (1)$$

Where I_{cl} and I_{co} are the light intensity of the cladding and core modes respectively. The phase change $\Delta\varphi$ can be expressed as

$$\Delta\varphi = \frac{2\pi}{\lambda}\cdot\Delta n\cdot L \qquad (2)$$

where L is the distance between the two up-tapers, and is the effective refractive index difference between the core and cladding modes. When a stress exerts on the proposed structure, there will be a micro deformation resulting in the change of the effective refractive index of the core and cladding modes and the L, which finally leads to a variation of the output intensity.

IV. EXPERIMENTAL SETUP

Systematic diagram of the experimental setup is shown in Fig. 3. An optical laser is used as the light source, and a photoelectric transducer is utilized to translate the optical signal to electronic signal. The DUTS is glued on a thin galvanized sheet acting as the substrate. The electronic signal is observed by an oscilloscope and collected with a data acquisition device.

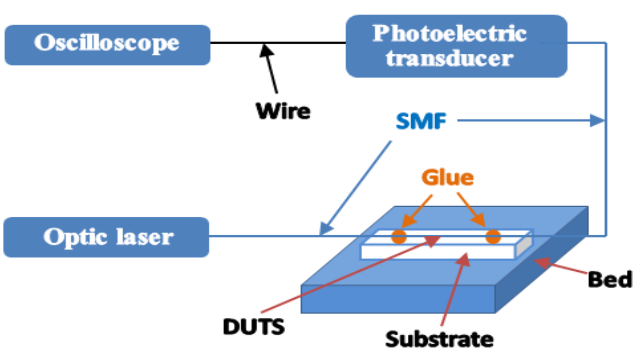

Fig. 3. Systematic diagram of the experimental setup

V. FABRICATION AND DISCUSSION

A. Fabrication of the DUTS

A commercial fiber splicer (Fujikura FSM-80S) is used to fabricate the interferometer and the fiber used is the common telecommunication SMF. In up taper fabrication process, only the value called "overlap" is set to be 147, while the other parameters, such as discharge power and duration time, etc. are set to be default. The transmitted spectrum of 20 cm-interval DUTS is shown in Fig. 4.

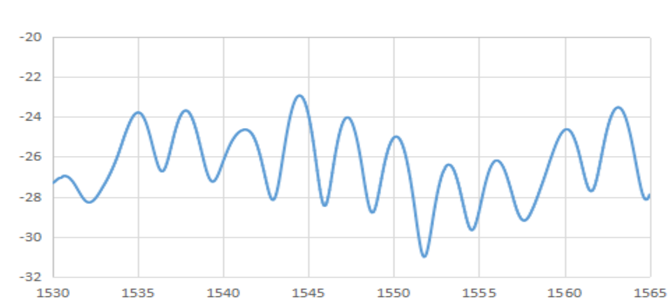

Fig. 4. Transmitted spectrum of the 20cm-interval DUTS

B. The Systematic Test

The wavelength of the laser source is set to be 1544.3nm. When the subject (denoted with subject 1) breathes, the output light intensity varies, as is shown in Fig. 5. The respiration rate is 10 times/50 sec. Every fluctuation cycle represents one time breath.

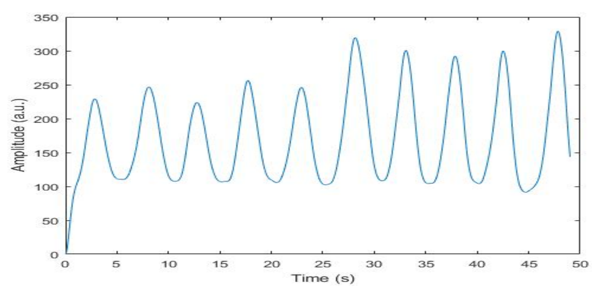

Fig. 5. Output light intensity under respiration of Subject 1

C. Other Sets of Examples

Other Subjects (2-5) with different respiratory rates are as well addressed and the results are shown in Fig. 6.

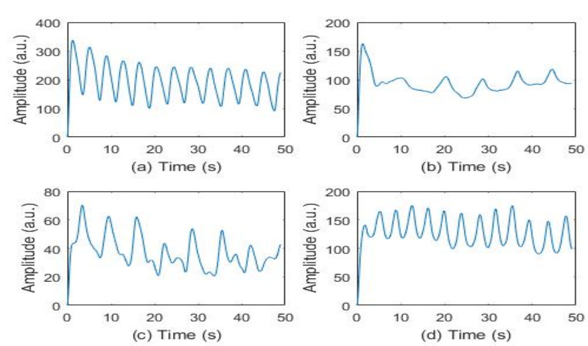

Fig. 6. Output light intensity under respiration of (a) Subject 2, (b) Subject 3, (c) Subject 4, (d) Subject 5

As shown in Fig. 6, the respiration rates for Subject 2-5 are 13, 6, 8 and 12 times per 50 seconds respectively. The proposed DUTS shows the ability to effectively monitor people's respiration in a wide range of breath rate.

VI. Conclusion

In summary, we demonstrated a simple non-invasive Mach-Zehnder modal interferometer based on dual-up-taper structure for monitoring people's respiratory rate in a wide measure range. The sensing system is non-invasive and cost-effective.

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