Coupling characteristics of two uniform microfibers

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The coupling characteristics of two uniform microfibers are experimentally demonstrated. The uniform microfiber is fabricated from a silica-based single mode fiber (SMF) using an oxy-butane flame-brushing method. With the reduction of the overlapping length, the optical power oscillation is more obvious due to the improvement in the coupling coefficient. The output spectrum is also shifted to a shorter wavelength as the overlapping length is reduced. It is observed that the average wavelength shift of 0.88 nm is obtained for every reduction of overlapping length in the order of 0.02 mm. These characteristics are useful for designing micro-scale photonic filters.

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1. Introduction

Microfibers are of interest for a range of emerging fiber optic applications, since they offer a number of useful optical and mechanical properties such as very strong evanescent field, strong confinement, flexibility, high nonlinearity, high configurability, controllable dispersion and robustness [1-5]. Initially, the development of microfiber has been promoted by the growth in demand for optical components for telecommunications and more recently as a result of their increased application in fiber sensors and lasers [6-8]. Microfibers can be evanescently coupled to form various micro-scale photonic devices, of which the evanescent coupling between the microfibers plays an important role and dictates the performances of these devices. Therefore, it is essential to study the effects and performances of a coupling between microfibers both theoretically and experimentally. Usually, a microfiber is made by stretching a heated fiber, forming a structure comprising a narrow stretched filament (the “taper waist”), each end of which is linked to unstretched fiber by a conical tapered section called the “taper transition” [9].

In this paper, we experimentally investigate the output spectrum characteristics of the coupling between two uniform microfibers. In this work, the microfibers are assumed to have uniform diameters and independent taper angle. Experimental results show that the output spectrum shift is indeed dependent on the overlapping length. A relationship between spectrum shift and the overlapping length of the coupler is also investigated. The analysis and results are given in more detail in this paper compared to other references [8-9].

2. Experiment

First, a uniform microfiber is fabricated from a silica-based single mode fibers (SMF) using an oxy-butane flame-brushing method [9]. The adiabatic tapering of the microfiber is realized by a precise movement of the stage to which the fibers are attached as well as the movement of the flame. The waist diameter of the fabricated microfiber is about 2 μm and the microfiber length includes two symmetrical transition sections each of which is about 50 mm. The microfiber is cleaved into two in the middle to get a pair of microfibers with a nearly identical structure. Fig. 2 shows the setup for evanescent coupling experiment, in which an amplified spontaneous emission (ASE) wideband source from an Erbium-doped fiber amplifier (EDFA) is injected into one end of the SMF while the other end is connected to an optical spectrum analyzer (OSA). In the experiment, two microfibers were brought in close proximity in air so that they were uniformly coupled by the assistance of two surface attractions, Van der Waals force and electrostatic force. The output spectrum characteristics due to energy exchange between two microfibers were investigated for different interaction or overlapping lengths.

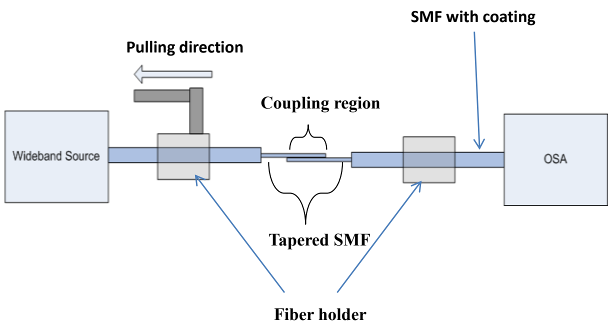

Fig. 1. Experimental setup.

3. Results and discussion

Fig. 2 shows the scanning electron microscope (SEM) image of the coupling region with a total coupling diameter of about 4.4 μm. In the experiment, the coupling length was varied by simply pulling one microfiber using the high precision optical stage while keeping the other in contact as shown in Fig. 1. First, the output spectrum of the coupler was observed for different overlapping lengths. Figs. 3(a), 3(b) and 3(c) show the normalized output spectrum of the coupler with a total coupling diameter of 4.4 μm for different overlapping lengths of 9.92, 9.90, 9.88 mm respectively. Basically, the lower and higher order modes coherently interfere and beat with each other in the coupling region, resulting in the optical power oscillating between the two microfibers as shown in Fig. 3. It can be observed that the oscillatory spectrum is more obvious when the overlapping length is shorter. This is attributed to the coupled optical power of the microfiber-based coupler being a periodic function of the overlapping length [9]. As the overlapping length increases, optical power oscillation is less obvious and the energy exchange is even smaller approaching the coupler end since the light travels in a zigzag path when the coupler is formed by microfibers. At a shorter overlapping length, light travels in an almost straight line.

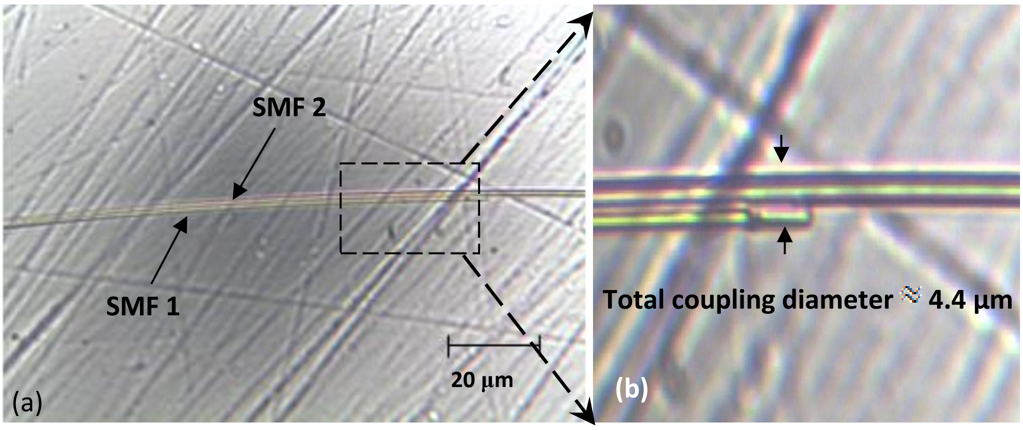

Fig. 2. SEM images of the attached microfibers with waist diameter of 4.4 μm at different views (a) normal (b) close-up.

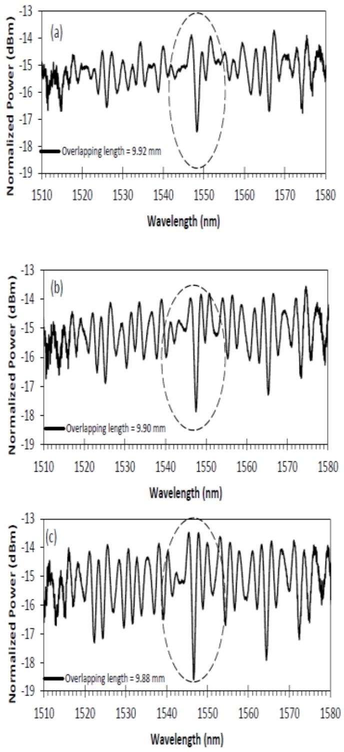

Fig. 3. Optical comb spectrum of the coupler with a total coupling diameter of 4.4 μm at three different overlapping lengths of (a) 9.92 (b) 9.90 and (c) 9.88 mm. A section of the spectrum which is marked in dashed-circle is observed to change with the overlapping length.

As also observed in Fig. 3, the output spectrum shifts to a shorter wavelength as the overlapping length is reduced. Fig. 4 shows close-up view of the optical power distributions which are obtained when the overlapping length is reduced from 9.96 mm to 9.88 mm in a step of 0.02 mm. As shown in the figure, when the overlapping length is decreased from 9.96 mm to 9.94 mm, the wavelength shifts of about 0.93 nm towards a shorter wavelength is obtained. As the overlapping length is further reduced to 9.88 mm, the average wavelength shift is around 0.88 nm as the overlapping length $\Delta\lambda$, is reduced in the order of 0.02 mm. This is attributed to the change in the interaction pathlength, which affects the interference. Fig. 5 shows the relative output power as a function of the overlapping length. It is obtained that the output power decreases as the ovelapping length increases from 9.88 mm to 9.96 mm. This is attributed to the strong dependence of the coupling effeciency with overlapping length. These results show that this architecture can be potentially used as a filter by carefully controlling the profiles and overlapping lengths of the microfibers, which provides an alternative way for designing micro/nano scale filters.

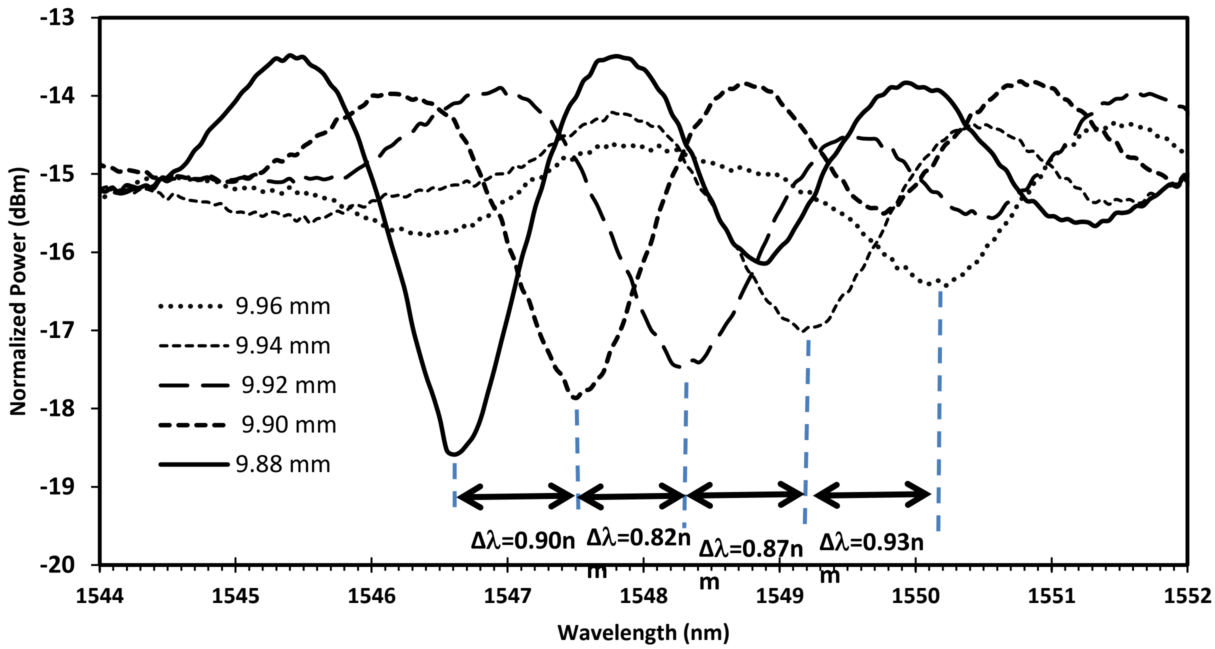

Fig. 4. Close-up view on the optical power distribution for different overlapping length. Wavelength shift is observed at nanometer scale.

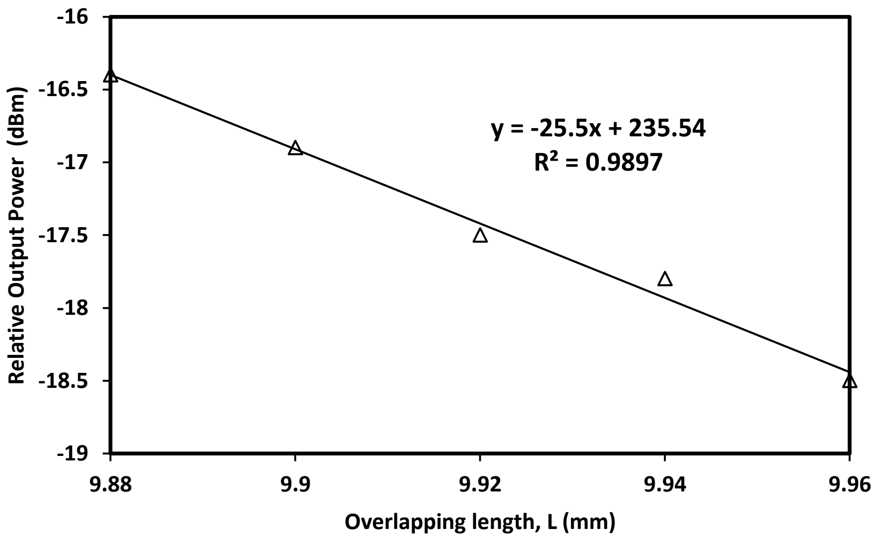

Fig. 5. Relative output power as a function of overlapping length.

4. Conclusion

The oscillatory spectrum obtained by the coupling between two uniform microfibers is investigated. The microfiber is made from a standard SMF using a flame brushing technique. It is observed that the optical power oscillation is more pronounced at a shorter overlapping length. The linear relationship is also obtained between the output spectrum wavelength and overlapping length. The optical spectrum is shifted to a shorter wavelength region as the overlapping length decreases at a rate of around 0.88 nm / 0.02 mm.

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