Optical Fiber Micro Spectrometer Employing Self-Focusing Radiated Tilted Fiber Grating

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Abstract: We propose and demonstrate an all-fiber micro spectrometer based on self-focusing radiated tilted fiber grating, which has the tunability in both spectral resolution and measurement range by simply changing the radian curvature of the self-focusing radiated tilted fiber grating.

1. Introduction

With the rapid development of spectral analysis technology, optical spectrometer has been one of the most important instruments in the field of industry, medicine and agriculture. Conventional spectrometers consist of many bulky optical elements including slit, dispersive element, lens system and detector and require delicate system design and complex components to achieve high spectral resolution and wide spectral range. With the popularization of spectral analysis technology, there is an increasing requirement for miniaturizing and lowing cost of spectrometers [1]. It has been proposed to use a concave grating which has the ability of both light dispersion and focusing to avoid focusing lenses to reduce the footprint of the spectrometers [3,4]. Even though omitting the lens system can significantly reduce the volume of the spectrometers, fabricating concave grating requires a high-precision control of etching and results in high device price, which limits the application of concave grating in cost sensitive miniaturized spectrometers. A compact spectrometer based on in-fiber diffraction grating has been proposed in [2], in which a 45° radiated tilted fiber grating (RTFG) was utilized as an in-fiber dispersive element to replace traditional volume diffraction grating. For the 45° RTFG, the transmitted light will be coupled out of the fiber core and emitted from the side in a nearly vertical direction [5]. Different from the planar silicon waveguide [6], optical fiber is much more flexible and can be bent freely. Applying a small curvature to the 45° RTFG has a negligible impact to light coupling from launched core mode to cladding modes which determines the transmission characteristics of the RTFG but will alter beam emission direction spatially along the RTFG.

In this paper, we propose a compact and low-cost all-fiber spectrometer employing a self-focusing 45° RTFG, in which the RTFG is curved in an arc fiber structure with a certain radius of curvature. Performing similarly as the concave grating, a curved 45° RTFG adds a quadratic phase distribution to the light emission leading to beam convergence at the focal plane where wavelengths are separate in space. The proposed spectrometer is only composed of a curved 45° RTFG and a detector array with 512 pixels. The proof-of-concept spectrometer prototype has a small footprint of 50×50×20 mm after mitigating the lens systems. By changing the radius of curvature of the RTFG, wavelength separation at the focal plane can be adjusted, resulting in a tunable spectral resolution and range. We experimentally demonstrate an all-fiber spectrometer with a finest resolution of 0.53 nm and a maximum wavelength range of 300 nm from 1400 nm to 1700 nm.

2. Principle

The schematic of the micro spectrometer based on self-focusing RTFG is shown in Fig. 1(a), in which the radiated light at the same wavelength from different positions of grating has the different emission angle by curving the RTFG into an arc structure, and finally converges on same pixels of the detector array. The detector array is located at the focal plane. The focal length is determined by the radius of curvature of the RTFG. The focusing process of self-focusing RTFG and lens based RTFG are given in Fig. 1(b) and (c). All-fiber spectrometer employing the self-focusing RTFG has a shorter spatial light path which is beneficial in reducing system footprint.

A RTFG with a tilted angle between 23° and 67° along the fiber axis can radiate the core mode out from the fiber at a wavelength dependent emission angle. As shown in fig. 1(d) and (e), the RTFG is fabricated in single mode fiber by UV-exposure, which has a grating period of 788 nm and a tilted angle of 45°, corresponding to a radiation wavelength range of 1400 to 1700 nm [7].

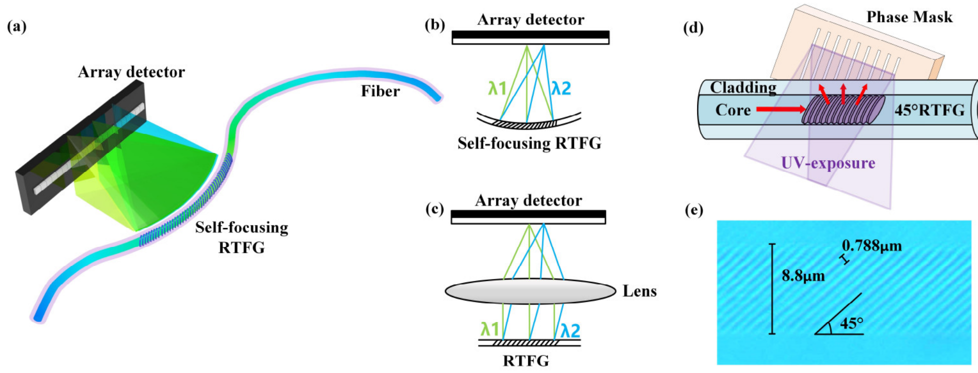

Fig.1 (a) Schematic of the all-fiber micro spectrometer based on self-focusing RTFG, the focusing process of (b) self-focusing RTFG and (c) lens based RTFG, (d) Fabrication of 45° RTFG by UV-exposure and (e) Micrograph of 45° RTFG.

3. Experimental results and discussion

The spectrometer prototype is illustrated in Fig. 2(a), a self-focusing RTFG is fixed on a curved flexure structure that has a radius of curvature of 50 mm. The detector array has a pixel size of 25 μm×500 μm and number of total pixels of 512 along the propagation direction of the RTFG. A tunable laser with the wavelength range between 1480 nm and 1640 nm is used to characterize the spectral response of the spectrometer. Fig. 2(b) shows the light distribution on the detector array with a single wavelength input. Fig. 2(c) shows the spectral response by sweeping the laser from 1480 nm to 1640 nm with a wavelength increment of 10 nm where 17 clear spectral peaks can be clearly identified. The intensity at each wavelength is normalized. The full width half maximum (FWHM) of the system over the whole wavelength range is given in Fig. 2(d), which has a variation range between 50 μm and 80 μm mainly caused by optical aberration. The line dispersion by applying different radius of curvatures R (30 mm,50 mm,100 mm) to the self-focusing RTFG is shown in Fig. 2(e), where all the three dispersion curves provide great linearity and the values of the linear dispersion are 27.451 μm/nm, 46.183 μm/nm and 94.805 μm/nm, respectively. The linear dispersion is proportional to the radius of curvature, which indicates that the spectrometer employing the self-focusing RTFG with a bigger radius of curvature will have a higher resolution but a narrower wavelength range using a detector with a fixed size. The measured resolution under three different radii of curvature, 30 mm, 50 mm and 100 mm is 1.82 nm, 1.08 nm and 0.53 nm, respectively, with associated bandwidth range of 455 nm, 270 nm and 132 nm. Current supported wavelength range is around 300 nm limited by the emission range of the RTFG which can further enlarged by cascading the RTFGs of different radiation wavelength range.

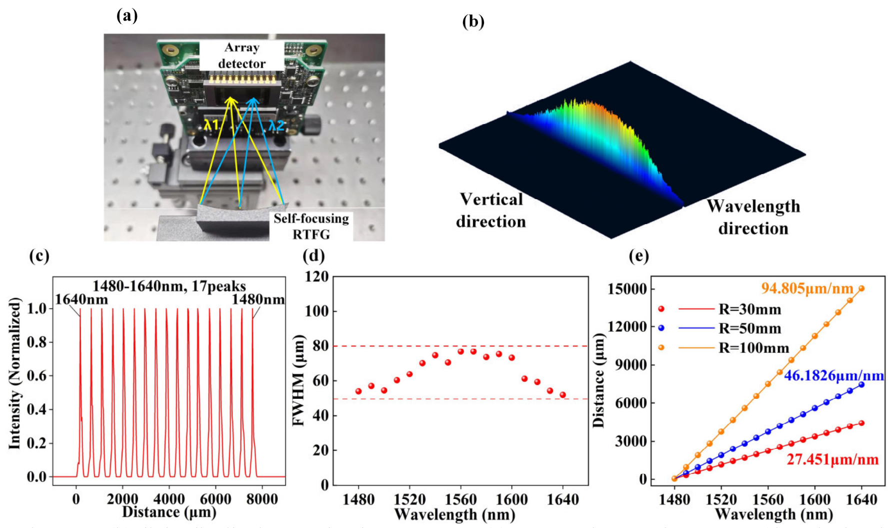

Fig.2 (a) Experimental set up, (b) light distribution on the detector array, (c) measured spectral response, (d) 3-dB bandwidth with different wavelength from 1480 nm~1640 nm and (e) line dispersion curve under different radius of curvature R (30 mm,50 mm,100 mm)

We use a fiber Bragg grating (FBG) demodulation system to evaluate the performance of the all-fiber micro spectrometer, as shown in Fig. 3(a), where a broadband amplified spontaneous emission (ASE) source is applied. Transmission spectra of the FBG with a sharp notch at the wavelength of 1550 nm are measured using both 1) the proposed micro spectrometer with a spectral resolution of 1 nm and a range of 270 nm and 2) a commercial optical spectrum analyzer (OSA, YOKOGAWA) under a resolution of 1 nm, see Fig. 3(b). The spectral shape measured by the all-fiber micro spectrometer nicely overlaps the one captured by the commercial OSA, confirming its decent spectral analysis performance. Small power discrepancies at some wavelength range are mainly caused by the wavelength-dependent responsivity of the detector array which can be mitigated after calibration. The size of the all-fiber micro spectrometer in the system can be compressed to about 50×50×20 mm including the printed circuit board of the detector array.

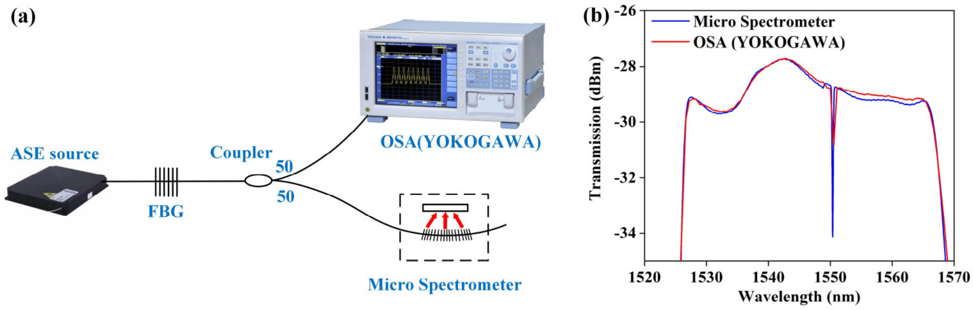

Fig.3 (a) Testing set up for the spectral performance of the all-fiber micro spectrometer, (b) Transmission spectrum.

3. Conclusion

We experimentally demonstrated an all-fiber micro spectrometer based on self-focusing RTFG for the first time. The RTFG is slightly curved to enable beam self-focusing and wavelength separation at the detector plane. The spectrum resolution and range can be adjusted by changing the radius of curvature of the RTFG. All-fiber micro spectrometer showed a finest resolution of 0.53 nm and a maximum wavelength range of 300 nm, limited by the emission wavelength range of the RTFG which will be further enhanced in our future work. The all-fiber micro spectrometer with a compressed volume of 50×50×20 mm shows a comparable performance to a commercial OSA in spectral analysis.

4. Acknowledgment

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5. References

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