Multimode Interference Tunable Filter in Chalcogenide Fiber

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Abstract—**We demonstrate a tunable multimode interference filter, assembled with chalcogenide fibers. This filter has an insertion loss of 1.46 dB, a FWHM bandwidth of 26 nm, and a wavelength tunability of 84 nm from 1926 nm to 2010 nm.**

Keyword—tunable filter, chalcogenide fiber, multimode interference, core offset

1. Introduction

Tunable filters compatible with the wavelength range of 2-12 µm in the mid-infrared (MIR) are desirable for their applications in laser systems, spectroscopy, optical sensing, and free-space communication systems. Compared to MIR tunable filters in bulk materials [1] or MEMS [2], an all-fiber solution has outstanding advantages that include robustness, optical beam stability, compactness, and interconnection with other optical fiber components. Chalcogenide glass fibers such as As_2Se_3 are transparent in the MIR up to 12 µm with intrinsically high nonlinearity and photosensitivity. They also constitute a good platform to build MIR optical components such as fiber couplers, supercontinuum sources, amplifiers and fiber filters.

All-fiber and MIR compatible tunable filters demonstrated in the past include fiber Bragg gratings (FBG) [3], fiber acoustic-optic filters [4], Fabry-Perot (FP) filters [5], and long period grating filters. In addition to the existing MIR compatible tunable filter technologies, multimode interference (MMI) filters composed of singlemode-multimode-singlemode (SMS) structure provide simplicity, ease of fabrication, and low cost, in addition to high performance [6]. MMI filters are easily used in a transmission configuration. Wavelength tuning is accessible via mechanical bending [6].

In this letter, we demonstrate the first all-fiber chalcogenide MMI tunable bandpass filter. A multimode As_2Se_3 fiber is fabricated following a procedure depicted in [7]. The multimode As_2Se_3 fiber is butt-coupled to single mode fiber (SMF) by UV epoxy, ensuring a well-controlled core to core offset.

2. Theoretical analysis

The MMI filter consists of SMS fiber structure with core to core offset as depicted in Fig. 1. The MMF segment is a three-layer structure with an As_2Se_3 core, a Cyclo Olefin Polymer (COP) cladding, and a PMMA coating [7]. The fundamental mode that propagates in SMF excites a set of eigenmodes when coupled to the MMF. The interference among guided modes at the MMF output gives rise to self-imaging effects.

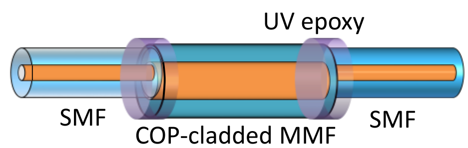

Fig.1. Singlemode-multimode-singlemode fiber structure with core to core offset.

The input field is decomposed into linearly polarized eigenmodes (LP_{nm}) of MMF, where n and m are the indices for the guided azimuthal and radial components. The field distribution is expressed as the superposition of all excited modes [8]:

$$E_{MMF}(r,\theta,z) = e^{-i\beta_{0,1}z} \cdot \sum_{n=-N}^{N}\sum_{m=1}^{M} C_{n,m}E_{n,m}(r,\theta)e^{-i(\beta_{n,m}-\beta_{0,1})z} \quad (1)$$

where $C_{n,m}$, $\varphi_{n,m}(r,\theta)$ and $\beta_{n,m}$ are the mode excitation coefficient, field profile and propagation constant of the LP_{nm} mode, respectively. Thus, the transmission spectrum depends on the modes and their relative power that are excited in the MMF segment. Especially, the transmission spectrum could be tuned through adjusting the offset at the SMF-MMF interfaces. The induced offset also increases the extinction ratio while keeping the peak transmission.

3. Experimental characterization and discussion

Figure 2 illustrates the setup to characterize and tune the MMI filter, including a supercontinuum (SC) source, the MMI filter, an optical spectrum analyzer (OSA), and a translation stage. The SC source provides a broadband spectrum from 1200 nm to 2100 nm. The multimode As_2Se_3 fiber has a length of 67 mm and core/clad diameter of 40/190 µm with refractive index (RI) of 2.8/1.49. The MMI filter is attached on a rectangular beam that is bent under compression of a translation stage with displacement of Δs. The RI distribution is asymmetric due to both curvature change and induced stress-optic effect, resulting in asymmetric mode distribution and varied propagation constant of each mode. In consequence, the interference pattern observed via the transmission spectrum of the MMI experiences a wavelength shift.

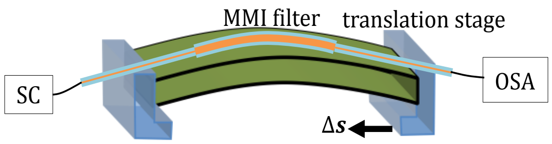

Fig. 2. Schematic to characterize and tune the MMI filter.

Figure 3 shows the measured transmission spectrum of the MMI filter. It has a transmission peak at a wavelength of 1955 nm, an insertion loss of 1.46 dB, a FWHM bandwidth of 26 nm and an extinction ratio of 17.2 dB. Transmission peaks have a free spectral range of 130 nm.

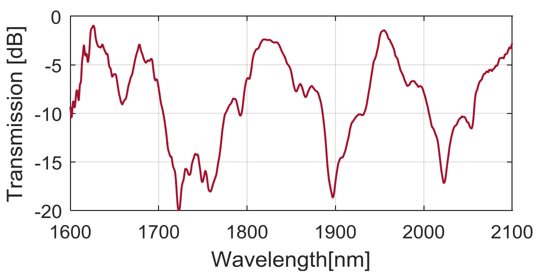

Fig. 3. Transmission spectrum of the MMI filter.

Figure 4a shows wavelength-tuning of a filter transmission peak in response to bending of the MMF. First, the peak initially centered at a wavelength of 1952 nm shifts continuously to 1926 nm. Then, a second peak at 2010 nm wavelength emerges and is continuously tuned to 1952 nm to complete a tuning cycle. Thus, the total single peak wavelength tunability is 84 nm, covering 1926 nm to 2010 nm. Figure 4b illustrates the detailed wavelength shift with the displacement. The peaks shift to shorter wavelengths as the curvature increases.

4. Conclusion

In conclusion, we have investigated the first all-fiber chalcogenide MMI tunable bandpass filter assembled with SMS structure. Core to core offset is especially induced. The filter consists of the As_2Se_3 MMF showing great stability and wide tunability through mechanical bending. With the available lab instruments operated around the wavelength of 2 µm, transmission spectrum from 1600 nm to 2100 nm is measured. The fabricated chalcogenide MMI filter has a single wavelength tunability of 84 nm, an insertion loss of 1.46 dB, an extinction ratio of 17.2 dB, as well as a FWHM bandwidth of 26 nm. It is worth noting that the central wavelength could be customized at any MIR wavelength by controlling the length, diameter and coupling condition of the MMF. By constructing this type of MMI filter with all chalcogenide segments, it illustrates an easy and low-cost solution for MIR compatible tunable filters with great potential in the application of MIR tunable lasers and mode-lock lasers.

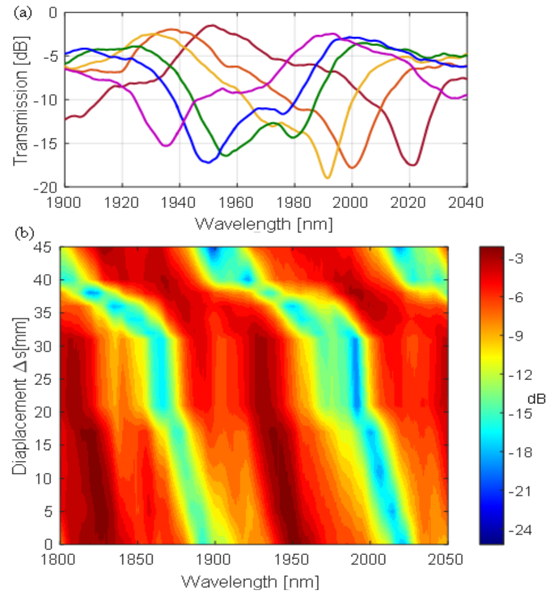

Fig. 4. (a) Tuning transmission peak of the MMI filter. (b) Relationship between displacement and wavelength shift.

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