Chalcogenide Fabry-Perot Fiber Tunable Filter

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***Abstract*—We present an all-fiber Fabry-Perot filter that consists of chalcogenide fibers terminated with high-reflectivity coatings. The tunable filter has large free spectrum range over 300 nm and a finesse of 15.**

Keyword*—*mid-infrared, tunable filter, chalcogenide fiber

1. Introduction

The mid-infrared (MIR) wavelength range, spanning 2-20 μm, is attractive for both research and technology applications. The strong characteristic molecular absorptions in the MIR are most useful to chemical sensing and laser cutting. Free-space communications utilize the transparent windows of earth's atmosphere at 3-5 μm and 8-13 μm. The MIR also has minimal collateral damage while treating with soft tissues [1]. With an aim to build all-fiber systems that operate in the MIR, building-block components need to be designed.

Several all-fiber optical filter technologies have been developed for telecommunications, including tunable Fabry-Perot (FP) filters [2]. However, these filters are limited to wavelengths <2 μm. This motivates the fabrication of a MIR compatible, all-fiber tunable filter.

In this report, we present the first all-fiber Fabry-Perot tunable filter (FFP-TF) based on thin-film coated chalcogenide fibers. Chalcogenide glasses such as As_2S_3 and As_2Se_3 are transparent to MIR transmission up to 11 μm and 15 μm [3]. Such fibers are coated with high-reflectivity thin films made from calcium fluoride (CaF_2) and Germanium (Ge) to enable FP operation up to 13 μm, limited by the transparent window of these two materials. To the best of our knowledge, this is the first demonstration of FP filter made of Chalcogenide glass. The joint deposition of mid-infrared-compatible CaF_2 and Ge to obtain high-reflectivity (HR) coatings is also demonstrated for the first time..

2. Design

Fig. 1. shows the structure of the FFP-TF. As_2S_3 fibers provided by *CorActive High-Tech* are used as substrates for the deposition of dielectric materials. The deposited quarter-wavelength multilayer structure is designed to get broadband high-reflectivity centered at a desirable spectral region. A ferrule or V-groove may be adopted to keep the alignment of the fibers and tuning is achieved by changing the air gap distance within the cavity.

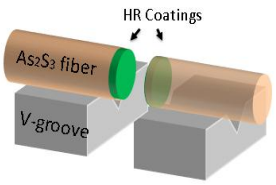

Fig.1.Structure of FFP-TF.

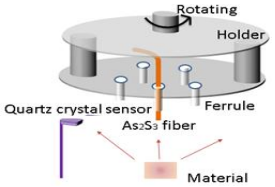

Fig.2. Electron-beam evaporation system.

The choice of materials for HR coatings mainly depends on factors such as (1) refractive indices, (2) transmission wavelengths, (3) compatibility with other materials and (4) stability of the multilayer structure. Here, we choose CaF_2 as the low refractive index material with $n_L = 1.42$ at $\lambda = 2$ μm [4], and Ge as the high refractive index material with $n_H = 4.1$ at $\lambda = 2$ μm [5]. These coatings are applied using electron-beam evaporation because of its compatibility with a variety of materials and ease of operation.

3. Experiment

Multilayered coatings are deposited on polished fiber facets in the electron-beam evaporation machine, schematized in Fig. 2. One end of the fiber is kept on the holder and the other end goes through a ferrule to keep the fiber vertically oriented. The holder is rotating to improve the coatings uniformity. Dielectric materials are heated and diffused by an electron-beam and subsequently condense on fiber facets. During deposition, thickness is monitored using a quartz crystal sensor and the chamber pressure is kept under 5×10^{-6} Torr.

Before multilayered coatings deposition, it is necessary to calibrate the crystal sensor and the real refractive index for each material. For this purpose, a single layer of CaF_2 and Ge is deposited on a piece of silicon chip. Then the thickness is verified using a surface profiler (Dektak 150), ellipsometer and thin-film thickness reflection measurement system.

To fabricate HR coatings, materials with high and low refractive index are alternately deposited on the fiber facets with quarter-wavelength ($d_i = \lambda_c / 4n_i$) thicknesses. The thickness accuracy of each layer is controlled within an error of 15 nm, which corresponds to the stability of the quartz crystal sensor. The center-wavelength of HR coating is arbitrarily set to 1.6 μm in this experiment, resulting into layer

thicknesses of 305 nm and 97 nm for CaF_2 and Ge, respectively. The deposition rate is set to 1.5 to 2 Å/s. HR coatings with structure of "HLH" and "HLHLH" are deposited on As_2S_3 fibers. The optical properties of the deposited coatings are characterized using a supercontinuum source and an optical spectrum analyzer. The FP cavity consists of two fibers with HR coating facing each other as shown in the Fig. 1.

4. Results and discussion

It is theoretically expected that the HR coatings as described will cover a broad spectral range of 1.1-2.8 µm. Fig. 3. shows the measured reflection spectrum of multilayered coatings on As_2S_3 fibers. The surface roughness of the coating is measured using atomic force microscopy. A roughness of 10 nm is observed, with an expected impact to reduce the theoretical reflectivity.

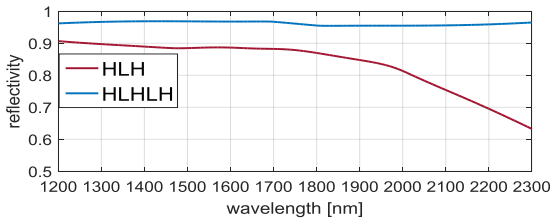

Fig. 3. Reflection spectrum of HR coating on As_2S_3 fiber.

The FP features of different cavity lengths are obtained in Fig. 4. A FSR of 300 nm with a finesse of 15 is obtained using air gap or gap with index matching liquid. The finesse might be limited by the coupling loss of the cavity gap. And the micro-lens formed by liquid drop on fiber tips can increase the finesse to 27, though the FSR is then below 25 nm.

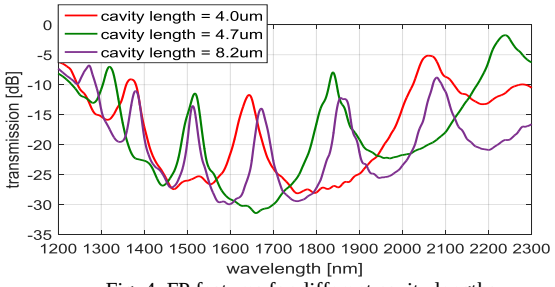

Fig. 4. FP features for different cavity lengths.

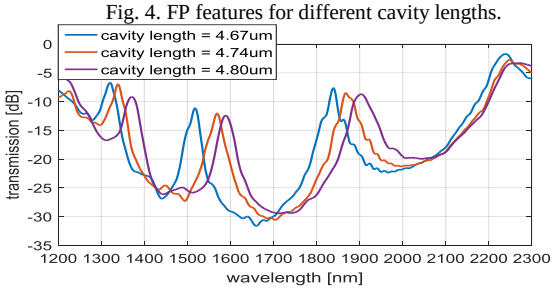

Fig. 5. FP features within 0.2 um variation of cavity length.

By changing the cavity length with small increments, FP transmission peaks are continuously shifting as shown in Fig. 5. A tunable filter with FSR above 300 nm and a finesse of 15 are obtained. The fiber to fiber insertion loss consists of a constant ~3 dB loss while an additional that wavelength-dependent loss is also observed. We believe that the wavelength-dependent loss arises from the Gaussian free-space propagation among two flat mirrors and also from imperfections in the HR coating.

5. Laser with Fabry-Perot filter

The FFP-TF with transmittance shown in Fig. 4 has been used in the assembly of a Tm-doped all fiber tunable laser shown in Fig. 6. An EDFA with a power of 1.5 W pumps the Tm-doped fiber via a 1550 nm/1850nm wavelength-division multiplexer. An isolator removes any unwanted back-propagation light in the loop. The laser wavelength tuned from 1835nm to 1920nm is illustrated in Fig. 7.

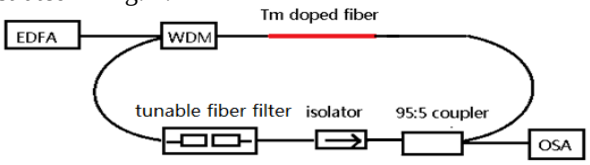

Fig. 6. Tm-doped all fiber tunable laser

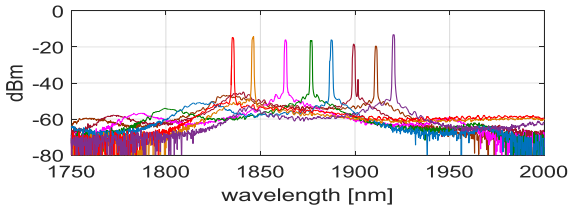

Fig. 7. Tuning of the Tm-doped laser wavelength

6. Conclusion

An all-fiber Fabry-Perot filter based on chalcogenide fiber has been demonstrated for the first time. The tunable FP filter has a free spectral range >300 nm and a finesse of 15. Stable multilayers of CaF_2 and Ge have been evaporated on As_2S_3 fiber facets to produce high-reflectivity coating compatible with the MIR. A tunable laser is constructed with this MIR-compatible tunable filter. Such filter design is beneficial for MIR applications.

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