Bandpass Filters on End-Faces of Optical Fibers

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Abstract *Bandpass filters based on a Fabry-Perot structure are coated on end-faces of optical fibers. The layer design and the deposition process were optimized to achieve high transmission. Bandwidths of less than 1 nm were obtained.*

Introduction

We have developed thin film Fabry-Perot filters which act as narrow bandpass filters directly coated on fiber end-faces. This is to achieve a very high level of integration with a reduction of optical elements. Such filters have the potential for mass production because of the very small fiber cross-section. A combination of such filters can be integrated in very compact modules, which are flexible in resolution and spectral range.

Filter coatings on fiber end-faces

For filter fabrication, substrates are coated with quarter wave layers consisting of Ta_2O_5 and SiO_2 deposited by electron-beam evaporation. The fiber end-faces are cleaved. After cleaving, the fiber end-faces were subjected to multi-step cleaning procedures before deposition. Wet chemical as well as high electric field cleaning procedures were tested to achieve coatings with highest quality. Further details about the preparation of the fiber end-faces before coating are described elsewhere[1]. Methods to increase the adherence of the coatings on the fiber end-faces and to achieve high damage thresholds are described in Meister et al.[2,3].

Absorption losses in Fabry-Perot filters are a very important issue. Even very small k-values of the coating materials can lead to significant transmission losses due to the multiple reflections in the filters. The coated fibers are tempered at 200°C to decrease stoichometeric defects in the Ta_2O_5 layers and to reduce the absorption to $k = 3.8 \cdot 10^{-5}$ at a wavelength of 945 nm.

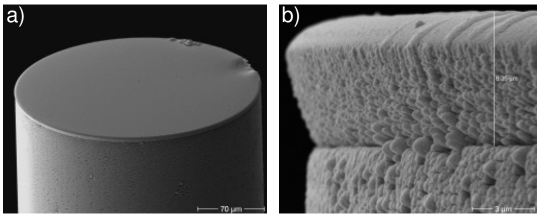

Fig. 1: SEM images of a) the entire fiber end-face coated with a stack of 44 quarter wave layers, and b) side view of this filter-coating (physical thickness ~6 µm)

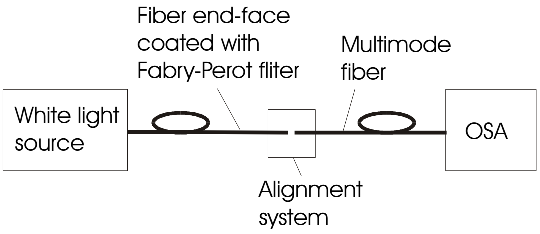

Fig. 2: Experimental setup for transmission measurements of Fabry-Perot filter directly coated on fiber end-faces

Fig. 1 shows scanning electron microscope (SEM) images of a fiber end-face coated with filter consisting of 44 quarter wave layers with a physical thickness of ~6 µm. The filters are designed for a wavelength of 945 nm.

Experimental setup

The optical performance of the filter-coatings was analyzed by means of an Optical Spectrum Analyzer (OSA) with a minimum resolution of 0.1 nm. The filters were illuminated over a broad spectral range provided by a white light source.

The transmission spectrum of the bandpass filters are measured with the setup seen in Fig. 2. The filters are coated on the output of a standard single mode fiber (SMF28). A second uncoated multimode fiber (62.5 µm core diameter) was precisely aligned close to the fiber end-face coated with the Fabry-Perot filter. To determine the filter losses, the spectral transmission was compared to the spectral intensity of the white light transmitted through an uncoated fiber.

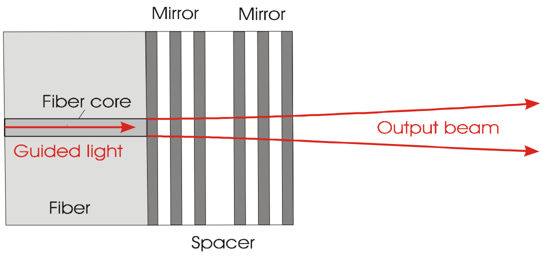

Fig. 3: Illustration of a beam (single-) passing a Fabry-Perot filter at the output of a single mode fiber

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Tab. 1: Transmission -3dB bandwidths and filter losses at 945 nm wavelength depending on the stack formula of Fabry-Perot filters on fiber end-faces

Filter formula	Experimental bandwidth [nm]	Theoretical bandwidth [nm]	Experimental filter losses [dB]	Theoretical filter losses [dB]
$(HL)^6HLL(HL)^6H$	4.5	4.50	-0.8	-0.45
$(HL)^7HLL(HL)^7H$	2.2	2.21	-1.2	-0.78
$(HL)^8HLL(HL)^8H$	1.3	1.15	-2.2	-1.45
$(HL)^9HLL(HL)^9H$	0.9	0.68	-3.8	-3.23
$(HL)^{10}HLL(HL)^{10}H$	0.7	0.51	-7.5	-8.2

Results and discussion

Fabry-Perot filters containing a single λ/2 spacer are coated on the fiber end-faces. Filters with different numbers of λ/4 layers in the mirror stacks are investigated, which corresponds to a change of the reflectivity of the filter mirrors.

Fig. 4 shows the transmission spectrum of a Fabry-Perot filter directly coated on a fiber end-face as well as the white light spectrum (upper line) transmitted through a comparable but uncoated fiber. The stack formula of this filter was $(HL)^7HLL(HL)^7H$, where H indicates high-index and L indicates low-index layers. The -3 dB bandwidth of the transmission peak is 2.2 nm. The transmission loss of the filter is 1.2 dB.

The number of layers in the mirror stacks and therefore the reflectivity of the mirrors are varied to investigate its effect on the optical performance of the Fabry-Perot filter on fiber end-faces. The reflectivity was successively increased by additional pairs of high and low index layers. The results of the transmission measurements are summarized in Tab. 1.

The influence of the divergent output beam has to be considered for theoretical calculation of the transmission spectrum. Nevertheless the optical thickness of the Fabry-Perot filter is much shorter than the Rayleigh length of the beam and therefore the beam is well collimated during a single pass through the filter, see Fig. 3, the beam divergence is not negligible if one considers multiple reflections in the filter. The effective bandwidth of the filter illuminated by a divergent beam will appear broader, because the transmission function is a sum of the functions for each angle of incident. This also results in a reduction of the maximum transmission[4,1]. Theoretical calculated bandwidths as well as losses of the filters considering divergent output beam of a Gaussian shape and a layer material absorption of $k = 3.8*10^{-5}$ are given in Tab. 1.

For the first 3 filters, the experimentally measured filter bandwidths are in a good agreement with the calculated bandwidths. This filters show moderate losses of up to 2.2 dB. There are additional losses for the measured filters compared to the calculated ones. The filter with stack formula $(HL)^{10}HLL(HL)^{10}H$ on a fiber end-face shows a transmission bandwidth of 0.7 nm, but the filter loss is with -7.5 dB very high.

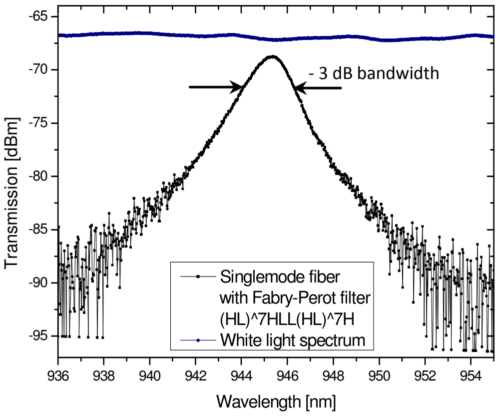

Fig. 4: Transmission spectrum of a bandpass filter directly coated on the end-faces of a SMF28 fiber

Conclusion

It can be concluded that the divergent output beam of the fibers has a significant influence on the -3 dB bandwidths as well as on the filter losses for Fabry-Perot filters with very high reflectivity (last two filters in Tab. 1).

Fabry-Perot filters coated on fiber end-faces with up to $(HL)^8HLL(HL)^8H$ quarter wave layers are well suited as bandpass filters for fiber optical applications.

Acknowledgement

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References

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