Spectral response analysis of novel tapered fiber Bragg gratings based Fabry-Perot interferometer

Konrad Markowski[1*], *Piotr Araszkiewicz*[1], *Juliusz Bojarczuk*[1], *Tomasz Osuch*[1,2]

[1]*Warsaw University of Technology, Institute of Electronic Systems, ul. Nowowiejska 15/19, 00-665 Warszawa*
[2]*National Institute of Telecommunications, Szachowa 1, 04-894 Warsaw, Poland*

1. Introduction

The new concept of Fabry-Perot interferometer (FPI) that consists of two linearly chirped fiber Bragg gratings (TCFBG) written in tapered optical fiber is presented. In this structure, the Bragg mirrors parameters, i.e. grating length, chirp rate, as well as location and configuration with respect to the taper profile determines their properties, such as: spectral width and the resultant chirp. In particular, various configurations of FPI consisting of TCFBGs of various lengths (and thus different spectral responses) written in thermally tapered optical fiber are studied.

Numerical analysis of proposed FPI is based on modified coupled mode theory and transfer matrix method [1], [2]. The influence of both, gratings and tapered optical fiber parameters on spectral responses is considered. Due to the different temperature and strain response of such a FPI, it can be used as a two parameters sensor.

2. Theory and mathematical model

In presented concept of Fabry-Perot interferometer (FPI), two fiber Bragg gratings is considered as inscribed in taper transition that corresponds to their significantly different spectral widths. Furthermore, the dimensions and taper profile have been chosen so that only one fundamental mode will be propagating through presented structure. Thus, for further calculations, propagation of fundamental mode – LP_{01} – is considered. For presented configurations, real taper diameter, which is represented by Fig. 2, is used.

To mathematically evaluate spectral response of FP interferometer, coupled mode theory (CMT) and transfer matrix method (TMM) notation is used. CMT differential equations are used to describe the interaction of the EM wave with the periodical fiber structures. However, TMM notation elements are one of a form of solutions of these equations for the fiber Bragg grating structures [2]. These two mathematical approaches can provide an easy apparatus to create model of fiber Bragg gratings structures with flexible parameters. Like in [3], presented numerical analysis is based on piecewise uniform approach, where one grating is divided into finite number of homogeneous uniform sections. In presented mathematical approach, the tapered fiber Bragg gratings model [1] is used.

One may say that Fabry-Perot interferometer, which is the subject of this poster, can be described as two tapered chirped fiber Bragg gratings (TCFBG) separated by cavity. Furthermore, the whole FPI can be represented by the following formula:

$$T_{FP} = T_{TCFBG_1} * T_{PS} * T_{TCFBG_2} \quad (1)$$

where T_{TCFBG_1}, T_{TCFBG_2} are matrices describing the first and second grating. T_{PS} is phase shift matrix corresponding to the cavity length.

To form F-P interferometer in tapered optical fiber, resonant wavelengths of both TCFBGs should be matched. Thus the following condition should be satisfied [1]:

$$\Lambda_2 = \frac{n_{eff_1}}{n_{eff_2}} * \Lambda_1 \quad (2)$$

where Λ_1, Λ_2 are periods of first and second grating; n_{eff_1} and n_{eff_2} are effective refractive indices for the first and second TCFBG.

Having a FPI matrix, reflectance can be calculated using the following formula [2]:

$$R(\lambda) = \left|\frac{T_{FP_{21}}(\lambda)}{T_{FP_{11}}(\lambda)}\right|^2 \quad (3)$$

where $T_{FP_{21}}(\lambda)$ and $T_{FP_{11}}(\lambda)$ are elements of the FPI T-matrix..

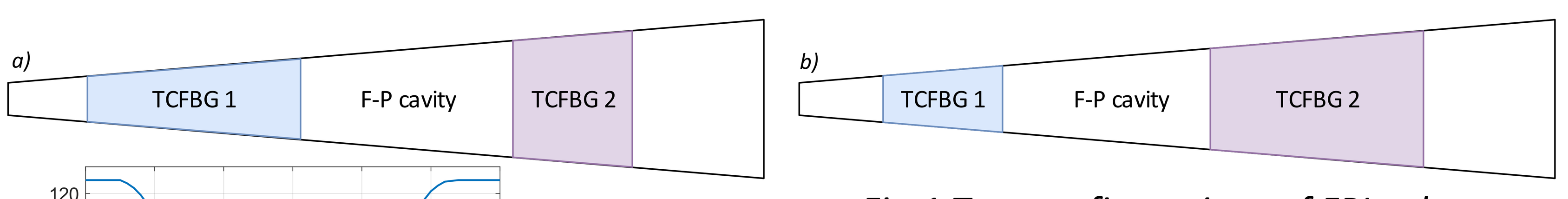

Fig.1 Two configurations of FPI, where spectral width of: a) TCFBG1 > TCFBG2, b) TCFBG2 > TCFBG1.

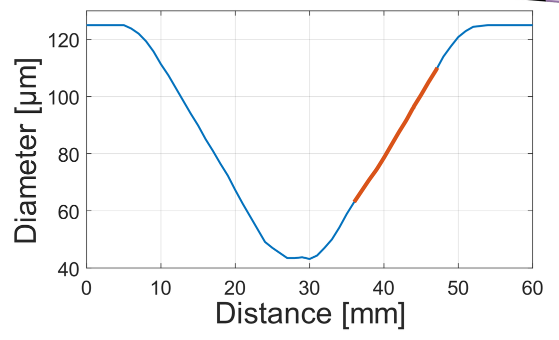

Fig.2 Position (thinner line) of Fabry-Perot interferometer in a fiber taper.

3. Results

For further calculations, physical parameters of the FPI are proposed in table 1. Fig. 3 presents reflectance graph of first configuration, where longer grating is written in thicker part of the fiber. In Fig. 4 reflectivity spectrum of the second FPI configuration (presented in Fig. 1b) is shown. The resultant parameters, which was obtained by tuning mathematical model parameters are shown in Tab. 2. Such parameters can help with further real application of FPI.

Parameter	Value
Maximal cladding diameter	125 μm
Waist diameter	43.2 μm
Taper length	65.2 mm
Taper slope	2.51 $\mu m/mm$
Refractive index of the core	1.4513
Refractive index of the cladding	1.4440
Change of refractive index induced by UV radiation	$5 * 10^{-4}$
Initial period of the phase mask	1061 nm
Phase mask chirp rate	0.35 nm/mm

Tab.1 Parameters of fiber and PM.

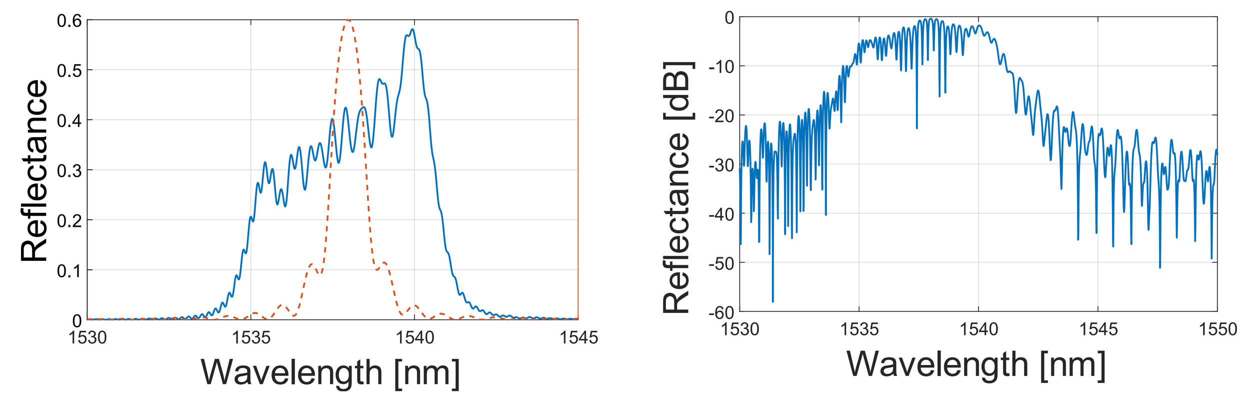

Fig.3 Reflectance for first case. On the left: linear reflectance of the first grating (solid line) and linear reflectance of the second grating (dashed line). On the right: reflectance of FP resonator in logarithmic scale.

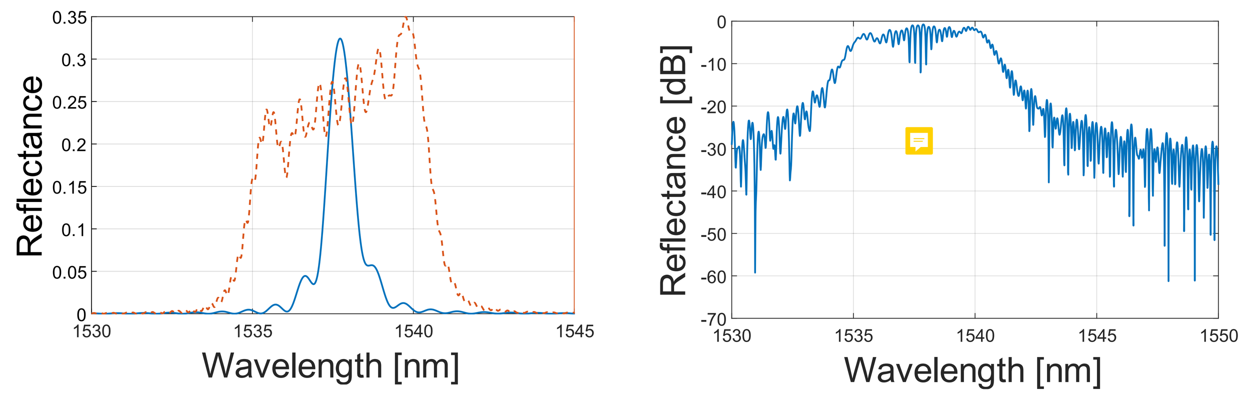

Fig.4 Reflectance for second case. On the left: linear reflectance of the first grating (solid line) and linear reflectance of the second grating (dashed line). On the right: reflectance of FP resonator in logarithmic scale.

Any change of grating length or position must be followed by tuning initial period of grating, because Bragg wavelength depends on period of phase mask and effective refractive index, which changes with fiber core diameter. After modifying position of wider grating in tapered fiber, change of transmission slope for such a grating is observed.
When spectrally wider grating is written in thinner part it has bigger spectral slope; when wider grating is inscribed in thicker part, it has smaller slope. This occurs, because for relatively smaller diameter of fiber core, the confinement factor of the fundamental mode and consequently amplitude of reflectance is changing faster in wavelength domain than for relatively bigger diameter [4].
Analyzing reflectance of F-P interferometer in logarithmic scale, one may say that center of the resonating frequencies depends on the mutual spectral position of both TCFBGs. For the first configuration (Fig. 1a), amplitude depth of resonant peaks in the reflected spectrum around the Bragg wavelength is higher than in the second configuration. This difference occurs because of the common wavelengths, where spectrally narrower gratings has the same or higher reflectivity responses amplitude than spectrally wider gratings. If such common part of reflectance is spectrally wider, the difference of amplitude is more noticeable. Moreover, when spectrally wider grating is inscribed in thinner part of the taper, the FSR is smaller for lower wavelengths and when such a grating is inscribed in thicker part, the FSR is smaller for higher wavelengths. It depends on mutual configuration and resulted chirps value of both TCFBGs

Configuration 1		Configuration 2	
Parameter	**Value**	**Parameter**	**Value**
Length of first grating	8 mm	Length of first grating	2 mm
Length of cavity	1.2 mm	Length of cavity	1.2 mm
Length of second grating	2 mm	Length of second grating	8 mm
Initial period of phase mask for first grating	1061.105 nm	Initial period of phase mask for first grating	1062.820 nm
Initial period of phase mask for second grating	1061.175 nm	Initial period of phase mask for second grating	1060.475 nm

Tab.2 CFBGs parameters used for FPI modelling.

4. Conclusions

In this work new concept of FPIs consisted of two linearly chirped fiber Bragg gratings written in tapered section of optical fiber is presented.
The results show that the spectral responses of proposed Fabry-Perot interferometer written in fused tapered fibers can be widely tailored by the appropriate selection of their parameters. Furthermore, presented model can be used to choose real parameters to inscribe F-P interferometer. Such FPI can be further used in simultaneous temperature and strain sensing systems.

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