Evaluation of optimal FBG filter apodization function for HDWDM

Optimālas FBG optiskā filtra apliecējfunkcijas novērtējums HDWDM sistēmās

O. Ozoliņš, Ģ. Ivanovs

Keywords: Fiber Bragg gratings, Wavelength division multiplexing.

Abstract - High performance optical filters are groundwork for realization of high speed dense WDM communication systems. One realization of optical filtering is based on fiber Bragg grating (FBG) filters. We foresee that lower channel spacing and higher data transmission rate WDM systems will need FBG optical filters with inscribed more complex apodization profiles.

Introduction

Optical wavelength division multiplexing (WDM) transmission systems are forging ahead towards higher data transmission rate and lower channel spacing to utilize available bandwidth more effectively. High performance optical filters are groundwork for realization of high speed dense WDM transmission systems [1].

One realization of optical filtering is based on fiber Bragg grating (FBG) filters. A FBG is periodic variation of the refractive index along the propagation direction in the core of optical fiber that reflects particular wavelengths of light and transmits all others. Low channel isolation from adjacent channels is one of these imperfections in optical filter parameters. To ensure high channel isolation we need to inscribe FBG filters with complex apodization profiles [2]. In this paper we demonstrate performance of different apodization profiles and their influence on high speed dense WDM systems channel spacing. We foresee that lower channel spacing and high data transmission rate WDM systems will need FBG optical filters with inscribed more complex apodization profiles.

System setup

To evaluate impact of different FBG apodization profiles on high speed dense WDM communication system we used combination of two different simulation programs.

Firstly, we used Bragg Grating Filters Synthesis 2.6 (BGFS 2.6) simulation program for mathematical description of FBG optical filter. In the simulation program we realized different FBG optical filters with defined apodization profiles. This simulation program is based on Transfer Matrix Method. This method is used to simulate periodic non-uniform FBG filters. It is applied to solve the coupled mode equations and to obtain the spectral response of the fiber Bragg grating. In this approach, the grating is divided into uniform sections. Each section is represented by a 2×2 matrix. By multiplying these matrices, a global matrix that describes the whole grating is obtained (see Fig. 1. and equation 1):

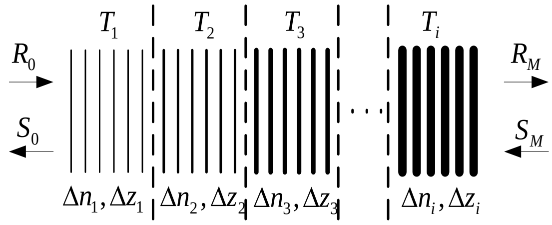

Fig.1. Transfer matrix method used to obtain the spectral characteristics of a fiber Bragg grating (Δn - average index of refraction, Δz - section length, R_0, S_0, R_M, S_M - electromagnetic waves amplitudes)

$$\begin{cases} T_M = T_1 \cdot T_2 \cdot T_3 \cdot .. \cdot T_i, \\ \begin{bmatrix} R_M \\ S_M \end{bmatrix} = T_M \cdot \begin{bmatrix} R_0 \\ S_0 \end{bmatrix}. \end{cases} \quad (1)$$

The main drawback of this method is that *M* may not be made arbitrarily large, since the coupled-mode theory approximations are not valid when uniform grating section is only a few grating periods long. Thus, it requires $\Delta z >>$ grating period [3, 4].

Secondly, we used OptSim 5.0 simulation program to simulate high speed dense WDM transmission systems. This simulation program uses method of calculation that is based on solving a complex set of differential equations, taking into account optical and electrical noise, linear and nonlinear effects [5]. Us we noticed before, in research are used two simulation programs: BGFS 2.6 – to realize FBG filters amplitude and phase responses and OptSim 5.0 to numerically evaluate high speed dense WDM transmission systems.

Simulation scheme and parameters

Simulation scheme consists of four channels, which is chosen to evaluate influence of nonlinear optical effects (NOE).

The transmitter consists of data source, NRZ driver, continuous wavelength laser source and external Mach-

Zehnder modulator. The data source produces a 10 Gbit/s bit stream, which represents the information we want to transmit via optical fiber. Then we use a driver to form NRZ pulses from incoming information bits. The pulses are then modulated with continuous wavelength laser irradiance in Mach-Zehnder modulator to obtain optical pulses. Then formed optical pulses are sent directly to a 40 km long standard single mode fiber (SSMF). The utilized fiber has a large core effective area 80 μm^2, attenuation α = 0.2 dB/km, nonlinear refractive coefficient $n_k = 2.5 \cdot 10^{-20}$ cm/W and dispersion 16 ps/nm/km at the reference wavelength λ = 1550 nm [5]. Receiver block consists of PIN photodiode (typical sensitivity -17 dBm) and Bessel – Thomson electrical filter (4 poles, 7.5 GHz -3dB bandwidth). Parameters for simulation scheme are chosen based on experimental two channel scheme which is realized in our Fiber Optics Transmission Systems Laboratory. Simulation scheme and measurement results were equal so applied numerical results in this paper are actual.

Results and discussion

The main problem is to ensure high channel isolation between adjacent channels. To realize channel isolation performance evaluation of FBG optical filter we used eye diagrams, bit error rate (BER) and optical signal spectrum in different system configurations.

TABLE 1

BER values for 10 Gbit/s WDM systems with different channel spacing using FBG with different apodization profiles data transmission speed. BER values measured at the worst channel.

Channel spacing	100 GHz	50 GHz	25 GHz
Blackman	1,07E-12	2,29E-12	1,69E-11
Cosinusoidal	9,64E-13	6,00E-12	1,88E-11
Gaussian	9,79E-13	2,06E-12	1,23E-11
Kaiser	9,87E-13	2,24E-12	1,47E-11
Polynomial	2,22E-09	1,24E-08	3,27E-08
Ramp	6,99E-09	6,92E-08	7,12E-08
Rectangular	4,94E-06	2,26E-05	1,46E-04
Sinc	1,10E-12	3,18E-12	2,32E-11
Tanh	1,79E-09	3,52E-09	4,97E-09
Triangular	1,01E-12	1,11E-11	1,94E-11
Unsymetric	1,11E-12	2,66E-12	3,44E-11

We have chosen eleven different apodization profiles, three channel spacing values: 100 GHz, 50 GHz and 25 GHz and data transmission speed: 10 Gbit/s. We optimized simulation scheme transmitter parameters to realize 25 GHz WDM transmission system, because original parameters ensure realization of ~31 GHz WDM transmission system [6]. In combination of all these parameters we have simulated 33 different WDM transmission systems.

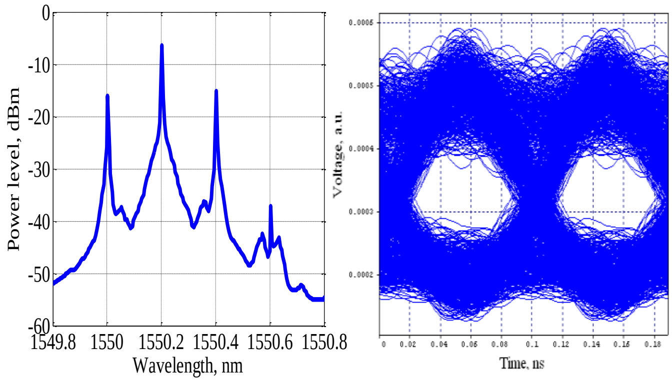

Fig.5. 10 Gbit/s 25 GHz 4 channel WDM system spectrum after 25 GHZ FBG filter with rectangular apodization profile and the second channel eye diagram (BER = 1,46E-4) [2].

The results of BER dependence on channel spacing using FBG with different apodization profiles are presented in table 1. From results we can see that BER values are higher at 25 GHz channel spacing because of greater NOE influence and 25 GHz FBG filters greater delay, which also influence optical signal detection. At all channel spacing values, the worst performance showed the 100 GHz, 50 GHz and 25 GHz FBG optical filters with rectangular apodization profile. This is mainly because of great undesirable side lobes in optical filter amplitude response. These imperfections in filter amplitude response reduced channel isolation.

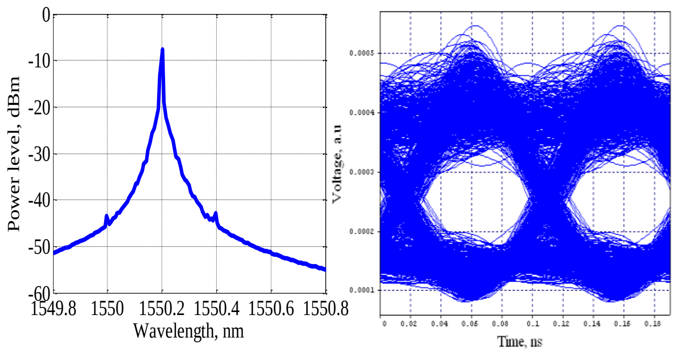

Fig.6. 10 Gbit/s 25 GHz 4 channel WDM system spectrum after 25 GHZ FBG filter with Gaussian apodization profile and the second channel eye diagram (BER = 1,23E-11) [2].

Adjacent channel had high optical power (see Fig.5.) after optical filter and this factor consequently resulted in system degradation (BER level exceeded 1.0E-9).

Conclusions

We see from simulation results that lower channel spacing and high data transmission rate WDM systems need FBG optical filters with inscribed more complex apodization profiles. As we can see in Fig.6 Gaussian apodization profile ensures best adjacent channel isolation.

Acknowledgement

This work has been partly supported by the European Social Fund within the National Program "Support for the carrying out doctoral study program's and post-doctoral researches" project "Support for the development of doctoral studies at Riga Technical University".

References

1. Agrawal G. Nonlinear Fiber Optics (Third Edition). Academic Press – 2001.
2. Ozoliņš O., Ivanovs Ģ. Realization of Optimal FBG Band–Pass Filters for High Speed HDWDM // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 4(92). – P. 41–44.
3. Phing H.S., Ali J., Rahman R.A. and Tahir B.A. Fiber Bragg grating modeling, simulation and characteristics with different grating lengths. Journal of Fundamental Sciences. – 2007.-No.3, -P. 167-175
4. Kashyap R. Fiber Bragg grating // Academic Press. – 1999
5. Bobrovs V., Ivanovs G. Parameter Evaluation of a Dense Optical Network // Electronics and Electrical Engineering. – 2006. – No.4 (25). – P. 33-36.
6. Bobrovs V., Ivanovs G. Investigation of minimal channel spacing in HDWDM systems // Electronics and Electrical Engineering. – 2009. – No.4 (92). – P. 53-56.

O. Ozolins received his B.S and M.S in telecommunication engineering from Riga Technical University, Latvia, in 2007 and 2009, respectively.

He is currently working as a scientific assistant in Riga Technical University Faculty of Electronics and Telecommunications, Institute of Telecommunications, Latvia. His research interests include different types of optical filters for HDWDM systems, Fiber Bragg gratings as optical filters and dispersion compensator, gain flattening filters.

He is a member of European Optical Society (EOS) and student member of Optical Society of America.

O. Ozoliņš, Ģ. Ivanovs Optimālas FBG optiskā filtra apliecējfunkcijas novērtējums HDWDM sistēmās

Augstas veiktspējas optiskie filtri ir pamats uagsta ātruma blīvu WDM sakaru sistēmu realizācijai. Viena optisko filtru realizācija ir balstīta uz Šķiedras Brega režģiem. Mēs prognozējam, ka maza intervāla starp kanāliem un augsta datu pārraides ātruma WDM sistēmu realizācijai būs nepieciešams izmantot Šķiedras Brega režģus ar ierakstītām sarežģitākām apliecējfunkcijām.

О. Озолинш, Г. Ивановс. Оценка оптимальной огибающий FBG оптического фильтра для систем HDWDM

Реализация производительного оптического фильтра является одним из ключевых элементов для реализации высоко скоростных HDWDM. Одна реализация оптического фильтра основона на FBG фильтре. для. Мы предвидим что для реализации высоко скоростных HDWDM надо использовать FBG фильтры с сложный огибающий.