NUMERICAL SIMULATIONS OF ALL OPTICAL SWITCHING IN NONLINEAR FBGS USING XPM AND SPM EFFECTS

Ľubomír Scholtz, Michaela Solanská, Libor Ladányi, Jarmila Müllerová

Institute of Aurel Stodola, Faculty of Electrical Engineering, University of Žilina, ul. kpt. J. Nálepku 1390, 03101 Liptovský Mikuláš, Slovak Republic
E-mail: scholtz@lm.uniza.sk

Received 28 April 2017; accepted 06 May 2017

1. Introduction

The current expanding of broadband networking leads to increasing requirements for optical networks. Due to the requirements on the transfer capacity the new most efficient devices and elements are necessary to be developed. One of the methods to increase the bandwidth of the network is using all-optical signal processing in optical networks due to relatively slow signal processing in electrical domain. All-optical signal processing, including the signal regeneration and wavelength conversion is very important for current and future ultra-high bit rate communications systems, since current electronic processing speeds are approaching fundamental limits near tens to hundreds of Gb/s. Optical switching technologies have great impacts on the performance of the optical networks. Nowadays several technologies of optical switching already exist. Each of them has some advantages and disadvantages. The most important performance parameter is the switching time. This parameter indicates the velocity of the change of the switched state.

Devices based on nonlinear effects are capable to achieve short switching times. Nonlinear fiber Bragg grating (FBG) is a promising candidate for all-optical switching and processing in which the effect of nonlinear transmittance and/or optical bistability can be used for fast switching and controlling the switching behaviour of the grating. The combination of nonlinear material and distributed feedback in FBG results in the formation of optical bistability, where the output intensity can reach two values depending on the previous intensity. Optical bistability has been observed in different optical devices and materials [1]. As appropriate the chalcogenide glasses appear. Chalcogenide glass offers many advantages as a platform both for fiber and integrated all optical devices due to the large Kerr nonlinearity, very low two-photon absorption and transparency from visible to IR region [2]

Due to optical bistability effect in FBG all-optical switching is possible. Switching in FBG means the change of the transmission state of the grating. Depending on the required options the switching can be completed by switching from the refection to the transmission state of the grating (or vice-versa) what is possible by the Bragg wavelength shift caused by the change of the input intensity and therefore changing the detuning of the probe from the centre of the photonic band gap [3]. In self-switching the dynamic effects as the modulation instability are more pronounced and the necessity of optimization of these effects impacting temporal and spectral characteristics of the transported signal plays an important role.

2. Results

In our simulations materials As_2Se_3, $Ge_{10}As_{10}Se_{60}$ and $Ge_{10}As_{10}Se_{60}Te_{20}$ were selected as the third order nonlinear media. Kerr coefficients and effective refractive indexes of this materials are shown in Tab. 1. The characteristics of the grating were simulated with the parameters as follows: the grating length L = 0.9 cm, the Bragg and probe wavelengths λ_B=λ= 1550 nm, the amplitude of the periodic index change Δn was selected to be 9×10^{-5}.

Tab. 1. *Kerr coefficients and effective refractive indexes [4].*

	$Ge_{10}As_{10}Se_{80}$	As_2Se_3	$Ge_{10}As_{10}Se_{60}Te_{20}$
n[-]	2.64	2.81	2.90
$n_2 = \times 10^{-18}$ [m^2/W]	3.9	14.0	20.0

However, performance of all-optical devices based on Kerr effects is limited by two-photon absorption (TPA). TPA results in the production of free carriers with long lifetimes. These carriers slow down response time of nonlinear interaction and limits its usefulness [5]. Impact of the TPA on suitability of material for all-optical devices performance can be characterized by well-known nonlinear figure of merit (FOM), $FOM = n_2/\beta\lambda$, where impact β is two-photon absorption coefficient. FOM > 1 is required to achieve suitable performance of all-optical devices based on Kerr effects. In [6] an FOM=1.8 at 1550 nm for material As_2Se_3 was calculated. Here was measured values of $\beta = 0.25\, GW/cm^2$. β for $Ge_{10}As_{10}Se_{60}Te_{20}$ is two times larger than for As_2Se_3 material [7]. According to this, $Ge_{10}As_{10}Se_{60}Te_{20}$ has calculated FOM equal to 1.29.

Depending on the signal intensity transited through the grating the reflectance pass-band varies. A high intensity signal causes the optical push broom [8]. Due to this effect the intensity causes the changes of the medium refractive index what leads to the detuning of the Bragg wavelength such that with the increasing intensity the Bragg wavelength is shifted to higher wavelengths.

For the low input intensities gratings manifest similar spectral responses (Fig. 1 – black dashed curve). This is due to the approximately the same average refractive indexes of the materials. However, changes of the input intensity affect the spectrum of light reflected by the gratings. The changing of the input intensity results in the wavelength shift. In Fig. 1 spectra for these materials at the input intensity of 250 MW/cm^2 are depicted. These results were obtained with long Gaussian pulse. From these figures one can observe that for the materials with higher nonlinear coefficient wavelength shift of spectra is more significant. At the input intensity of 250 MW/cm^2 the wavelength shift for $Ge_{10}As_{10}Se_{60}Te_{20}$ is equal to 0.27 nm, for $Ge_{10}As_{10}Se_{60}$ equal to 0.2 nm and for As_2Se_3 equal to 0.15 nm. The change of input intensity up to the value of 280 MW/cm^2 causes so significant wavelength shift in the GT grating that the grating will reflect completely different wavelength region and switching to a different wavelength channel in the ultra-dense wavelength division systems can be expected.

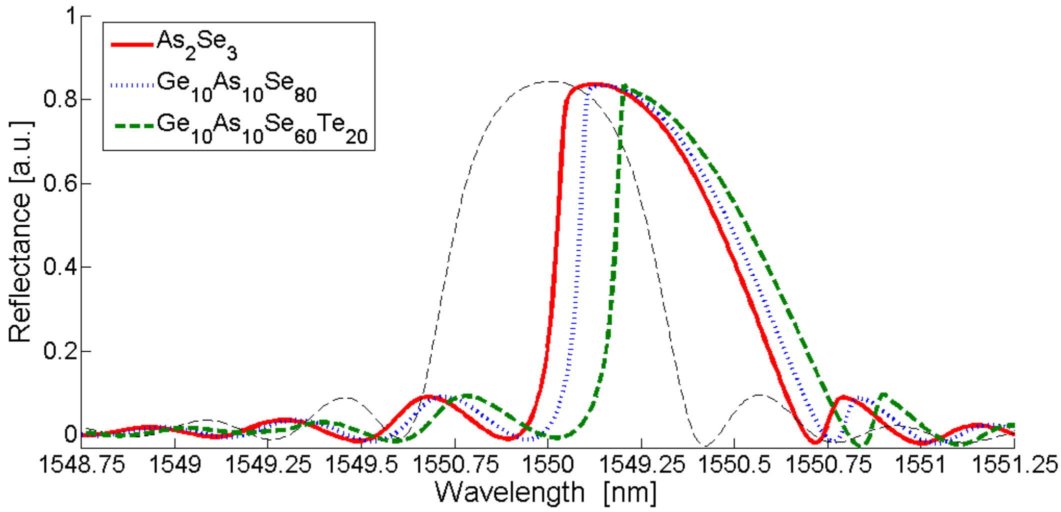

Fig.1: *Wavelength dependency of group delay for the gratings at 250 MW/cm^2. Black dashed curve represents the spectrum with neglecting the nonlinear effects.*

Hence, nonlinear phenomena are strongly dependent on the spectral shape of the grating, especially the group delay. This time taken for a pulse to traverse the grating versus wavelength was calculated as first derivation of complex transmissivity argument with respect of frequency. The group delay is greatly enhanced near the stopband edges, as shown in Fig. 2. Group delay at central wavelength of the grating for each material is approximately 30 ps. In the figure group delay dependencies of gratings at low intensity respectively with neglecting of nonlinear effects are depicted. As can be seen in whole regime the $Ge_{10}As_{10}Se_{60}$ grating exhibits the lowest group delay.

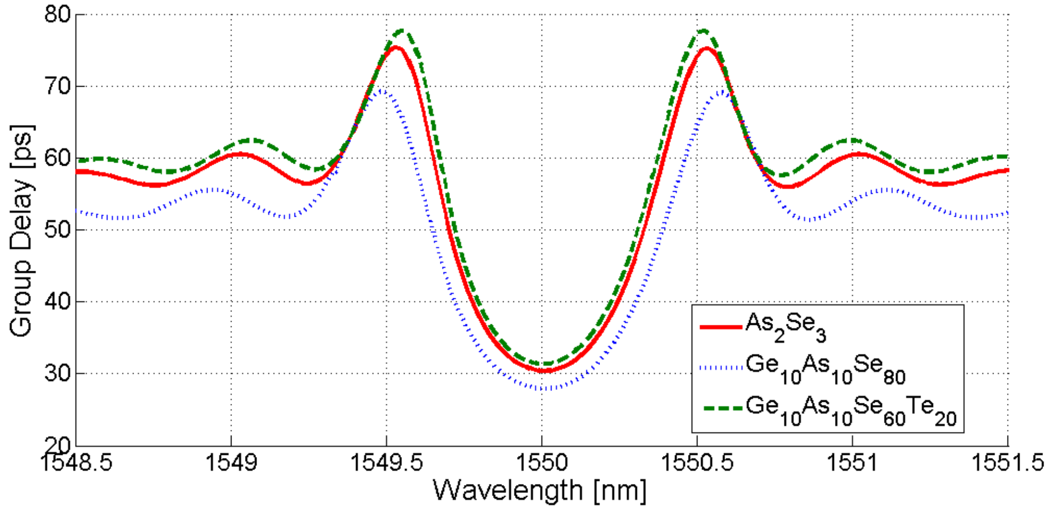

Fig.2: *Wavelength dependency of group delay for the gratings with neglecting the nonlinear effects.*

With the increment of tuning power, the spectrum is redshifted and starts exhibits no symmetricity. These results also correspond with results about grating frequency response where the maximum reflectivity corresponds to the minimum time delay. For wavelengths near the first reflectivity zeros, the time delay is maximum corresponding to several round-trips before the light exits the grating.

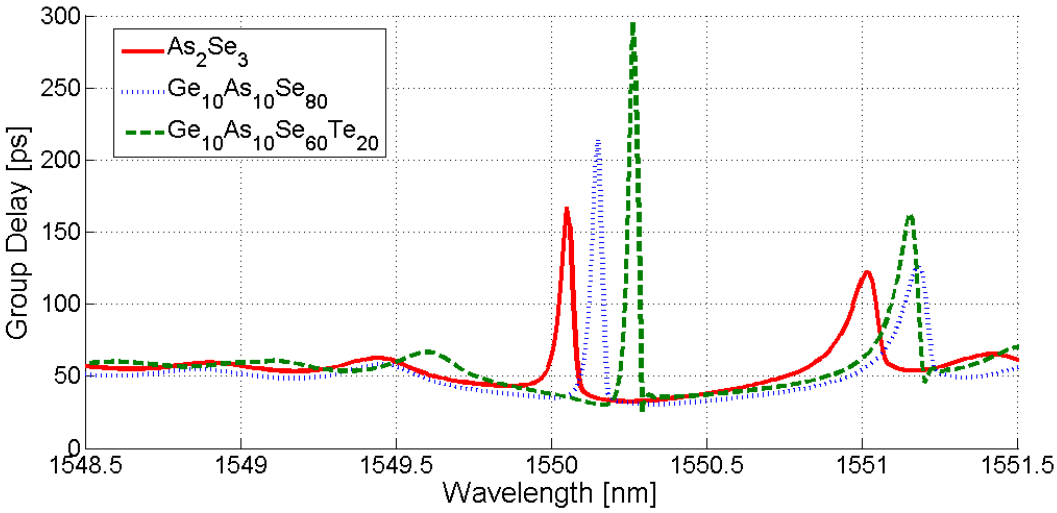

Fig.3: *Wavelength dependency of group delay for the gratings at intensity 250* MW/cm^2.

3. Conclusion

In this paper spectral behavior of FBGs based on three chalcogenide glasses was numerically analyzed. Spectral shifts and changes of group delays with increasing of intensity of gratings based on these materials were analyzed and described. The numerical method used for the simulations was the time-domain transfer matrix method based on the split step methods.

Acknowledgement

This work was partly supported by the Slovak Grant Agency under the project VEGA 2/0076/15 and by the Slovak Research and Development Agency under the projects APVV-15-0152, APVV-0888-12.

References:

[1] I. V. Kabakova, D. Grobnic, S. Mihailov,E.C. Magi, C. M. Sterke and B.J. Eggleton, *Opt. Express*, **19(7)**, 5868 (2011)
[2] V.G. Ta'eed, M.R.E. Lamot, D.J. Moss and B.J. Eggleton, *Opt. Express*, **14(23),** 11242 (2006).
[3] Yosia , Shum Ping , Lu Chao, *Opt. Express*, **13(13),** 5127 (2005)
[4] S. Cherukulappurath, et al., *Opt. Commun.*, **242**, 313 (2004).
[5] B. J. Eggleton, V. G. Ta'eed, B. Luther-Davies, *Photonics Spectra*, **41**, (2007)
[6] H.C. Nguyen, K. Finsterbusch, D.J. Moss, B.J. Eggleton, *Electronic letters* **42(10)**,1 (2006)
[7] A. Zakery, S.R. Elliott, Springer, Verlag Berlin Heidelberg (2007)
[8] C.M. Sterke, *Opt. Lett.* **17**, 914 (1992)