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Experimental Demonstration of Wavelength-Selective In-Fiber Optical Intensity Modulation

M. Rajabvand, F. Behnia and M. T. Fatehi
EE Department, Sharif University of Technology, Azadi St. Tehran, Iran, P.O. 11365-9363, Fax. +98 21 6602 3261.
Rajabvand@ee.sharif.ir

Abstract: In this paper we report on experiments with a fiber-based optical intensity modulator. It uses tunability of FBG in its transition band, to add the low speed labels on WDM signals in a wavelength-selective manner.

1. Introduction

The fiber Bragg gratings have the best potential for achieving any desired spectral characteristics in all-fiber geometry. This distinguishing feature has made the FBG a fundamental component in fiber optic communication and sensor systems [1]. When the spectral shaping flexibility combines with tunability of FBG in an optical device, the controllable and reconfigurable fiber-based systems emerge [2]. Such components are enabler of true all-optical networks, in which signal conversion from optical to electrical is avoided.

Traditionally, mechanical stresses are applied to FBG by piezoelectric transducers (PZT) or by other means to tune the Bragg wavelength. PZT displacement is coupled to the FBG to move its reflection band so that one desired optical channel would lie totally inside the reflection band (or totally outside of it). Recently, we have proposed a new operation mode of FBG, which focuses on its transition bands of spectra [3]. When the wavelength of optical signal is in the transition region and the tuning voltage is low enough to guarantee the small-signal operation, optical power at the output of FBG will follow the variations of the applied voltage. We have shown that the combined PZT and FBG act as a wavelength-selective modulator (WSM), and can be described analytically by the intensity modulation equation [3]:

$$P_{out}(t;\lambda_c) = (B_0 - A_0\eta V(t))P_{in}(t;\lambda_c)\,, \quad (1)$$

where $P_{out}(t)$ and $P_{in}(t)$ are transmitted and incident optical signals, respectively; B_0 is the transmission coefficient at the optical carrier wavelength (λ_c); A_0 is determined from the slope of FBG spectra and PZT specifications and η is mechanical coupling coefficient between FBG and PZT.

In this paper, we report on practical implementation of the WSM using multilayer piezo actuators (MLP) and FBG, and compare the measurements results with theoretical predictions.

2. Experiment

Fig. 1 shows the experiment set up for investigating the operation of WSM. The DWDM DFB laser source consists of eight 20 mw modules with individually selectable center wavelengths from 1551 to 1560 nm. The center wavelength tolerance is ± 0.01 nm, and the tuning range of every laser module is ± 1 nm. A variable attenuator is placed to control the optical power level. The laser light is transmitted via a fiber optical coupler to FBG. The measured transmission power spectrum of FBG is shown in Fig. 1, as well. Its maximum reflectivity is 93 %, the center wavelength is 1556.08 nm, and FWHM is 1.78 nm. The two ends of FBG are glued to a MLP. Dimensions of MLP are 10×10×36 mm, its nominal displacement is 32 μm @ 100 v, and resonant frequency is about 45 kHz.

When an electrical signal *V(t)* from the function generator is applied to MLP, the FBG is axially pulled from each end. The actuator displacement causes a corresponding change in the FBG length and consequently grating period and index of refraction. As a result, the Bragg wavelength fluctuates with *V(t)*, which in turn varies (modulates) the reflectivity of the FBG at wavelength of the optical carrier. We measure the transmitted and reflected optical power variations individually using two InGaAs analog photodiodes with responsivity of about 0.9 A/W @ 1550 nm. The measurements results are discussed in the next section.

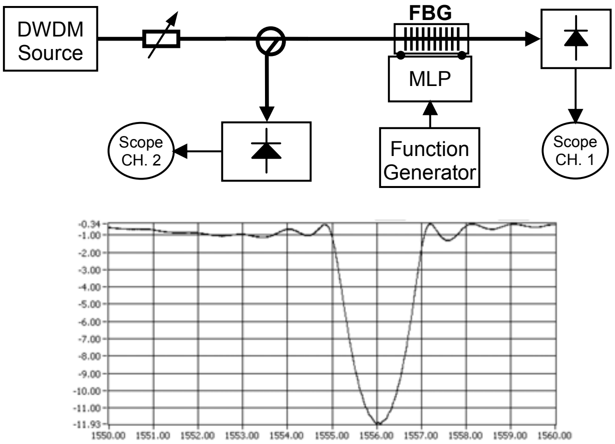
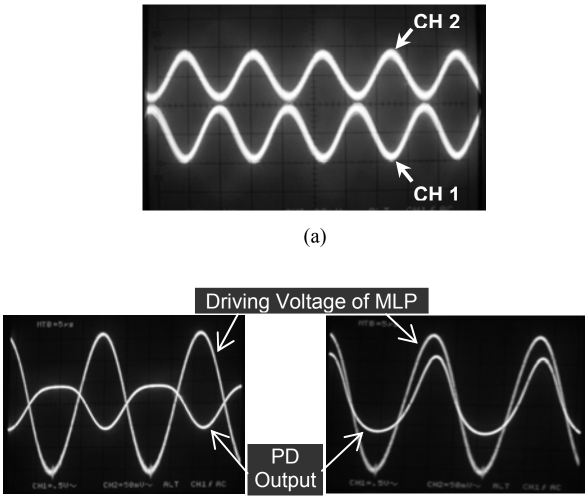


Fig. 1 WSM experiment set up and measured transmission power spectra for FBG.

3. Results and discussion

Fig. 2(a) shows the oscilloscope traces of signals in CH. 1 and CH.2, which measure the signal intensity transmitted through and reflected off the WSM, respectively. The phase difference π between the CH. 1 and CH. 2 signals is due to complementary variations of the reflected and transmitted power ($P_{ref} = P_{in} - P_{trans}$). The optical signal wavelength is tuned near the upper edge band, on wavelength λ_c=1557.0nm, and experiences 1.5 dB transmission loss. During the increasing segment of *V(t)*, the MLP displacement increases and pulls the fiber grating in length. Because of tensile strains, the Bragg wavelength shifts to upper wavelengths, and decreases the transmission coefficient at λ_c. Thus the transmitted signal is modulated in opposite phase with respect to *V(t),* and the reflected signal experience co-phase modulation. If amplitude of *V(t)* is quite large and/or λ_c is chosen to be in neighborhood of extrema of FBG spectra, uniform ascending/descending of transmission coefficient within tuning range fails and nonlinearity effects appear. Fig. 2(b) and (c) show the nonlinearly modulated transmitted and reflected signals, respectively. In fact, the modulation coefficient A_0 in equation (1) does not remain constant but it will be time variant which goes to zero at the extrema.

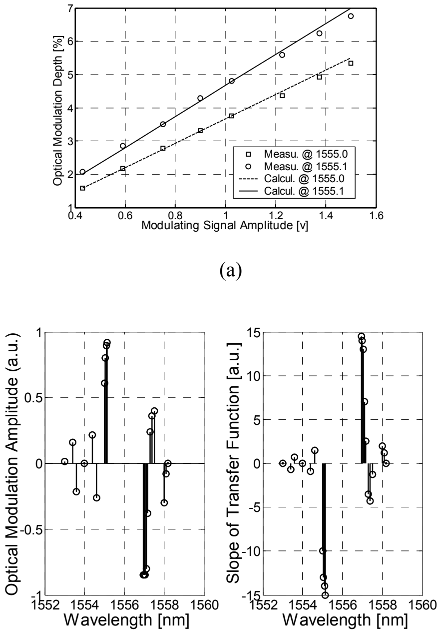


(a)

(b) (c)

Fig. 2 (a) Oscilloscope traces of transmitted (CH 1) and reflected (CH 2) WSM signals, (b), and (c) nonlinearity effects on transmitted and reflected WSM signals, respectively.

Fig. 3(a) shows the measured (marked) and calculated (line) optical modulation depth versus modulating signal amplitude. The maximum Bragg wavelength movement for V(t) ≤ 1.6 v is less than 0.002 % and the small-signal condition is therfore satisfied. The experiment results are in good agreement with linear modulator model in equation (1). The modulation depth is preferably kept small (less than 10%) to avoid excessive loss of the optical signal passing through the WSM. We also have measured the amplitude of modulated signal at different wavelengths from 1552.5 nm to 1558.5 nm. The wavelengths 1555.0~1555.1 nm, and 1557.0~1557.1 nm are low loss ranges of FBG and modulation amplitude is relatively high, as shown in Fig. 3 (b), and (c). At wavelengths next to these ranges some small modulations amplitudes are seen that arise from the slope of transfer function in the side lobes. Thus fiber gratings with enough transition bands and without side lobes are ideal for WSM and will be free from interference and crosstalk in WDM networks.



(a)

(b) (c)

Fig.3 (a) the measured (marked) and calculated (line) optical modulation depth versus modulating signal amplitude (b) Amplitude of Optical intensity modulation vs. laser wavelength, (c) Rate of change of transmission coefficient with respect to wavelength.

4. Conclusion

In this paper, we considered the tunability of FBG in transition band and implemented an all-fiber optical intensity modulator. The measurement results confirmed the concept of wavelength-selective modulation and its theoretical model. An array of WSM can be used for all-optical modulation of low speed labels on WDM signals [3].

Acknowledgment

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