Bulgarian Chemical Communications, Volume 47, Special Issue B (pp. 15–20) 2015

Research of 16-channel fiber-optic (FO) system for measuring long period sensor networks (LPSN)

V. Plachkova[1*], P. Balzhiev[2], G. Dyankov[1], T. Eftimov[1], P. Petrov[1]

[1] *Faculty of Physics, Paisii Hilendarski University of Plovdiv, 24 Tsar Asen Str., BG-4000 Plovdiv, Bulgaria*
[2] *Faculty of Telecommunications, Technical University of Sofia, 8 Kl. Ohridski Blvd., 1000 Sofia, Bulgaria*

Progress in fiber optic technology offers great opportunities to develop a wide range of highly sensitive fiber-optic sensors in many new application areas. In the field of the sensors we witness an increased interest in the simultaneous measurement of two or more physical parameters [1,2]. These measurements are carried out with sensors based on a simple and effective detection of the signals by using a linear CCD photodiode matrix in combination with a diffraction grating to measure the spectral shifts, which are proportional to the phase change introduced into the sensing fiber. The resulting responses are linear [3].

The tested 16-channel system is compared to a single-channel spectrometer on the basis of a long period grating (LPG) with a photodiode.

The possibilities of the spectrometer based on linear CCD photodiode array in combination with diffraction grating for measuring single-channel and multi-channel measurement and simultaneous recording of data using software developed for this purpose were investigated.

The sensitivity of the 16-channel spectrometer was tested by measuring the change in the spectrum of LPG due to mechanical stress, change of the refractive index and the influence of temperature [4].

Key words: long period sensor, linear CCD photodiode matrix, long period grating, sensitivity of the 16-channel spectrometer

INTRODUCTION

The study of the behavior of any system is done most effectively by a comparison to some already tested analogous system. In our case it is an optical spectrum analyzer (OSA) AQ6331.

There has been no completely uniform appearance of the spectrum of choice for testing a LPG, the resulting spectrum of the 16-channel CCD-based OSA is wider, in contrast to that of AQ6331. This is due to the non-uniformity of the structure of the two spectral analyzer.

SENSITIVITY OF LPG TO TEMPERATURE, STRAIN, BENDING AND REFRACTIVE INDEX

- *Sensitivity to temperature*. The temperature sensitivity is expressed by the differential equation [4]

$$\frac{d\lambda}{dT} = \frac{d\lambda}{d(\delta n_{\text{eff}})}\left(\frac{dn_{\text{eff}}}{dT} - \frac{dn_{\text{cl}}}{dT}\right) + \Lambda \frac{d\lambda}{d\Lambda}\frac{1}{L}\frac{dL}{dT} \quad (1)$$

In the differential equation λ is the wavelength, T – the temperature, n_{eff} – the effective refractive index of the core, n_{cl} is the effective refractive index of the shell, $\delta n_{\text{eff}} f = n_{\text{core}} - n^{(m)}_{\text{cladd}}$, L is the length of the LPG and Λ its period.

- *Sensitivity to the refractive index*. Sensitivity of sensors based on LPG to the refractive index is given by [4]

$$\frac{d\lambda}{dn} = \frac{d\lambda}{dn_{\text{eff}}}\frac{dn_{\text{eff}}}{dn} \quad (2)$$

- *Sensitivity to stress*. The sensitivity of the sensors based on long period gratings (LPGs) to tensile is described by the differential equation [4]

$$\frac{d\lambda}{d\varepsilon} = \frac{d\lambda}{d(\delta n_{\text{eff}})}\left(\frac{dn_{\text{eff}}}{d\varepsilon} - \frac{dn_{\text{cl}}}{d\varepsilon}\right) + \Lambda \frac{d\lambda}{d\Lambda} \quad (3)$$

- *Sensitivity to bending*. Manifested in two ways: as a change in the central wavelength in the bands of attenuation ***or*** split in two of every one of the attenuation band.
- *Multiple sensitivity*. If the sensor is sensitive to n values $x_i (i = 1, \ldots, n)$, which in case of Δx_i result in changes of the center wavelength with $\Delta\lambda_i$, then these changes are described by a matrix [4]

$$\begin{pmatrix} \Delta\lambda_1 \\ \Delta\lambda_2 \\ \vdots \\ \Delta\lambda_n \end{pmatrix} = \begin{bmatrix} K_{11} & K_{12} & \ldots & K_{1n} \\ K_{21} & K_{22} & \ldots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ K_{nl} & \ldots & \ldots & K_{nn} \end{bmatrix} \begin{pmatrix} \Delta x_1 \\ \Delta x_2 \\ \vdots \\ \Delta x_n \end{pmatrix} \quad (4)$$

* To whom all correspondence should be sent:
vania_plachkova@abv.bg

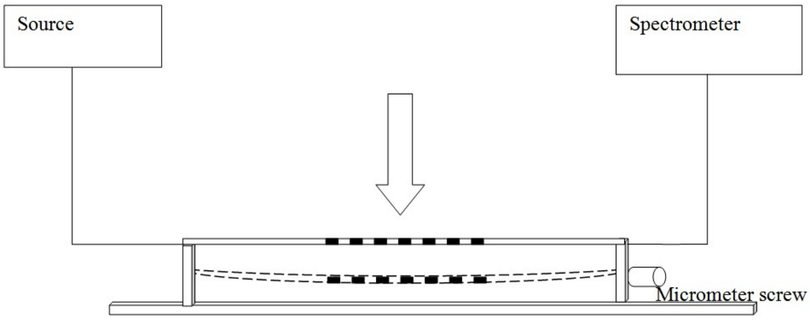

Fig. 1. Scheme of the experimental setup used to study the effects of bending on the optical fiber long period diffraction gratings.

Usually, however, it is preferred that the sensors are sensitive to only a couple of parameters, in principle they are sensitive to

- refractive index and temperature
- temperature and bending

STUDY OF THE SPECTRAL RESPONSE OF LONG PERIOD GRATINGS (LPG) UNDER BENDING STRESS

Scheme of the experimental setup used to study the effects of bending on the optical fiber long period gratings is presented in Fig. 1.

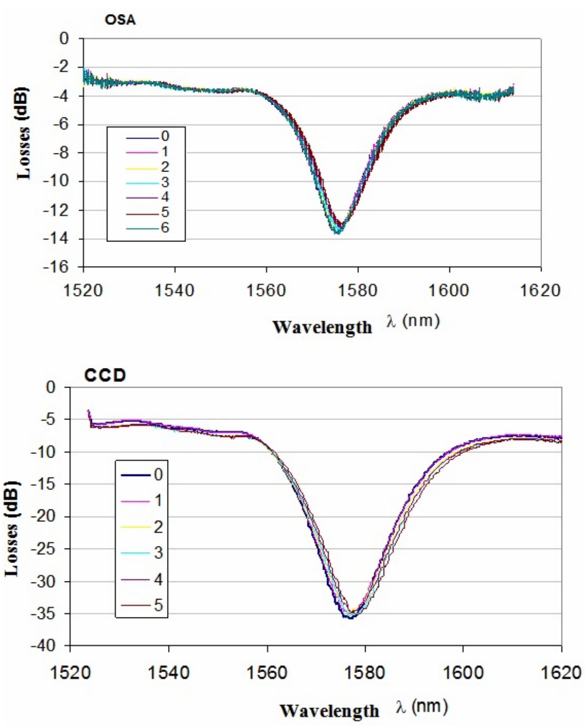

Fig. 2. Impact through pressure registered with OSA AQ6331 and CCD-based spectrometer.

The C + L broadband ASE source (1522–1622 nm) of 16-channel system was used as a light source for both the OSA and the CCD based spectrometer. Since the AQ6331 model does not allow processing software on a computer, it has built in specific software for operation.

Bending responses were recorded under the same conditions to investigate the granting of the long period grating in the experimental setup through 100 μm. The spectrum of the signal to both spectrum analyzers is the same.

The spectra of the LPG measured in parallel with both the AQ6331 OSA and the CCD-based spectrometer are shown in Fig. 2. The figure shows the effects by pressing a certain depth in μm recorded with SA AQ6331 and CCD-based spectrometer. Fig. 3 shows the spectral shift by means of the pressure $d\lambda/dx = 0.306$ nm/OE. In Fig. 4 is a quadratic approximation around the minimum in a mechanical process.

Impact through pressure to the LPGs studied in parallel with CCD-based spectrometer and OSA AQ6331 indicates that both spectrum analyzers

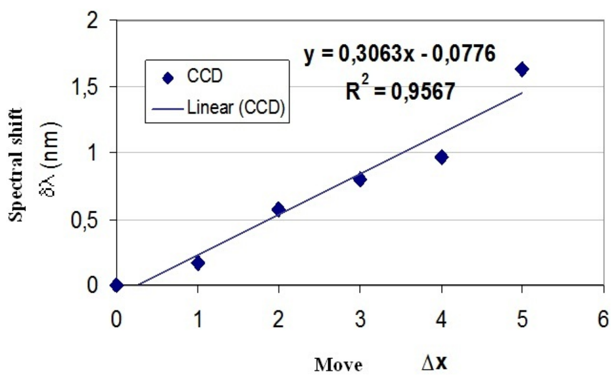

Fig. 3. Spectral shift by pressing with $d\lambda/dx = 0.306$ nm/OE.

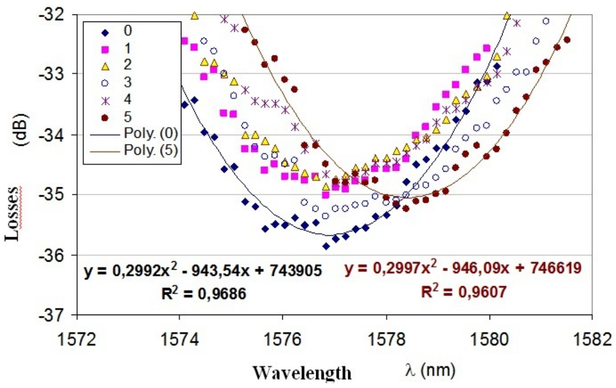

Fig. 4. Quadratic approximation around the minimum in mechanical impact.

have the same response to the minimum for the same depth pressure. This indicates that the CCD-based spectrometer in no way inferior to the most renown OSA AQ6331 and can also be used as effectively as it in the study of the responses of LPGs under pressure.

STUDY OF THE SPECTRAL RESPONSE OF LPGS TO SURROUNDING REFRACTIVE INDEX CHANGES

The scheme of the experimental set-up used for the recording of the response under the effect of a change in the refractive index is the same as in Fig. 1, the surface of the grating is wetted with water by means of a dispenser. Fig. 5 shows the impact by changing the refractive index of water recorded with an optical spectrum analyzer AQ6331 and CCD-based spectrometer again mentioned the shift of the minimum.

The spectrum of an LPG is changed by changing the refractive index of the surrounding medium in which the grating is located. The index of refraction depends on the content of the medium. In this case it is chosen to alter this parameter of the LPG with water (refractive index of water is 1.33). Thus, changing the environment of the LPG from air to water will cause a spectral shift.

This sensitivity of the LPGs is widely used in biosensimg for analyzing various fluids, solvents, solid materials, which are characterized by different refractive indices.

STUDY OF THE SPECTRAL RESPONSE OF LPGS TO TEMPERATURE CHANGES

The response of the LPG to temperature variations was determined only with CCD-based spectrometer, as it is the subject of research studies. Before we explore the LPG's response to controlled temperature

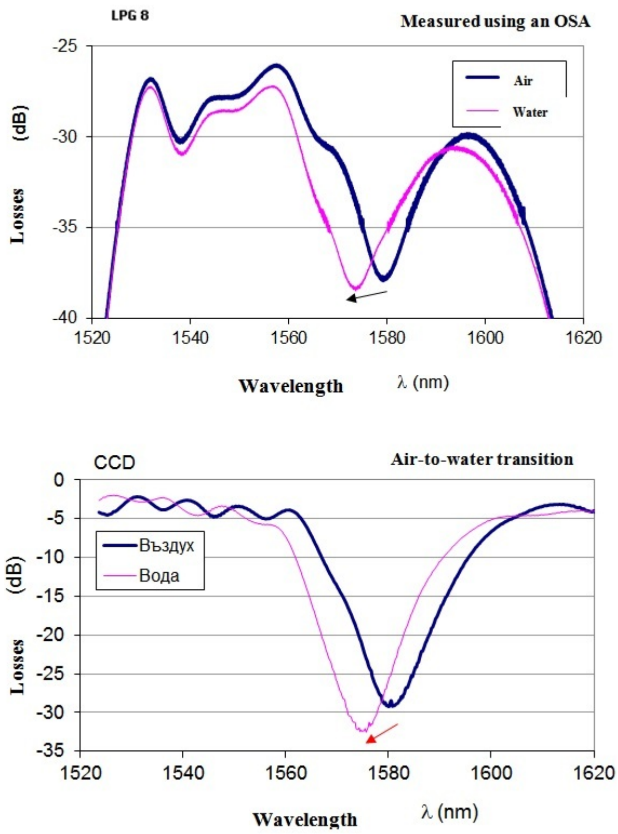

Fig. 5. Response to changes of the refractive index from air to water registered with AQ6331 OSA and CCD-based spectrometer: $d\lambda = -5.48$ nm

changes we record the stacked consecutive spectral responses caused by heating the grating with a solder (Fig. 6) during which the temperature cannot be controlled accurately. Measurements gave very good results, which provides grounds for further studies at higher temperatures than those used in this thesis.

The experimental setup used to determine the response of the spectrum of at lower temperatures of a Peltier cooler, power supply, temperature

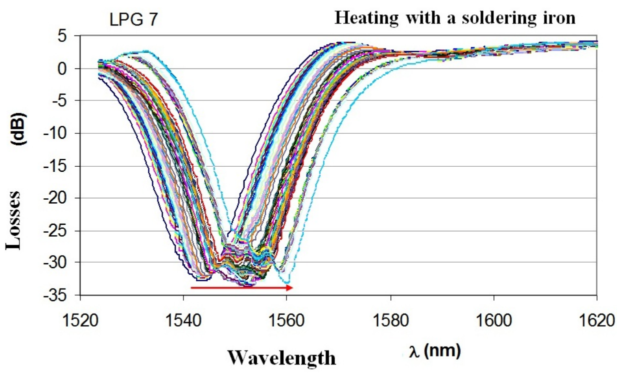

Fig. 6. Spectral shifts caused by heating with a solder.

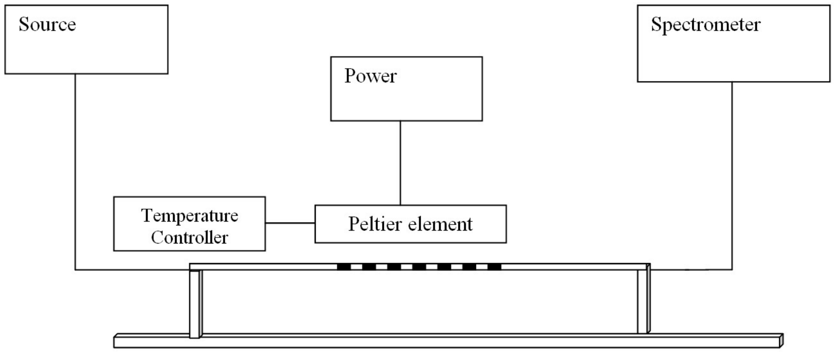

Fig. 7. Scheme of the experimental setup used to register the response under the influence of temperature changes (in average temperature intervals).

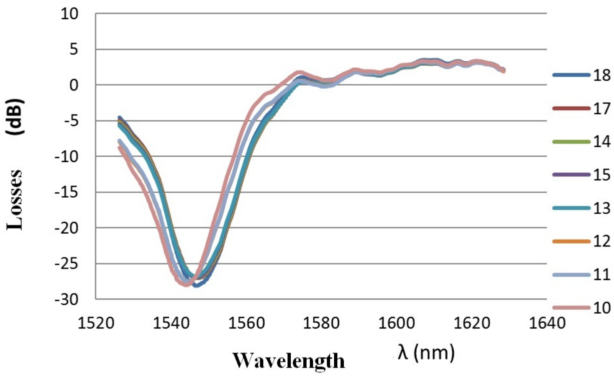

Fig. 8. Spectral shifts of a LPG as a result of heating with low temperatures.

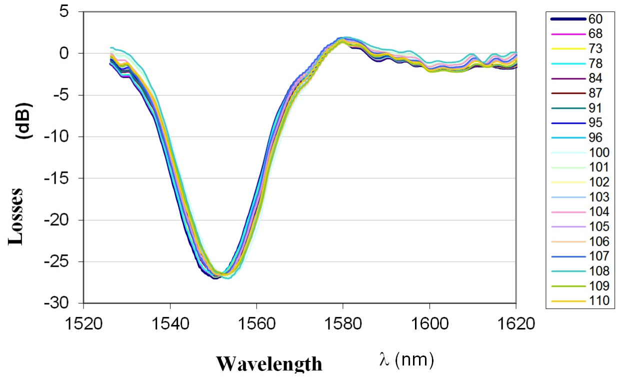

Fig. 10. Spectral responses of an LPG to heating from 60°C to 110°C.

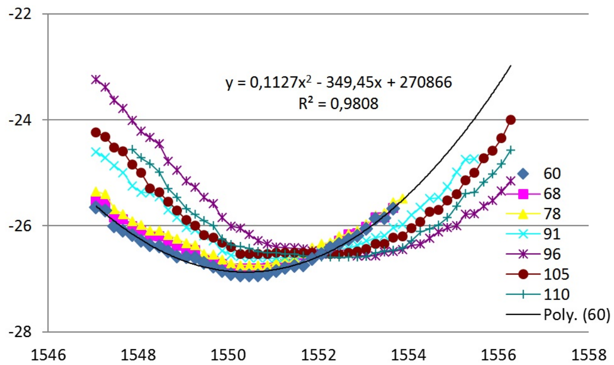

Fig. 9. Quadratic approximation around the minimum used to determine the resonance wavelenth.

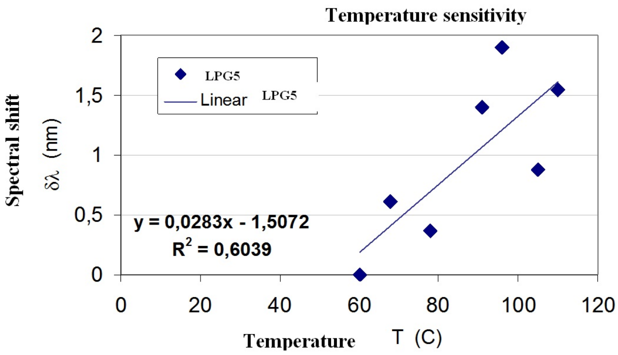

Fig. 11. Temperature sensitivity of a LPG.

controller for measuring the temperature, the CCD-based spectrometer and a computer. The response was recorded at room temperature of about 220°C, such as the grating is first heated and then cooled. Threshold of Peltier heating element reaches 490°C, and on cooling to 110°C. A flow chart of the experimental set-up used for the recording of the response under the effect of the change in temperature (temperature at average intervals) is shown in Fig. 7. Fig. 8 shows the observed spectral changes and Fig. 9 illustrates the quadratic fitting of the minimum used to determine the shifts. The responses are set to the minimum of a LPG as a result of heating and cooling to a lower temperature. Fig. 9 represents a quadratic approximation around the minimum when heated at high temperatures.

The experimental setup used to determine the spectral response of a LPG under the influence of high temperatures is the same as in Fig. 10, except that polarity of the Peltier elements is reversed and it is used as heater, which reaches a high temperature range. The response was recorded from 60°C to 110°C. Fig. 10 presents the response of the minimum of the LPG due to heating it to higher temperature. Fig. 11 represents the temperature sensitivity of the LPG. As a whole the tested LPG is very weakly sensitive to temperature $S_T = 28.3$ pm/°C.

From the spectra for different levels of the temperature can be seen that the bars are sensitive to higher temperatures, it is of course quite by accident and has not been a major goal.

As described in section 2, this type of arrays are typically designed to be sensitive to the two mentioned parameters, i.e. those gratings used for the tests are not specifically designed to study the responses in temperature influence, and are specialized for the other two parameters, but however with them sufficiently gives the dependence of the temperature in the temperature range 10°C recorded by CCD-based 16-channel spectrophotometer.

CONCLUSIONS

- The 16-channel CCD - based spectrometer can analyze 16 different responses of long period gratings with the same signal quality for any channel number.
- The 16-channel CCD - based spectrometer provides the same sensitivity to spectral shifts as the standard AQ6331 OSA.
- 16-channel CCD - based spectrometer exhibited excellent repeatability of signals after multiple switching between channels.
- 16-channel CCD - based spectrometer has an extremely wide range of applications both in science and industry in areas such as: biosensing, temperature and strain sensing.

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ИЗСЛЕДВАНЕ НА 16-КАНАЛНА ВЛАКНЕСТО-ОПТИЧНА (ВО) СИСТЕМА ЗА ИЗМЕРВАНЕ НА ДЪЛГОПЕРИОДИЧНИ (ДПР) СЕНЗОРНИ МРЕЖИ

В. Плачкова[1], Пл. Балджиев[2], Г. Дянков[1], Т. Ефтимов[1]

[1] *Физически факултет, Пловдивски университет "Паисий Хилендарски", ул. "Цар Асен" №24, 4000 Пловдив, България*

[2] *Факултет по телекомуникации, Технически университет–София, бул. "Климент Охридски" №8, 1000, София, България*

(Резюме)

Прогресът във влакнесто-оптичните технологии предлага изключителни възможности за разработка на широк спектър от високо-чувствителни влакнесто-оптични сензори в много нови области на приложения. В областта на сензорите се прояви завишен интерес към измерване на два и повече физически параметъра едновременно. Тези измервания се извършват със сензори, основаващи се на проста и ефективна схема за детекция на сигналите, с използване на линейна фотодиодна CCD матрица в комбинация с дифракционна решетка, за да измери спектралните отмествания, които са пропорционални на фазовите промени, въведени в сензорното влакно. Получените отклици са линейни.

Изследваната 16-канална система е сравнена с едноканален спектрометър на основата на дългопериодична решетка с фотодиод.

Изследвани са възможностите на спектрометъра на основата на линейна фотодиодна CCD матрица в комбинация с дифракционна решетка за едноканално измерване и многоканално измерване, както и едновременното записване на данни посредством разработен за целта софтуер.

Чувствителността на 16-каналения спектрометър е тествана чрез измерване промяната на спектъра на дългопериодични решетки, следствие въздействие на механично напрежение, промяна на показателя на пречупване и влияние на температурата.