Th analysed resistor ($R=1k\Omega$) was designed as long resistor. The majority of its area - in spite of ability of power distribution – has a big influence on strength growing. If $1k\Omega/0.125W$ will be made from the paste with $1k\Omega$ sheet resistance, it immunity on the same kind of disturbance will be decreased twice.

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ANALYSIS OF THE PARTICIPATION OF THE REFRACTION INDEX CHANGE UNDER THE INFLUENCE OF THE TEMPERATURE AND THE THERMAL EXPANSION OF THE SENSORS BASED ON FIBER BRAGG GRATINGS

In this article calculations concerning FBG (Fiber Bragg Gratings) parameters, designed for the temperature sensors construction, are presented.

As a result of the thermal expansion of the material, in which the grating is described, the temperature influence manifests itself in grating's dimensions change, and as a consequence in grating's period change. The change of the reflection wavelength is a result of such behaviour. Moreover the temperature has also an influence on the refractive index change of the FBG and in consequence the change of the wavelength.

In this work we have made the analysis participation of thermal expansion as well as refraction index change, which influence the reflected wavelength.

Our considerations include the problem of optimization the conversion characteristic.

1. Introduction

A wide range of fiber sensors based on Fiber Bragg Gratings (FBG) have been introduced. Fiber sensors use a variety of techniques to detect the measurands. Some of these are based on intensity, phase, polarization, or wavelength changes [1]. The Bragg wavelength of FBG is very sensitive to the environment. This property is exploited in the sensing applications [2]. In this work we have made the analysis thermal expansion and refraction index change, which influence the shifted wavelength. This feature allows us to optimize the conversion characteristics of the fiber Bragg gratings sensors.

2. Principle of operations

The Bragg wavelength λ_B by the constant value of grating's period Λ and refractive index n is expressed by the following equation [3, 4]:

$$\lambda_B = 2n\Lambda \tag{1}$$

where: Λ – grating's period

The temperature change has an influence on fiber length L and/or refractive index n [5] and this cause change of Bragg wavelength λ_B according to equation (2).

$$\frac{1}{\lambda_B}\frac{\partial \lambda_B}{\partial A} = \frac{1}{n}\frac{\partial n}{\partial A} + \frac{1}{L}\frac{\partial L}{\partial A} \tag{2}$$

where: A – the given physical quantity (temperature).

In this article we consider the fiber length change L with exception of refractive index n change.

Under the influence of grating's temperature there is a change of thermal expansion of material and grating's length and automatically grating's period's change, which bring the change of reflection wavelength.

This can be expressed by the following equation [6]:

$$\frac{\Delta \lambda_B}{\lambda_B} = \left[(1 - p_e)\alpha + \xi\right] \cdot \Delta T \tag{3}$$

where: $\Delta\lambda_B$ – the Bragg wavelength change caused by the temperature,
λ_B – the Bragg wavelength in room temperature,
p_e – thermooptical coefficient (in room temperature its equal 0,22),
α - thermal expansion coefficient of fiber with the grating (equal 5 x 10-7 1/K),
ξ – the elastooptic constant (also called thermo-optical efficiency ~7 . 10-6 K-1) of the optical fiber.

The value of α coefficient for most materials decreased along with temperature increase, which has an influence on sensitivity fall.

The phenomenon of the refractive index value change under the temperature change names thermooptical effect [7]. This effect is quantitative described by the thermooptical coefficient p_e.

3. The thermal changes of the refraction index on the basis of the boron-silicon glass

The value of refraction index depends on medium (glass) density to a large extent. Glasses with larger density are characterized by larger refraction index, because of the light speed, which is smaller in such mediums than the light speed in big density medium [8]. For a fixed wavelength, the change measure of the refraction index is the refraction index value increment dn to the temperature increment (in the range of 1^{o}C) ratio. This relationship characterizes the optical medium in the specific temperature range and environmental conditions. The increments of the refraction index along with temperature can occur in the wide range (from 10^{-6} to 10^{-4} ^{o}C). The physical mechanism of the dn/dT changes is twofold: one is an effect of the density ρg changes, which are caused by the thermal expansion of the material and also there is an effect of the spatial position influence, and elementary entities property which determines the refraction and their polarization ability. This duality is perceptible by the Lorenz equations analysis [9]. This equations describes the molar refraction R_λ [9]:

$$R_\lambda = \frac{n_\lambda^2 - 1}{n_\lambda^2 + 2}\frac{M}{\rho_g} \tag{4}$$

or

$$\frac{n_\lambda^2 - 1}{n_\lambda^2 + 2} M = \rho_g R_\lambda \tag{5}$$

Therefore the refraction index increment along with the temperature can by expressed by the following equation:

$$\frac{6n_\lambda}{\left(n_\lambda^2+2\right)^2} M \frac{dn}{dT} = \rho_g \frac{dR_\lambda}{dT} + R_\lambda \frac{d\rho_g}{dT} \tag{6}$$

The second module of (3.3), $R_\lambda \frac{d\rho_g}{dT}$ concerns the temperature changes of the density, which depends on the thermal, volumetric expansion coefficient α in the following way:

$$\frac{d\rho_g}{dT} = \rho_g \alpha \tag{7}$$

The refraction index change, which is dependent on the deformation of material, caused by the thermal expansion, can be expressed by the material constant and the linear, thermal expansion coefficient α_j (which is the elastooptic P_{ij} tensor):

$$\Delta\left(\frac{1}{n^2}\right)_i = P_{ij}\alpha_j \tag{8}$$

For example, for the isotropic mediums, when $\alpha_1 = \alpha_2 = \alpha_3$ we can receive:

$$\Delta\left(\frac{1}{n^2}\right)_i = \left(P_{11} + 2P_{12}\right)\alpha_1 \Delta T \tag{9}$$

Thus if we want to determine the refractive index value increment, caused by the thermal expansion in the temperature range of 1°C, we can get the following relation:

$$\left(\frac{1}{dT}\right)_\alpha = -\frac{n^3}{2}\left(P_{11} + 2P_{12}\right)\alpha_1 \tag{10}$$

However the refraction index depends on the linear expansion (α), as well as the absorption (χ) (it results from the experimental observations of the refraction index thermal changes). This can be expressed by the following equation:

$$\frac{dn}{dT} = \left(\frac{dn}{dT}\right)_\alpha + \left(\frac{dn}{dT}\right)_\chi \tag{11}$$

$\left(\frac{dn}{dT}\right)_\chi$ is connected with the short-wave absorption growth mechanism, caused by the ascending temperature, and therefore there is a shift short-wave limit of the transmission region of spectral absorption to the longer wavelengths. We can observe on the basis of the refraction index dispersion graph that there is a positive increase of this index if we approach to the short-wave limit.

Due to the nonlinearity of the function described by both of indexes, dn/dT increments may be described by two order curves with the minimums, maximums and the points of inflexion. This indexes decreases and increases along with the temperature growth. Figure 1 is an example of these temperature changes of the refraction index for the boron-silica glass. We can see the thermal expansion effect Δn_α, as well as the absorption changes effect Δn_χ.

The result curve for the temperature of 20°C is due to the common compensation. For the optical glasses (with the positive thermal expansion coefficient α in the typical range of temperature) dn/dT decreases along with the wavelength. If the temperature increases, the absolute value of the dn/dT increases but this changes may be positive as well as negative. For major optical glasses we can see that the thermooptical constant (dn/dT) changes are linear along with the thermal expansion coefficient. If thermooptical constant decrease, then the thermal expansion coefficient increase.

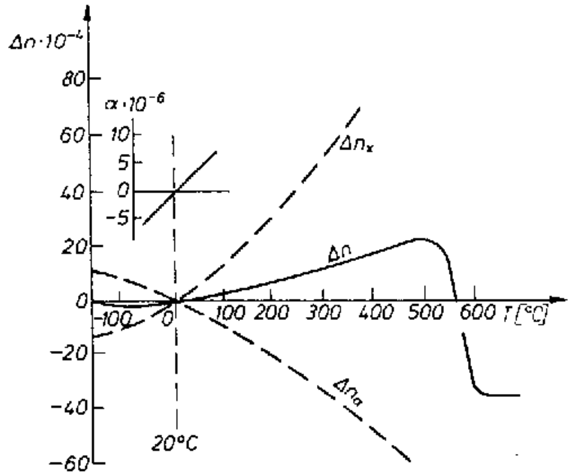

Fig. 1. Refraction index increments for the boron-silica glass versus the temperature:
Δn_α *– curve of the thermal expansion;* Δn_χ *– curve of the apsorption changes*

4. The measurements results

For the aim of practical confirmation of theoretic relationships, we have done examinations and measurements of the Bragg wavelength shift $\Delta\lambda_B$.

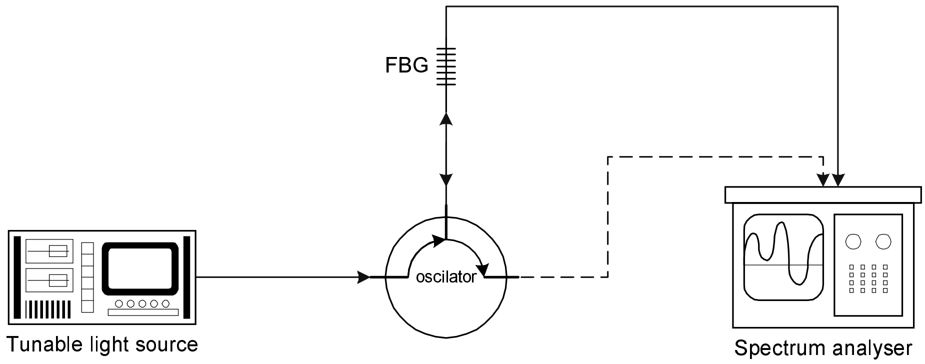

Fig. 2. Functional diagram of the measurement system

The temperature influence on Bragg wavelength presents best fig. 7.

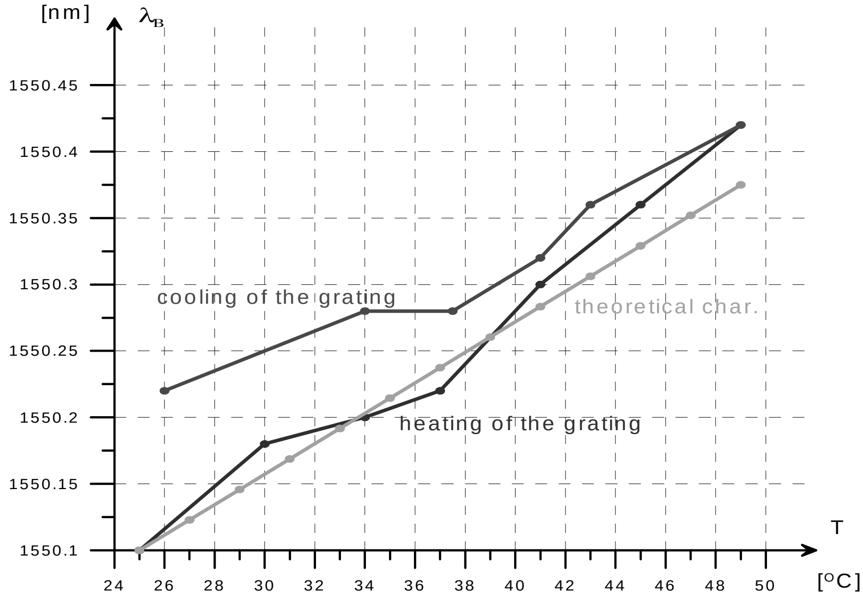

Fig. 3. Common presentation of the curve from laboratory measurements along with theoretical curve

5. Conclusions

Taking into account the bendiness of component charts of both effects: absorption of the short-wave radiation and the glass density change, it's necessary to receive a constant change of the refractive index Δn.

The results we showed on the charts provoke us to occupation of the conversion characteristics optimization problem. If the conversion characteristic may be linear, then the wavelength will be proportional to the measured temperature. It's very desirable feature for the temperature sensor.

As a result of the researches on the FBF element, it's convert characteristics (which are the $d\lambda/dT$ ratio) confirm that there is a possibility to achieve the linear conversion characteristic.

In order to achieve for conversion characteristic the linear character, it's also necessary to ensure the linear relationship of the refraction index n versus the temperature T.

We can see, that there are some temperature ranges, for which the refraction index change Δn is constant versus the temperature. This determine the linearity of a $n = f(T)$ function. The two linear characteristic components which was found in this way gives us the linear conversion characteristic as well.

By using the possibility of influence on the two effects characteristics (and by suitable doping) there is a possibility to maintenance of constant refraction index change versus the temperature.

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