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REFRACTOMETRIC TEMPERATURE CONVERTER

There had been analyzed the main optic methods for temperature measuring. There had been suggested the optical measuring temperature converter, the sensitive elements of which are made of dielectric with negative index of refraction.

Key words: *optical method, temperature, temperature converter, waveguide, negative index of reflection, sensor.*

Introduction. Reliability and stability of the system of any complexity depends, first of all, on the temperature of an environment and on separate nodes of this system. Therefore temperature control is one of the most important tasks of the modern science. Measuring converters based on refractometers have been often used for measuring liquid and gas temperature in specific conditions [1]. Such devices are used for measuring temperature in fluids and gases in medical institutions: to control hyperthermal therapy [2], to determine fluid, composition, for local precise temperature measuring in different objects in special conditions [3], to analyze the brain and joint liquids, subretinal fluid in the eye; in pharmaceutics – to research water solutions of different medical preparations in sanitary-hygienic laboratories; in food industry to analyze raw materials and in other branches.

Analysis of recent researches. Optical methods are often used for measuring temperature in complicated specific conditions. Explosion and fire safety allows to locate optical measuring devices in places where electronics do not work.

Fiber-optical measuring convertors are of two types: with external and internal modulation. In the first case the fiber transfers the optical signal. Information parameters of light signal allow to choose the intensity phase, frequency, polarization, spectrum etc. Then, the fiber transfers the modulated in accordance with the influence of the environment signal to the receiver.

In some cases the input fiber may act as an output one.

In the second case, the optic fiber transfers the light beam, which parameters undergo an influence in accordance with the environment parameter change directly such a method is a contract method, based on light distribution though the optic waveguide immersed into fluid.

However the existing methods and devices are characterized by the complexity of their structure, poor sensitivity, which restricts their application. The major drawback of these methods is high measurement error.

The new composite materials with negative index of reflection (NIR) and research of their unusual peculiarities resulted in issuing many papers, dedicated to the possible ways of their application [4, 5, 6]. Waveguides, built on the base of such materials, have special distribution of energy and mode composition of radiation. These unique peculiarities may be applied to both, information conversion and refractometric measurement.

The objective of the work is the development of refractometric temperature converter of improved accuracy and sensitivity.

Materials and results of the research. Fig. 1 presents the structural diagram of refractometric temperature converter.

The device comprises seriesly placed and optically connected sources of nonmonochromatic radiation, optical waveguide and processing block. The output of nonmonochromatic radiation source is connected to the input of the optic waveguide, which output is connected to input of processing block.

Refractometric temperature converter works as follows: the sources of nonmomochromatic radiation forms a light beam which goes to an optical waveguide, immersed into fluid.

The beam is spread in the core of waveguide and goes to the input of processing block, after which the data from the output of processing block are analyzed and the fluid temperature is determined.

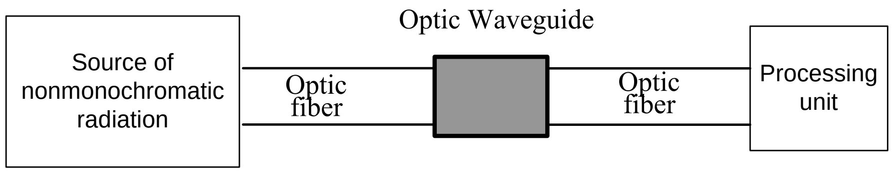

Fig. 1. Structural diagram of refractometric temperature converter

Let us consider the structure of sensitive element in details. It is a dielectric shank with a core, which has the refraction index n_1 and shell with the refraction index n_2. Sensitive element is completely immersed into fluid with refraction index n_3.

Such a structure of a sensor was described in [7]. The core of this waveguide is made of material with negative refraction index. The peculiarity properties of the materials with negative refraction factor are: negative refraction, simultaneous negative electric and magnetic permiability, antiparallelity of group and phase speeds [8].

Characteristic equation of three-layer flat waveguide looks like:

$$\frac{m_3}{m_2}k_2\tan(k_2 d)\pm\frac{m_3}{m_1}k_2\tan^{\pm1}(k_1 L)\pm k_3\frac{k_1}{k_2}\frac{m_2}{m_1}\tan(k_2 d)\tan^{\pm1}(k_1 L)-k_3=0, \quad (3)$$

where $k_1^2=k^2n_1^2-h^2$, h – propagation constant, $n_1=\sqrt{\varepsilon_1\mu_1}$ – refraction index of the core, $k_2^2=k^2n_2^2-h^2$, $n_2=\sqrt{\varepsilon_2\mu_2}+i\alpha_2$ – shell refraction index, α_2 – factor of light attenuation in the shell, $k_3^2=h^2-k^2{n_3}^2$, $n_3=\sqrt{\varepsilon_3\mu_3}$ – refraction index of the environment, $k=\frac{2\pi}{\lambda}$ – wave number of free space, λ – wave length, $2L$ – geometrical dimensions of the core, d – geometrical dimensions of the shell.

As was shown in [9], two-layer waveguide with NIR of the core have peculiar mode composition. Independent of parameter value, mode composition of waveguides at equal frequency will be similar.

The research of mode composition of the suggested three layer structure requires the construction of the dependence of the reduced frequency:

$$V=2kL\sqrt{n_1^2-n_3^2}, \quad (4)$$

of the normalized propagation constant:

$$b=\frac{\frac{h}{k}-n_3}{n_1-n_3} \quad (5)$$

Building a dependence changes the parameter V de to parameter n_3 - environment refraction index. Cutoff of the second mode takes place when $V=V_2$ and $b=0$:

$$b=\frac{\frac{h}{k}-n_3}{n_1-n_3}=0\Rightarrow h_2=kn_3 \quad (6)$$

where h_2 – propagation constant, with which the cutoff of the second mode takes place.

Substituting the value of propagation constant into the characteristic equation (3) the received equation will look as

$$\frac{m_3}{m_2} k_2 \tan(k_2 d) \pm \frac{m_3}{m_1} k_2 \tan^{\pm 1}(k_1 L) = 0, \qquad (7)$$

where $k_1^2 = k^2 n_1^2 - k^2 n_3^2$, $k_2^2 = k^2 n_2^2 - k^2 n_3^2$.

Solving this equation relative to variable n_3 with the rest set parameters we receive the next value of NIR of an environment, with which the cutoff of the second mode takes place in the waveguide. According to the received solution of reduced frequency, we determine the value $V_2 = 2{,}132$, which, independent on waveguide parameter value ensures the cutoff of the second mode.

Proceeding from the received value of the reduced frequency at the second mode cutoff moment and formula (7), we determine the dependence between the length of the wave which will ensure the second mode cutoff in this waveguide and NIR of an environment $\lambda_2 = f(n_3)$:

$$\lambda_2 = \frac{2\pi}{V_2} L\sqrt{n_1^2 - n_3^2} = 2{,}947 L\sqrt{n_1^2 - n_3^2} \qquad (8)$$

Since the refraction index depends on internal composition of the substance, it also depends on temperature, pressure, concentration, nature of solvent. Therefore, the systematization of obtained results needs a refraction index taken at temperature 20±0,3 **°C** in the natrium spectrum (598,3 nm). Refraction index, received under such conditions it is designated as n_{20} and is used in reference data of the main physical and chemical peculiarities of substances.

During measurement in conditions of other temperature it is necessary to introduce temperature amendments according to the formula

$$n_3 = n_{20} + 0.0002(20 - t), \qquad (9)$$

where n_3 – index of fluid refraction at temperature, which changes , n_{20} – standard refraction index, t – temperature, at which measurements took place [10].

From formula (9) we express t , receive:

$$t = \frac{(n_3 - n_{20})}{0.0002} - 20 \qquad (10)$$

As is seen from formula (8), wavelength of wave depends on refraction index, the processing block calculates NIR of the fluid on the wave length, and then the temperature is determined according to formula (10).

Fig. 2 presents the dependence between the length wave and water temperature in the vessel.

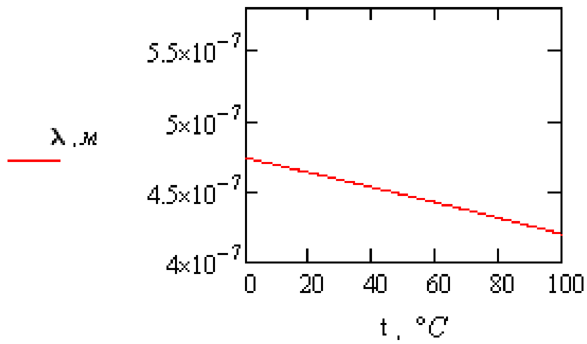

Fig. 2. Dependence of the wavelength on water temperature in the vessel

There is an approach to determination of fluid temperature [11]. Methodical error in such measuring conversion shall be calculated according to the formula:

$$\Delta = \frac{\partial T}{\partial n}\frac{\partial n}{\partial I} + \frac{\partial T}{\partial n}\frac{\partial n}{\partial \lambda}, \tag{11}$$

where T – fluid temperature, I – intensity of light beam, λ – wave length, n – index of fluid refraction.

Methodical error of the suggested device is determined:

$$\Delta' = \frac{\partial T}{\partial n}\frac{\partial n}{\partial \lambda}, \tag{12}$$

where T – temperature of fluid, λ – wave length, n – index of substance refraction.

As is seen form formula (11, 12), the suggested approach allows to eliminate the component of an error which appears in the result of registration of intensivity of light stream.

Conclusions. There had been suggested the refractometric temperature converter, the sensitive element of which is made of dielectric with negative index of refraction

Since the measurement of refraction index takes place without the registration of capacity, it eliminates the constituent of refraction which appears in the result of radiation source in stability. Thus, the research results in improvement of accuracy and sensitivity of the device.

REFERENCES

1. Pat. №3826978 USA, IPC G01N22/00 G01R27/04 Waveguide refractometr / Krawczewicz, Stanley T.; applicant. Exxon Production Research Co., Houston, Tex. – appl. no. 347525; apl. 04/03/1973; pub. 07/30/1974.

2. Егоров Ф. А. Волоконно-оптический термометр для контроля гипертермической терапии / Ф. А. Егоров, В. А. Королев, В. Т. Потапов // Лазерная медицина. – 2005. – № 3(9). – С. 53 – 54.

3. Волоконно–оптический зондовый термометр [Електронний ресурс]: Инновационное предприятие «НЦВО – Фотоника / Режим доступу: http://www.forc-photonics.ru/ru/production/volokonnye_sensornye_sistemy/1/13.

4. Shelby R. A. Experimental Verifcation of a Negative Index of Refraction / R. A. Shelby, D. R. Smith, S. Shultz // Science. – 2001. – №292. – P. 77 – 78.

5. Соколов А. Н. Волоконно-оптические датчики и системы: принципы построения, возможности, перспективы / А. Н. Соколов, В. А. Яцеев // Lightwave Russian Edition. – 2006.– №4. – С. 44 – 46.

6. Peter Markos Structures with negative index of refraction / Peter Markos, C. M. Soukoulis // Physica status solidy, 2003. – № 197(3). – P. 595 – 604.

7. Оптичний вимірювальний перетворювач рівня рідини [Електронний ресурс] / С. М. Довгалець, П. А. Хомчук, І. П. Борщова // Наукові праці ВНТУ. – 2009. – №3. Режим доступу до журн.: http://www.nbuv.gov.ua/e-journals/VNTU/2009-3/2009-3.files/uk/009vykoll_ua.pdf.

8. Shadrivov I. V. Guided modes in negative-refractive-index waveguides / I. V. Shadrivov, A. A. Sukhorukov, Y. S. Kivshar // Physical Review E. – 2003. – Vol. 3, № 67. – P. 10 – 14.

9. Довгалець С. М. Рефрактометричні вимірювання з використанням оптичних хвилеводів із від’ємним показником заломлення / С. М. Довгалець, А. Ф. Хомчук, П. А. Хомчук // Вісник Кременчуцького державного політехнічного університету. – 2008. – № 1 (9). – С. 56 – 60.

10. Ляликов Ю. С. Физико-химические методы анализа / Ю. С. Ляликов – М., "Химия", 1973. – 536 с.
11. Габа В. М. Измерение температуры с использованием оптических датчиков на основе двулучепреломляющих кристаллов / В. М. Габа // Технология и конструирование в электронной апаратуре. – 2009. – №1. – С. 45 – 52.

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