PROCEEDINGS OF THE YEREVAN STATE UNIVERSITY

Physical and Mathematical Sciences 2009, № 1, p. 40–44

Physics

OPTOCHEMICAL FIBER SENSOR FOR RESEARCH OF STRUCTURAL FEATURES OF A SOLUTION

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The process of irradiation of light energy from optical fiber's conic top covered with metal and dielectric layers is studied. As a dielectric layer is used the meniscus formed during an output of conic top from a solution. Peculiarities registered peak of radiation allow to explore structural features of solution.

***Keywords*:** optical fiber's conic top, optical sensor, resonant transfer of energy.

Sensors, created on optic filter base, due to a number of their features are very interesting and perspective. Their features are: many-mode spread possibility, interferential sensitivity, lability to electromagnetic noises, lightness, small sizes, which enables to make various sensors with high permission.

Covered with metal and dielectric layers the optical fiber conic top, which is used in microscopy of near-field as a scan sonde, has a lot of interesting physical features. In due course it becomes clear that various optical sensors can be made on the basic on these features [1–9].

Here we investigate light ray propagation features through the conic top of optic fiber covered with thin metal layer, where added dielectric layer is formed [10–20].

The longitudinal section of such structure is presented in Fig.1. It has two waveguides, first is the core of optical fiber (internal waveguide), where the light initially propagated, and the second one is the dielectric layer (external waveguide). When the metal layer is relatively thin, the inner and outer waveguides can connect resonantly, and as a result the energy of one of waveguide channel will transform to the other one. Such transformation will occur, if wave vectors of mode are very closed.

Propagating by the inner waveguide, the light energy part is reflected, and the second part transits into the core outer waveguide and get out of the fiber top. Thus experimentally measured wave energy is the energy irradiated from external waveguide. Hence it can be assumed that the energy transforms from internal waveguide mode to outer one at the certain distance from conic top. As mentioned,

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the connection mode wave vectors equality is necessary for resonance transformation that can occur only at the certain thickness of dielectric layer.

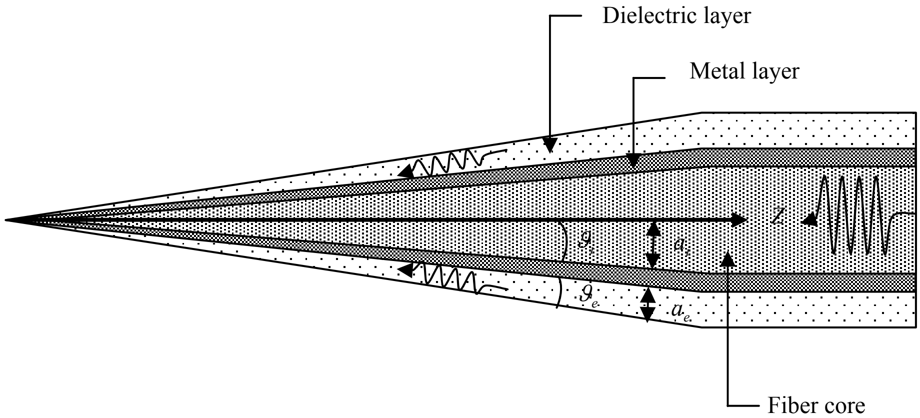

Fig. 1. Longitudinal section of fiber, covered with metal and dielectric layers.

In practice the resonance transformation can be revealed by changing dielectric layer thickness. Such layer can be got in the process of fiber top get out the liquid. Then a meniscus (a layer of transparent liquid) which changes its form simultaneously to fiber top movement is formed because of its surface tension. As if the waveguide vector of outer mode depends on dielectric layer thickness and hence from meniscus form, the wave vectors are equalized at top certain position relatively to liquid surface. At this time energy pumping from one mode to the other one and sharp increase of light power is observed. The purpose of experiment is to measure and register this energy.

Experimental scheme is presented in Fig. 2.

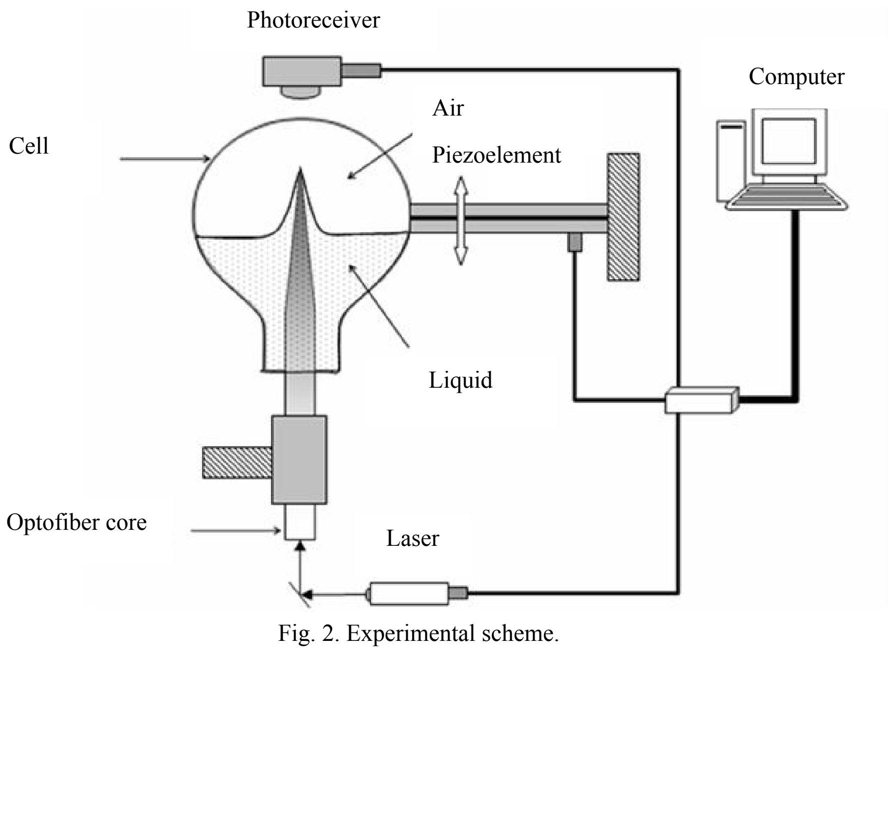

Fig. 2. Experimental scheme.

Radiation of semiconductor laser with power 30 *Mw* and wavelength 690 *nm* is introduced into optic fiber with diameter 100 μ. Fiber conic top angle is 20^0, it's covered with gold layer (thickness 50 *nm*) [4]. A solution of dimethylsulphoxide (DMSO) and water with different volume proportions is used as a liquid. Fiber top by means of piezoelement is transformed in cell with step of 0,15 μmol. During each step the radiation power from fiber top is register 10^4 times and averaged.

Here we investigate a cone as a sequence of cylinders with decreasing radiuses that is the transformation to the conic structure is realized adiabatically, which is used only at cone small corners [21].

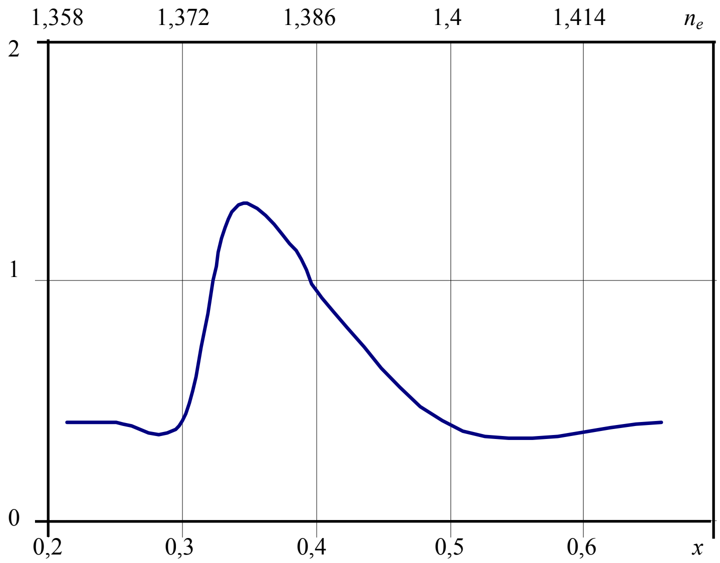

Fig. 3. Peak power dependence on solution compound.

For cylindrical waveguide the wave vector has the form [3]

$$\beta = \sqrt{n^2 \frac{\omega^2}{c^2} - \chi^2}\ , \tag{1}$$

where n is the medium refraction coefficient, ω is the wave frequency, c is the light rate, χ is the coefficient of connection between two waveguides. From theory of connected modes is known that χ is inversely proportional to parameters of wave localization region (area). Hence the wave vectors for outer and inner wave will be:

$$\beta_i = \sqrt{n_i^2 \frac{\omega^2}{c^2} - \frac{c_i}{a_i^2}^2}\ , \quad \beta_e = \sqrt{n_e^2 \frac{\omega^2}{c^2} - \frac{c_e}{a_e^2}^2}\ , \tag{2}$$

where n_i and n_e are the refraction indexes of optic fiber and liquid correspondingly (see Fig. 1), a_i and a_e are the parameters of outer and inner waveguides correspondingly, c_i and c_e are the constants, determined from theory (c_i, c_e ~1). For conic structure at $\vartheta_i\vartheta_e << 1$ *rad* the dependence of a_i and a_e from z coordinate will be $a_i = \vartheta_i z$, $a_e = \vartheta_e z$. From theory of bounded modes [22] it follows that the effective transformation of wave energy from one mode to the other will occur at equalization of wave vectors:

$$n_i = n_e , \qquad \frac{c_i}{\vartheta_i^2} = \frac{c_e}{\vartheta_e^2} . \qquad (3)$$

First condition is accomplished at selection of corresponding liquid. DMSO solution with water is used in our experiment, which refraction coefficient changes from 1,36 till 1,42, depending on DMSO quantity increase in water. Experiment is carried out separately for each solution, only fiber refraction coefficient (n=1,46) and temperature (in this case the room one) remain unchangeable.

The second condition can be accomplished by changing angle ϑ_e. ϑ_e decreases when fiber top logs out the liquid. Hence, the conditions (3) are accomplished at movement of fiber top relatively to liquid surface. A strong increase of outer power is observed at the moment of (3) accomplishment (Fig. 3).

Dependence of peak power on liquid volume ratio in solution $x = \frac{V_{\text{DMSO}}}{V_{\text{DMSO}} + V_{\text{H}_2\text{O}}}$ is shown in Fig.3. Coefficient of solution refraction is calculated by following formula:

$$n_{\hat{a}} = x n_{\text{DMSO}} + (1 - x) n_{\text{H}_2\text{O}} . \qquad (4)$$

Hence, a strong increase of peak power is revealed due to DMSO quality increase in water. It's explained: the structural changes occur at room temperature and DMSO certain concentration in solution. Method, suggested here, can be used for study of the structural features of solutions.

Received 16.04.2008

R E F E R E N C E S

1. **Janunts N., Baghdasaryan K., Nerkararyan Kh., Hecht B.** Opt.Comm., 2005, v. 253, p. 118–124.
2. **Hansperger R.G.** Integrated optics: Theory and technology. Berlin: Springer, 1984.
3. **Kawata S., Ohtsu M. and Irie M.** Nano-Optics. Springer, 2002.
4. **Stockle R., Fokas C., Deckert V., Zenobi R., Sick B., Hecht B. and Wild P. Urs** Appl. Phys. Lett., 1999, v. 75, p. 160–164.
5. **Udd E.** Fiber Optics Sensors. An Introduction for Engineeris and Sceintists Wiley, 1991.
6. **Yu T.S.F.** Fiber Optics Sensors. Marcel: Dekker, 2002.
7. **Janunts N.A. and Nerkararyan Kh.V.** Appl. Phys. Lett., 2001, v. 79, p. 299–301.
8. **Saleh B. and Teich M.** Fundamentals of Photonics. Wiley, 1991.
9. **Samble J.R.** Contemp. Phys., 1991, v. 32, p. 173.
10. **Babayan A., Margaryan N., Nerkararayan Kh.** J. Appl. Phys., 2000, v. 88, p. 3785–3790.
11. **Kretschmann E.** Z. Phys., 1971, v. 241, p. 313–317.
12. **Kurihara K., Suzuki K.** Anal. Chem., 2002, v. 74, p. 696.
13. **Kurihara K., Nakamura K., Suzuki K.** Sens. Actuators, 2002, B86, p. 49.
14. **Green R., Frazier R., Shakesheff K., Davies M., Roberts C., Tendler S.** Biomaterials, 2000, v. 21, p. 1823.
15. **Haake H.-M., Schutz A., Gauglitz G., Fresenius** J. Anal. Chem., 2000, v. 366, p. 576.

16. **Kurihara K., Ohkawa H., Shinozaki Y., Iwasaki Y., Tobita T., Niwa O., Suzuki K.** Proceedings of the Sixth European Conference on Optical Chemical Sensors and Biosensors. 2002, p. 155.
17. **Schroter U., Dereux A.** Phys. Rev., 2001, B64, p. 125420.
18. **Ito T., Sobue K., Ohya S.** Sens. and Actuators, 2002, B81, p. 187.
19. **Kurihara K., Iwasaki Y., Suzuki K.** Proceedings of the Fifth European Conference on Optical Chemical Sensors and Biosensors. 2000, p. 55.
20. **Rabe U., Janser K. and Arnold W.** Rev. Sci. Instrum., 1996, v. 67, p. 3281–3293.
21. **Abrahamyan T., Janunts E. and Nerkararyan Kh.** Applied Optics, 2006, v. 45, issue 32, p. 8194–8196.
22. **Raether H.** Surface Plasmons on Smooth and Rough Surface and on Gratings. Berlin: Springer-Verlag, 1988.

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Լուծույթի կառուցվածքային առանձնահատկությունները ուսումնասիրելու համար օպտոքիմիական մանրաթելային սենսոր

Ուսումնասիրվում է մետաղական և դիէլեկտրական շերտերով պատված օպտիկական մանրաթելի կոնաձև գագաթից լուսային էներգիայի ճառագայթման պրոցեսը: Որպես դիէլեկտրական շերտ ծառայում է կոնաձև գագաթի լուծույթից դուրս գալու ընթացքում գոյացած մենիսկը: Գրանցված ճառագայթման առանձնահատկությունները թույլ են տալիս ուսումնասիրել լուծույթի կառուցվածքային առանձնահատկությունները:

Э. Г. Геворгян.

Оптохимический волоконный сенсор для исследования структурных особенностей раствора

Изучается процесс излучения световой энергии из покрытой металлическим и диэлектрическим слоями конической вершины оптического волокна. В качестве диэлектрического слоя выступает мениск, образованный в процессе выхода конической вершины из раствора. Особенности зарегистрированного пика излучения позволяют судить о структурных особенностях раствора.