Journal of Optoelectronics and Advanced Materials Vol. 3, No. 2, June 2001, p. 373 - 376

CHALCOGENIDE FIBRE DISPLACEMENT SENSOR

S. Miclos, T. Zisu

National Institute of R & D for Optoelectronics INOE-2000, 1, Atomiştilor Str., POB MG-5, 76900 Bucharest-Magurele, Romania

Fibre optic technology offers the possibility for developing of a variety of physical sensors for a wide range of physical parameters. The main advantage of fiber optic sensors lies in their dielectric construction, providing electrical isolation, immunity from electromagnetic fields, small dimensions, and compatibility with optical fibre technology. A large number of fiber sensors in production are based on intensity modulation of the light either outside the fiber or within it. In the case of intensity sensors the physical perturbation to be measured interacts with the fibre or some device attached to the fibre to modulate the intensity of the light as it travels through the fiber. Intensity modulated fiber sensors have been demonstrated to be efficient for different applications. A variation of internal-modulation sensors are the microbending-loss sensors, which are characterized by a relatively simple construction, good performances and compatibility with multimode fibre technology. A very effective configuration for the microbending-loss sensors is that one based on clad mode detection. For clad modes detection the end segment of the fiber is bent and placed in an integrating sphere. The use of chalcogenide rather quartz fibre optic highly increases the sensitivity of the sensor. Experimental set-up, transmission characteristics and technical parameters are presented.

(Received June 1, 2001; accepted June 11, 2001)

Keywords: Fiber optic sensor, Micro-displacement sensor, Chalcogenic fiber, Microbending-loss sensor

1. Introduction

Fibre optic technology offers the possibility for developing of a variety of physical sensors for a wide range of physical parameters. The use of optical fiber samples for development of optical fibre sensors allows to obtain very high performances in their response to many physical parameters (displacement, pressure, temperature, electric field etc.) compared to conventional transducers [1]. The main advantage of fiber optic sensors lies in their all dielectric construction, giving electrical isolation, immunity from electromagnetic fields, small dimensions, and compatibility with optical fibre technology. Novel approaches based on sensor oriented technology had become very promising for development of fiber sensors with high performances.

A large number of fiber sensors in production are based on intensity modulation of the light either outside the fiber or within it. In the case of intensity sensors the physical perturbation to be measured interacts with the fibre or some device attached to the fibre to modulate the intensity of the light as it travels through the fiber. Intensity modulated fiber sensors have been demonstrated to be efficient for different applications. They are relatively inexpensive, easy to be fabricated and suitable for employment in harsh environments. A variation of internal-modulation sensors are the microbending-loss sensors, which are characterized by a relatively simple construction, good performances [1-4] and compatibility with multimode fibre technology. Depending on the deformer design and material it is possible to make acoustic, magnetic, electric, temperature, acceleration, displacement sensors, etc. Fiber-optic displacement sensors may have different important uses, which exploit the nonelectrical nature of these devices. For example as vibration monitors in generators, fiber sensors guard against costly equipment damage and they are immune to the high electrical noise that plagues piezoelectric vibration sensors. And in explosive atmosphers (e.g. in mines) fiber sensors could safely monitor equipment vibration. The use of chalcogenide rather quartz fibre optic highly increases the sensitivity of the sensor. Experimental set-up, transmission characteristics and technical parameters of a fiber optic displacement sensor, based on clad mode detection, are presented.

2. Experimental results

It is well known that when an optical fiber is bent, its transmission loss increases as some of the light propagating along the fiber is radiated out. Microbending along the axis of the fibre cause mode Periodic perturbations of the fiber axis result in strong intermodal power transfer when the period of the perturbation corresponds to the difference in propagation constants of the interactng modes. Respectively, the power lost from propagation to radiation modes is maximum, when the fibre spatial bent frequency equals the difference in propagation constants between propagation and radiation modes. It was shown [5], that in the case of fiber with power low index profile, the spacing between the adjacent mode groups is given by the following relation:

$$\delta\beta_m = [2(\alpha\Delta/(\alpha+2))^{1/2}/a]\,(m/M)^{(\alpha-2)(\alpha+2)}, \quad (1)$$

were m is the mode group number, α is the index profile parameter, Δ is the parameter characteri-zing the difference between core and clad indices, a is the radius of the fiber, M^2 is the total num-ber of modes,

$$M^2 = [\alpha/(\alpha+2)](n_o\kappa a)^2\Delta. \quad (2)$$

Parabolic graded index fibers which have a constant difference in propagation constant between neighbouring modes are used to enhance the sensitivity in sensor applications. In the case of optical fiber with a parabolic index profile the formula for a mode group spacing is given by the relation (5):

$$\delta\beta = (2\Delta)^{1/2}/a \quad (3)$$

If the microbendings are formed along the fiber axis with a periodicity Λ that satisfies the relation of resonance

$$\delta\beta_c = 2\pi/\Lambda_c\,, \quad (4)$$

a complete conversion of guided modes to radiation modes takes place[2]. The critical period of microbends Λ_c is determined from the relation (5):

$$\Lambda_c = 2\pi a/(2\Delta)^{1/2} \quad (5)$$

In the case of small distortions, optical power in the fibre clad is attenuated proportionally to the displacement amplitude.

We have proposed a modified sensor configuration based on clad modes detection[6]. The experimental setup is presented in Fig. 1. It consists of a segment of transmitting optical fibre, coupled to a segment of a multimode fibre, which serves as a sensor element, a light source, a conventional deformer and a fotodetector coupled to the end of the sensor fiber. The optical fibre which serves as a sensor element is a multimode graded index fibre. For effective clad modes detection the end segment of the fiber is bent as represented in Fig. 1, to allow the clad modes out. This bent segment of the fiber is placed inside the integrating sphere in front of the photodetector. The output end face of the fiber is positioned outside of the integrating sphere, to let the core modes out. By monitoring the light power in the clad modes the applied displacement can be detected.

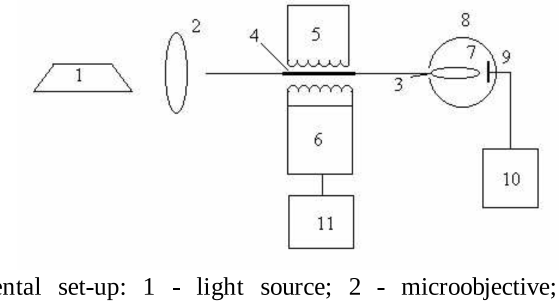

Fig. 1. Experimental set-up: 1 - light source; 2 - microobjective; 3 - optical fibre; 4 -glycerine; 5 - deformer; 6 - piezoelectric transducer; 7 - the bent segment of the fiber; 8 -integrating sphere; 9 - photodiode; 10 - lock-in amplifier; 11 - generator.

The deformer represents two grooved plates with five teeth. One plate of the deformer is fixed, and the other can be displaced relatively to the other by manually adjusting the differential micrometer or by means of piezoelectric transducer. For transmission measurements a set of grooved plates of different periodicity, covering the range from 1.4 to 4.0 mm with a step 0.2 mm, was used. Optical transmission characteristics of the fiber were measured with different light sources: a He-Ne laser, a luminiscent diode, a diode laser, etc. The fibre segment, suffering the microbending, is covered with glycerene, in order to facilitate the clading modes out. Optical transmission characteristics for different microbending periods are presented in Fig. 2. It can be seen that experimental plot lnT vs. displacement amplitude changes drastically with the microbending period Λ. For small distorsion amplitudes the transmittance characteristic has a good linearity (Fig. 3).

Microbending losses depend in a high degree on the coupling conditions. In order to investigate the dependence of transmittance characteristics on modes exciting conditions we examined the behaviour of microbending induced optical losses vs. the position of injection of light beam along the input fiber face. A monomode fiber was used for selective modes excitation in a multimode fiber. For this purpose the end segment of the monomode fiber was displaced transverse relatively to the input end face of the multimode sensor fiber to allow different modes group excitation. It should be mentioned that the number of modes, excited in a graded index fiber increases by incresing the distance from the fiber axis to the point of light beam focusing. In this case an He-Ne laser was used as a light sourse. The microbending induced losses increses with incresing the distance of light spotfrom the fiber axis. The character of this increasing is almost a monotonous one in respect to the period of microbends. The experimental dependence lnT vs. microbends period for a constant displacement amplitude is presented in Fig. 4.

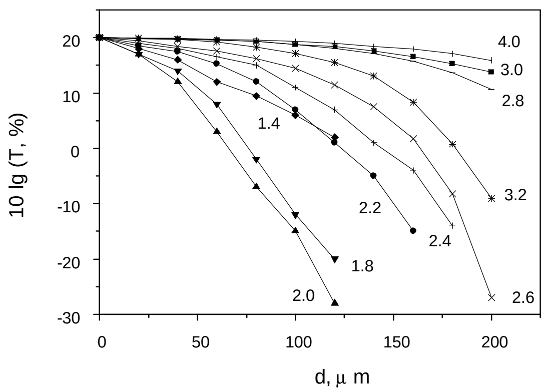

Fig. 2. Optical transmission characteristics vs. displacement amplitude for different microbend periods.= 1.4-4.0 m. The light source was a He-Ne laser coupled through a 90x microobjective.

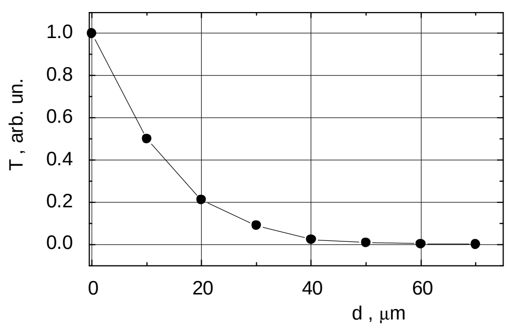

Fig. 3. Optical transmission characteristic for microbending period 1.8 mm.

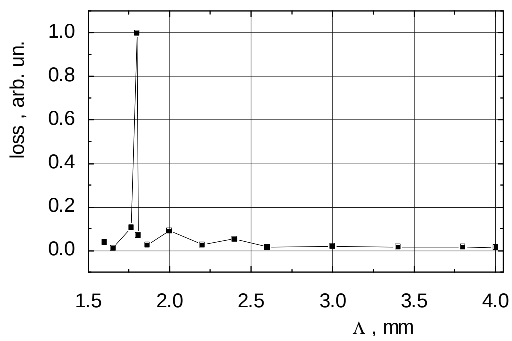

Fig. 4. Transmission vs. microbend period value for a constant deformation amplitude d = 100 μm.

An important resonant character of this dependence may be remarked. The microbending induced losses reach the maximum value for distortion period Λ = 1.8 mm. The character of the curve presented in Fig. 4 correlates with experimental results presented elsewhere [5].

For practical application of fiber sensor for displacement detection the linear part of transmission characteristics can be used (Fig. 3).

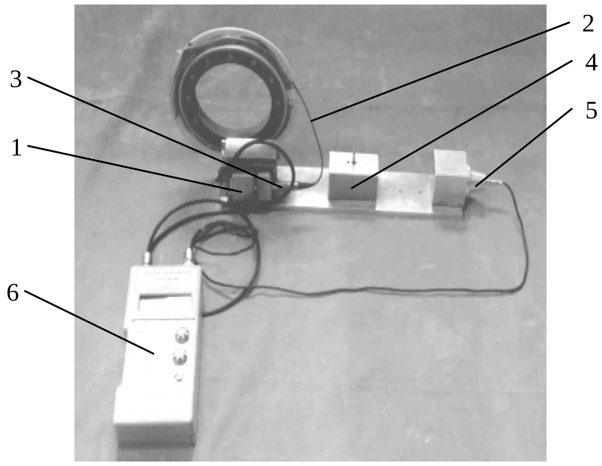

Fig. 5. The fibre optic displacement sensor. 1 - laser diode; 2 - transmitting optical fibre; 3 - conection; 4 - deformer; 5 - photodiode; 6 - electronic package.

On the basis of experimental results we have developed a compact model of fibre-optic displacemenmt sensor, presented in Fig. 5. It consists of a diode laser, a photodiode and an electronic package. A diode laser is coupled to a multimode transmitting fibre through a standard optical connector. The transmitting fibre, about 10 m long, is connected to a segment of the sensor fibre. The electronic package includes the power supply, the preamplifier, a A/D convertor, and a digital display.

The performances of the sensor are presented below:

- The range of displacement amplitudes : 0 - 60 μm;
- Sensitivity : 0.1 mV/ μm;
- The dynamic range : ~ 55 dB;
- Resolution : 0.1 μm;
- Deviation from the linearity : ~ 6 %;
- Error : 2.8 %.

References

[1] A. L.Harmer "Optical fiber sensors". VTT Symposion, No. 46, 5-76 (1984).
[2] A. D.Kersey, A. Dandridge, "Applications of fiber optic sensors". 39th Electron.Compon.Conf., Houston, Tex., May 22-24, 1989, (N.Y.), 472-478 (1989).
[3] N. Lagakos, T. Litovitz, P. Macedo, R. Mohr, R. Melster, "Multimode optical fiber displacement sensor", Applied Optics, vol.20(2),167-168 (1981).
[4] S. S. Sai, K. Srinivasan, "A novel fibre-optic integrated cladding mode detector for displacement sensing", Rev.Sci.Instruments, V.65, Nr.1, 242 (1994).
[5] J. N. Fields, "Attenuation of a parabolic--index fiber with periodic bends", Applied Physics Letters, vol. 36(10), 799-801 (1980).
[6] A. M. Andriesh, I. P. Culeac, V. Binchevici, V. Abaskin V. Schitsko "Fiber opticsensors for displacenment and vibration detection", 16th Annual Sem.Conf., CAS'93, October 1993, Sinaia, Romania, p.499.