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Side-hole optical fibre for wavelength 1300 nm

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Side-hole optical fibres are used for constructing pressure sensors because they have very high sensitivity to pressure and small sensitivity to temperature. To date this type of fibre has been produced for shorter wavelengths of 633 nm and 820 nm. This paper presents a new kind of side-hole optical fibres designed and developed for a wavelength of 1300 nm. Basic parameters of fibre were measured and compared with theoretical predictions.

1. Introduction

Side-hole (SH) optical fibres are highly birefringnet with linearly polarised modes. They have elliptical or circular cores with diameters from 1 to 3 μm [1]. Their cross-section is like that of Panda or Bow Tie fibres. The SH fibres differ from them in the method of stress induction. The areas producing stress are air channels parallel to the fibre core. Different cross-sections of SH optical fibres are shown in Fig. 1.

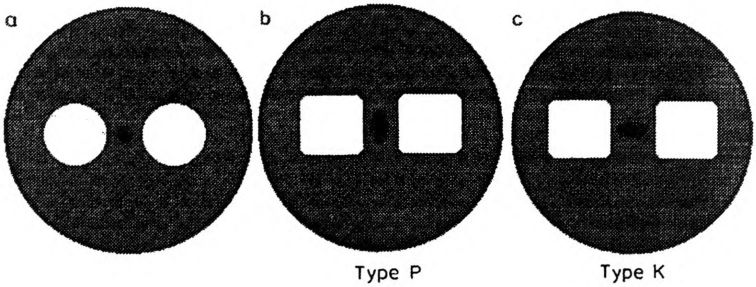

Fig. 1. Cross-sections of common types of SH optical fibres (**a**, **b**, **c**)

Their history dates back to 1986 when the first SH fibre (Fig. 1**a**) was fabricated [2] and its practical applicability was tested [3]. The SH fibres turned out to have considerable sensitivity to changes of external conditions, affecting their birefringence. The years that followed brought works on application of SH fibres to static and dynamic measurements of hydrostatic pressure. Attempts were also made at applying these fibres for measurements of elongation [4] and twisting [5].

Progress in the technology of producing SH fibres caused development of fibres with very high sensitivity to pressure and very low sensitivity to temperature [6], [7].

Optical fibres with very high selectivity to pressure are shown in Fig. 1**b**, **c**. There emerged a real possibility of applying SH fibres to measure very low hydrostatic pressures of 0.1 MPa and even 0.0001 MPa [8], and high pressure [9] without the necessity of applying temperature-compensation systems. Standard high-birefringence fibres are not applicable in this case because of low sensitivity to pressure and too high sensitivity to temperature. Very good SH fibres have up to now been produced and applied for wavelengths of 633 and 820 nm.

In order to control distribution of pressure in large structures or to build intelligent materials, a network of pressure sensors with transmission at a long distance is needed.

Much the same as in the development of telecommunication fibre it seems apparent that wavelenghts of 1300 nm and 1550 nm [10] are better for such complex sensor systems. Therefore the cost of optoelectronic components and of all the equipment will be lower because it is possible to make use of typical, mass-production components of telecommunication networks. Another advantage is lower attenuation at longer wavelengths. It means that maximum distance of transmission is longer. Sensors should have better characteristics owing to lower attenuation caused by Rayleigh scattering and less energy transfer between respective modes.

The results of research work on SH fibres for a wavelength of 1300 nm are persented in this paper.

2. Project and fabrication of optical fibre

In order to calculate the characteristics of optical fibre a simplified method of theoretical analysis using distribution of internal stresses in the fibre was employed [11]. The distribution of stresses was calculated by means of finite elements method with ALGOR program [9].

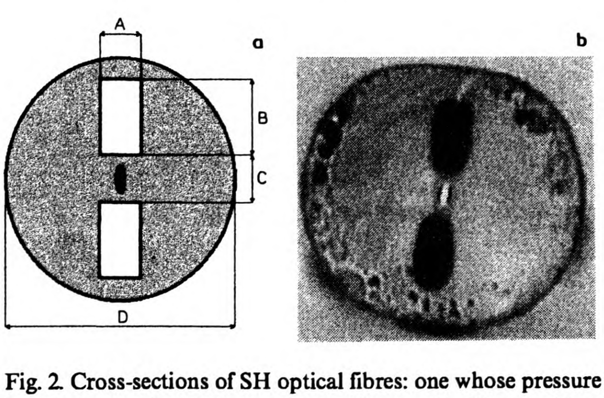

Fig. 2. Cross-sections of SH optical fibres: one whose pressure sensitivity, temperature sensitivity, and beat length were calculated (**a** – A = 19 μm, B = 37 μm, C = 17 μm, D = 125 μm), the other which was produced (**b** – A = 19 μm, B = 37 μm, C = 17 μm, D = 125 μm, respectively)

Calculations of the sensitivity to pressure and temperature were made without taking into consideration the influence of protective layers [12] for a fibre whose construction is shown in Fig. 2a. Such fibre structures were chosen for investigation by analogy with the fibres worked out previously for a wavelength of 633 nm [7], [13]. The results of calculations of sensitivity to pressure and temperature for the fibre of Fig. 2a are shown in Fig. 3.

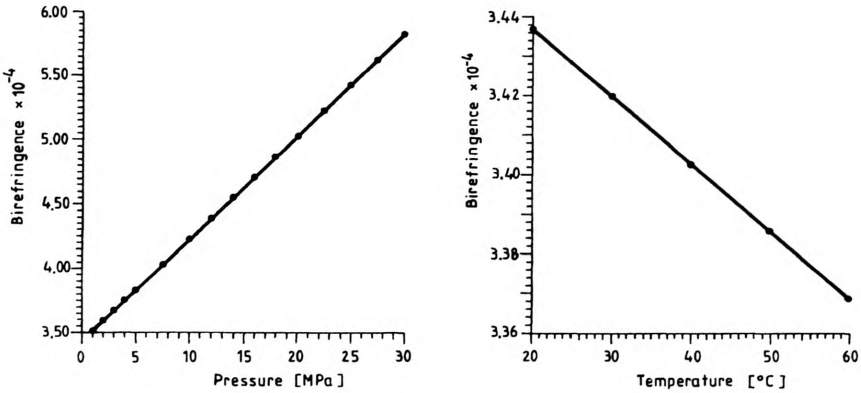

Fig. 3. Calculated dependence of the birefringence on pressue (**a**) and on temperature (**b**) of the SH optical fibre presented in Fig. 2**a**

The calculated sensitivity to pressure K_p is equal to 37 rad/MPa m. The calculated sensitivity to temperature K_T is equal to 0.8 rad/K m. The calculated beat length L_b is equal to 4 mm. The fibre type K was produced experimentally.

Optical fibres were fabricated by means of MCVD method. In order to get suitable fibre birefringence, the core was doped with GeO_2 18% M/M.

3. Measurements

The following measurements were performed in order to manufacture and determine the profile of new kinds of SH fibre:

– refractive index profile in preform rod (York P102),

– spectral attenuation – apparatus of our own construction, cut-off method,

– geometrical parameters – optical microscope with CCD camera type GP-KR222E by Panasonic,

– cut-off wavelength – apparatus of our own construction, single loop method,

– beat length – apparatus presented in Subsect. 3.1,

– sensitivity to pressure – apparatus presented in Subsect. 3.1,

– sensitivity to temperature – apparatus presented in Subsect. 3.1.

3.1. Apparatus

Apparatus with configuration of polarimetric sensor (Fig. 4) was set to measure beat length, sensitivity to pressure and sensitivity to temperature. In the case of

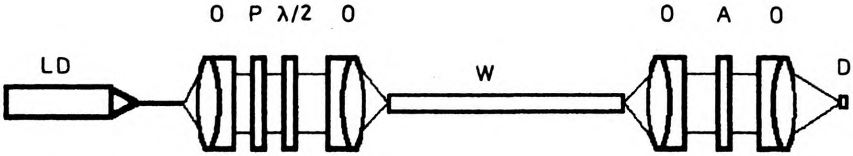

Fig. 4. Scheme of polarimetric sensors apparatus for measurements of pressure sensitivity, temperature sensitivity and beat length. LD – laser for wavelength 1300 nm pigtailed with multimode gradient index optical fibre 50/125 μm, O – objective, λ/2 – plate halfwave, A – analyser, D – detector, W – measured SH optical fibre

measurement of sensitivity to temperature the fibre examined was placed in the chamber with temperature linearly changing from 21 to 91 °C. Results were recorded on XY plotter.

Measurements of sensitivity to pressure were made after placing the fibre inside pressure chamber, full of argon, where hydrostatic pressure of gas was changing from 0.1 MPa to 5 MPa. Results were recorded on XT plotter.

Measurements of beat length were performed by moving press-point along the fibres so only one from among two orthogonally polarised modes was induced. On the spot of pressure part of optical power is transferred from one of polarisation components to another; it causes change of polarisation state at the end of fibre. During the experiment we can see periodic darkening and lightening of light spot at fibre's end. Measuring the distance between two consecutive darkenings (lightenings) we can determine the beat length of fibre.

3.2. Results

A photo of the cross-section of SH optical fibre is presented in Fig. 2b. In Figures 5–8, there are presented the basic parameters of preform and SH optical fibre, which were measured with the use of apparatus described in Subsect. 3.1.

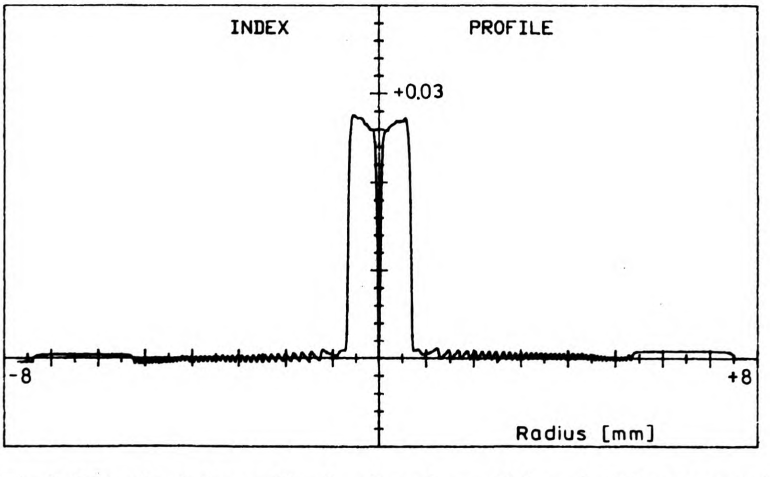

Fig. 5. Refractive index profile of preform from which optical fibre presented in Fig. 2b was produced. (York technology, step size 5 μm)

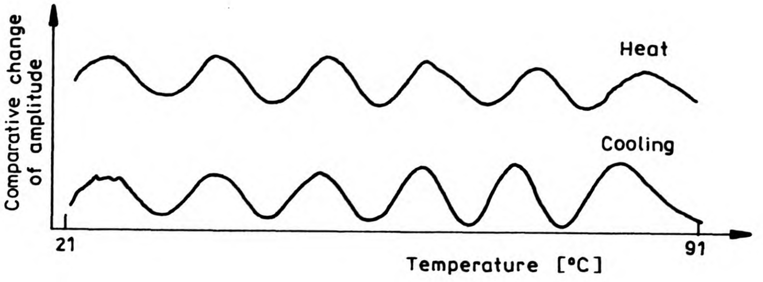

Fig. 6. Results of measurement of temperature sensitivity. The length of optical fibre was 1.5 m. The temperature was changed in border 21–91 °C. The temperature sensitivity is 0.3 rad/Km

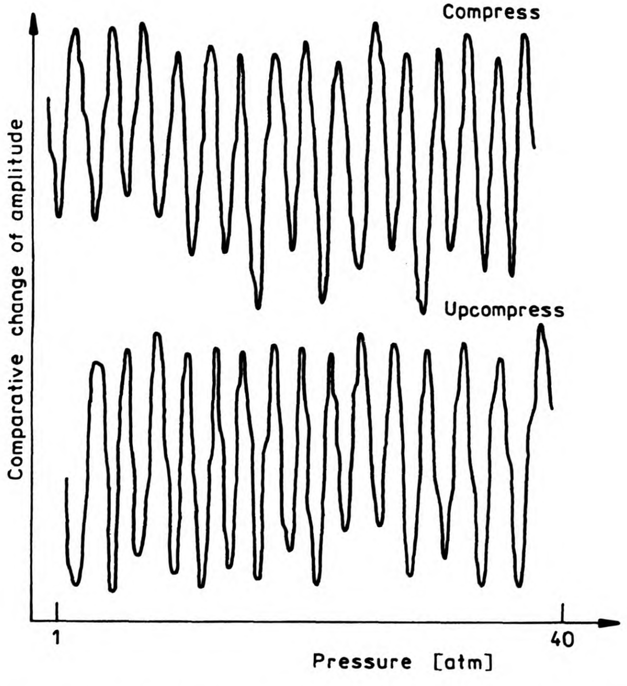

Fig. 7. Result of measurement of pressure sensitivity. The length of optical fibre was 1 m. The pressure was changed with the range 0.1–4 MPa. The pressure sensitivity is 24 rad/MPam

The longer axis of the core of optical fibre is 4 μm, the shorter one is 1.5 μm. The measured value of beat length L_b is 6 mm.

4. Discussion and conclusions

The measured basic parameters of the SH optical fibre produced are presented in Figs. 2**b**, 5, 6 and 7. The measured and calculated values of beat length L_b, pressure sensitivity K_p and temperature sensitivity K_T are presented in the Table.

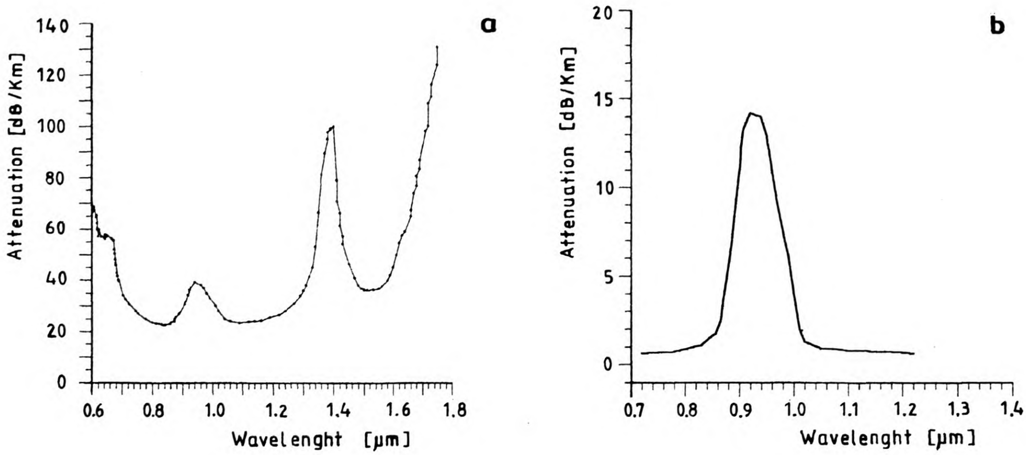

Fig. 8. Results of measurements: one is dependence of the attenuation on wavelength (a), and the other is cut-off wavelength (b)

Table. The comparison of calculated and measured values of the pressure sensitivity K_p, temperature sensitivity K_T and beat length L_b

	Calculated	Measured
K_p [rad/MPam]	37	24
K_T [rad/Km]	0.8	0.3
L_b [mm]	4	6

The measured and calculated values of L_b, K_p, K_T clearly differ from each other. Therefore measurements were executed many times using many samples of optical fibre. The results varied within $\pm 4\%$.

When working out the technology of producing SH optical fibres for wavelengths of 633 and 820 nm, the manner of calculation was checked many times and then modified [7], [9], [12]. Thus, a considerable divergence of the results of calculations and measurements of the order from 40 to 50% is caused by errors resulting from inaccuracies of measurements of optical fibre core dimensions. Another reason is difference between internal structure of projected fibres presented in Fig. 2**a** and internal structure of produced fibre presented in Fig. 2**b**. Exact explanation of the divergence of calculations and measurements will be possible in the future after far advanced technological investigations.

The calculated and measured pressure sensitivity is not very large. The ratio of pressure sensitivity to temperature sensitivity (fibre selectivity) is high enough and reaches about 70–80 MPa/K. The value of pressure sensitivity seems reasonable for a rather large distance between holes and core (Fig. 2**b**). By analogy to construction of SH optical fibres for smaller wavelengths we expect that pressure sensitivity for optimum structures of fibres will be bigger than 100 and perhaps 200 rad/MPam.

In this paper, we have presented a new kind of SH optical fibre intended to work at a wavelength of 1300 nm. This was a specially designed and produced SH optical fibre of type K. Its properties have also been measured. The results of calculations differ from the results of measurements by about 50%, which fact is partly explained.

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