Optica Applicata, Vol. XXIII, No. 1, 1993

Single-mode highly birefringent optical-fibre depolarizers of the Lyot type: experimental results

B. STÁDNÍK

Institute of Radio Engineering and Electronics of the Academy of Sciences of the Czech Republic,
182 51 Praha 8 – Kobylisy, Czech Republic.

The results of measurement of the depolarization coefficients of the fibre-optic depolarizers of the Lyot type made of highly birefringent optical-fibres are given.

1. Introduction

Variations of state of polarization of optical waves transmitted by birefringent single-mode optical fibres due to the random changes of fibre birefringences exhibit a severe problem in optoelectronic sensor devices [1]. Up to the present time, this problem has not been fully solved. However, interesting results have been gained in sensor systems using optical-fibre depolarizers diminishing the polarization noise. Various types of depolarizers have been proposed and demonstrated [2], [3]. Among them, the depolarizers of the Lyot type, consisting of two highly birefringent optical-fibre arms with the length ratio 2:1 and rotation angle of the birefringent axes at 45° to each other, are the most suitable for practical use. Their depolarization efficiency, however, depends on the group-delay time difference between two principal modes propagating in the fibre.

In this paper, we present experimental results concerning the depolarization efficiency of the Lyot optical-fibre depolarizers. We fabricated these depolarizers of highly birefringent optical-fibres of various types and measured their depolarization characteristics. We present evaluation of the results of the measurement.

2. Optical-fibre depolarizers of the Lyot type

The depolarization of single-mode highly birefringent optical-fibre Lyot depolarizers is caused by the group-delay time difference of transmitted modes of the fibre. It depends strongly on the spectral bandwidth of a light source. The group-delay time difference must be greater than the coherence time of a light source. If we suppose the average value of this group delay-time difference 5 ns/km for a highly birefringent optical fibre, then the necessary length of the arms of the optical-fibre Lyot depolarizer ranges from several metres to dozens of kilometres in order that the depolarization coefficient of the order of 20 dB could be achieved. The spectral bandwidths of light sources commonly used in practice extend from 100 kHz to 1000 GHz, being, for example, for the He-Ne lasers approx. 100 kHz, the laser diodes with an external cavity from 100 kHz to 10 MHz, and the conventional laer diodes from 10 MHz to 1000 GHz.

2.1. Fabrication of depolarizers

Depolarizers were made of single-mode birefringent optical-fibres of the bow-tie and inner-cladding types. The bow-tie fibres had the following parameters (at 830 nm): the beat length $\Lambda = 6.3$ mm, the attenuation $\alpha = 3$ dB/km, and the polarization-holding parameter $h = 1 \times 10^{-3}$/m. The cut-off wavelength was $\lambda_c = 750$ nm. The parameters of the inner-cladding fibres were $\Lambda = 3.3$ mm, $\alpha = 3.1$ dB/km, $h = 1 \times 10^{-4}$/m and $\lambda_c = 750$ nm. Two fibre arms of the lengths $l_1 = 5$ m and $l_2 = 10$ m were used. The performance of the depolarizer depends strongly on the angle between the birefringence axes of the fibre arms. In order to precisely adjust the angle 45°, we used a special experimental setup and measuring method (to be patented) allowing the misalignment of the birefringence axes to be less than $\pm 4'$.

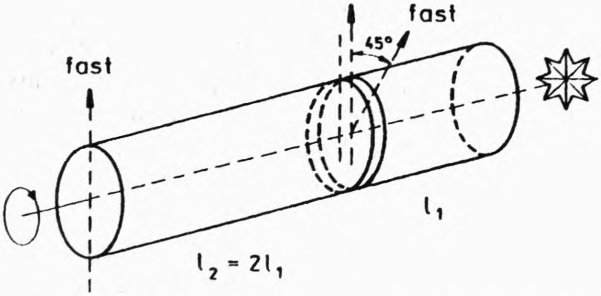

Fig. 1. Schematic arrangement of an optical-fibre depolarizer of the Lyot type

This is of the same order as that which can be obtained by the most precise interferometric method to be known up till now [4]. After alignment of the birefringence axes, the fibre ends were spliced to form a fixed connection. Finally, the depolarizers were wound into coils of the diameter of approx. 16 cm, suitable for measurement and use in sensor applications. The scheme of the depolarizer is shown in Fig. 1.

2.2. Depolarization-measuring procedure

The xenon lamp was used as a source of optical radiation. The variable spectral bandwidth ranging from 0.1 to 60 nm was obatined by means of a spectrometer in which both spectral grating and prism were used. The sensitive detection of output radiation was made by the lock-in amplifier technique. The schematic diagram of the setup is given in Fig. 2.

Our procedure of the measurement consists in measuring the omponents of coherency matrix [5]:

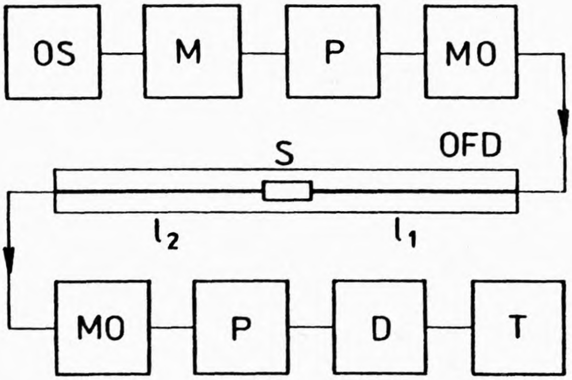

Fig. 2. Measuring setup: OS – optical source, M – monochromator, P – polarizer, MO – microscope objective, D – detector, T – plotter, OFD – optical-fibre depolarizer, S – splice, l_1 (l_2) – arms of the depolarizer

$$
\begin{aligned}
J_{xx} &= I(0°, 0),\\
J_{yy} &= I(90°, 0),\\
J_{xy} &= 1/2\{[I(45°, 0)-I(135°, 0)]+i[I(45°, 90)-I(135°, 90)]\} \; (= |J_{xy}|e^{i\rho}),\\
J_{yx} &= \mathrm{Re}J_{xy}-J_m J_{xy}
\end{aligned}
$$

where I is the output light intensity measured with the transmission axis of the polarizer rotated at a convenient angle.

The coefficient of the depolarization is given by

$$D = 1-\frac{\sqrt{\sum_{i=1}^{3} S_i^2}}{S_0}$$

where S_i are the Stokes parameters given by

$$
\begin{aligned}
S_0 &= J_{xx}+J_{yy},\\
S_1 &= J_{xx}-J_{yy},\\
S_2 &= J_{xy}+J_{yx},\\
S_3 &= i(J_{xy}-J_{yx}).
\end{aligned}
$$

The degree of the coherence is given by

$$\mu = |\mu_{xy}| = \frac{|J_{xy}|}{\sqrt{J_{xx}J_{yy}}}.$$

3. Results and conclusions

The best depolarization effect was achieved with the Lyot depolarizers made of highly birefringent optical-fibres with the inner cladding. The depolarization coefficient D_{lc} was higher than 85% for all the linear input polarizations as it is seen

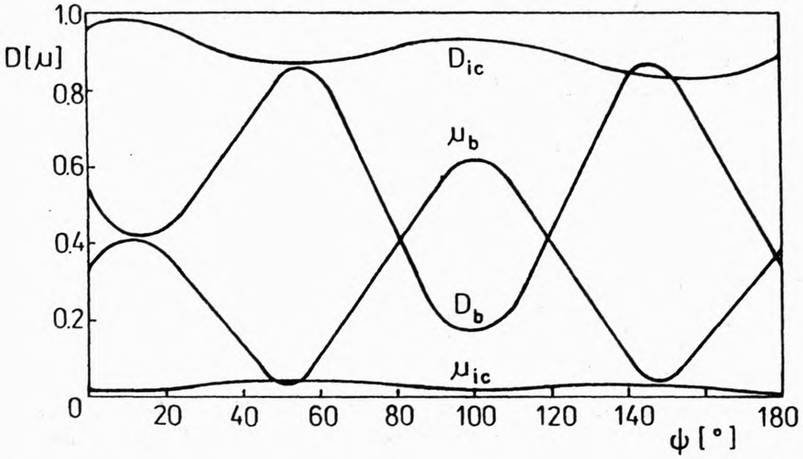

Fig. 3. Courses of dependences of both depolarization coefficients (D) and the degrees of coherence (μ) on the angle ψ between the directions of the fast birefringence axes and the polarization vector of the input radiation (ic – depolarizer made of birefringent fibre of the inner-cladding type, b – optical fibre of the bow-tie type)

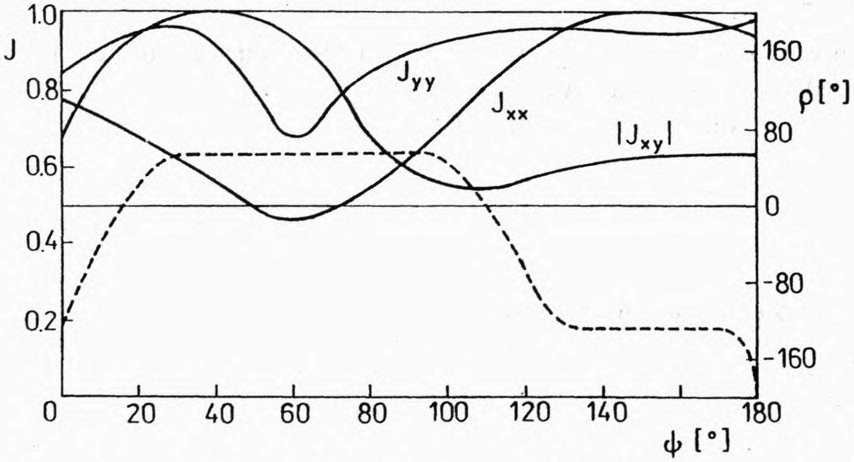

Fig. 4. Courses of elements of the coeherency matrix of the depolarizer made of birefringent fibres of the inner-cladding type

from Fig. 3. The course of the depolarization coefficient in dependence on the rotation angle of the input polarizer is practically constant. This depolarizer behaves like an ideal Lyot depolarizer.

The depolarizers made of the birefringent optical-fibres of the bow-tie type have the depolarization coefficients strongly dependent on the rotation angle of the input polarizer. Their depolarization coefficients vary from 85 to 20%, the highest value being obtained for the rotation angle of the input polarizer coincidental with one of the birefringent axes of the fibre (Fig. 4 and 5). It was concluded that the main cause of these great variations of the depolarization coefficients is the splice of the

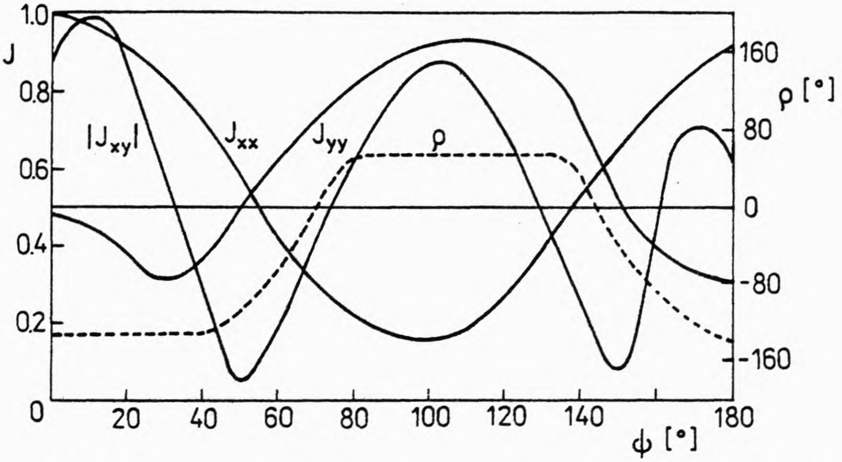

Fig. 5. Courses of elements of the coeherency matrix of the depolarizer made of birefringent fibres of the bow-tie type

two arms of the depolarizer. Fabrication of the homogeneous splice of the two pieces of rotated optical-fibres of the bow-tie type is technologically a much more difficult task than it is in the case of the optical-fibres of the inner-cladding type.

References

[1] Böhm K., Marten P., Petermann K., Weidel E., Electron. Lett. **17** (1981), 352.
[2] Hillerich B., Weidel E., Opt. Quant. Electron. **15** (1983), 281.
[3] Takada K., Okamoto K., Noda J., J. Lightwave Technol. **LT-4** (1986), 213.
[4] Takada K., Chida K., Noda J., Appl. Opt. **26** (1987), 2979.
[5] Born M., Wolf E., *Principles of Optics*, Pergamon Press, 1959.

Received June 21, 1993