Low Mode Asymmetry Highly Birefringent Microstructured Fibers

Alexander N. Denisov, Andrei E. Levchenko, Sergei L. Semjonov, and Evgueni M. Dianov
Fiber Optics Research Center, Russian Academy of Sciences, 38 Vavilov Street, Moscow, 119333, Russia
denisov@fo.gpi.ru

Abstract: We present numerical and experimental investigations of microstructured fibers with high birefringence and low mode asymmetry. Fibers with approximately equal mode sizes along the two orthogonal axes and birefringence up to 2.7×10^{-3} were fabricated.
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1. Introduction

In this paper we continue numerical and experimental investigations of highly birefringent microstructured fibers (HB MSFs) proposed earlier [1,2]. These HB MSFs have elliptical or circular core surrounded by two or more concentric rings of identical circular air holes. The holes in the first ring around the core have equal spacing Λ between the centers, except one or two pairs of holes with increased spacing $\Lambda 1$. Consequently, these HB MSFs have one or two wider bridges between the holes in the first ring.

Previously we have fabricated a number of HB MSFs with one wider bridge. SEM images of one of them are presented in Fig. 1.

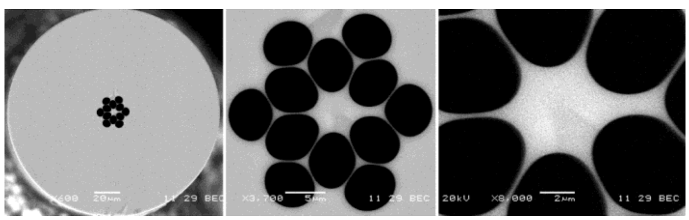

Fig. 1. SEM images of the HB MSF with one wider bridge at different scales.

It is clear from Fig. 1 that the shape of the HB MSF holes is not circular. But we used simulation of the fibers geometry with a simple model having circular holes for numerical calculations of its parameters in the first approximation [1]. As a result there was significant difference between the measured G_m and the calculated G_c values of group birefringence (λ = 1.53 μm): $G_m = (4.7\pm0.1)\times10^{-4}$ and $G_c = 4.2\times10^{-4}$. Thus it is necessary to create more adequate model for correct calculations of the fabricated HB MSFs parameters.

Additionally we have demonstrated numerically that it is possible to achieve significantly higher birefringence and simultaneously low mode asymmetry with some particular parameters of the proposed HB MSF having two wider bridges [2]. The aim of this work is to improve theoretical model as well as to fabricate and investigate fibers with significantly higher birefringence.

2. Model calculations

We have examined 10 different model structures that approximate geometry of the fabricated HB MSFs. A detailed description of their parameters and results of their comparative analyses will be presented at the Conference. Then we selected the model structure, which has the best accuracy of the HB MSF core description and the simplest geometric structure.

Using this model, we calculated group birefringence G_c for the HB MSFs fabricated previously. The G_c values thus obtained (λ = 1.53 μm) are presented in Table 1 together with some geometric parameters for one of the HB MSFs. Here D_{fiber} is the fiber diameter at particular cross section of the fiber sample, D_x and D_y are the core diameters along the *x*- and *y*-axes, respectively, and *e* is the ellipticity of the core, determined as $e = D_x/D_y$.

Table 1. Parameters of one of the fabricated HB MSF with one wider bridge.

Cross section	D_{fiber} (μm)	D_y (μm)	D_x (μm)	e	$G_c\times10^4$	$G_m\times10^4$
1	131.3	4.06	4.41	1.086	5.26	
2	128.7	3.96	4.24	1.071	4.62	5.10
3	132.7	4.07	4.43	1.088	5.01	

It is clear from Table 1 that the measured group birefringence G_m has the value inside the changing range of the calculated values of group birefringence which were determined for different cross sections of the fiber sample.

3. Experimental results

To achieve a high birefringence and low mode asymmetry we fabricated a number of HB MSFs with two wider bridges. We made a preform for the HB MSF with ellipticity $e = 0.8$ and two sufficiently large wider bridges. Then we drew it into the fibers with different diameters. SEM images of one of them are presented in Fig. 2.

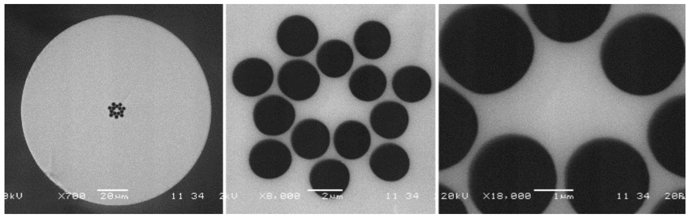

Fig. 2. SEM images of the HB MSF with two wider bridges at different scales.

Some parameters of the fabricated fibers are presented in Table 2.

Table 2. Parameters of the fabricated HB MSFs with two wider bridges.

D_{fiber} (μm)	D_y (μm)	D_x (μm)	e	$G_m \times 10^3$	$G_c \times 10^3$
171	3.86	3.16	0.82	1.1	1.1
125	2.75	2.23	0.81	2.7	2.2

It is clear from Fig. 2 that the shape of the HB MSF holes slightly differs from a circle. But we used simulation of the fibers geometry with a simple model having circular holes for numerical calculations of its parameters in the first approximation. Using this simple model, we calculated group birefringence G_c for the fabricated HB MSFs, which is also presented in Table 2.

Using this simple model we also calculated intensity distributions of the x- and y-polarized fundamental modes for the HB MSF presented in Fig. 2. These intensity distributions are presented in Fig. 3.

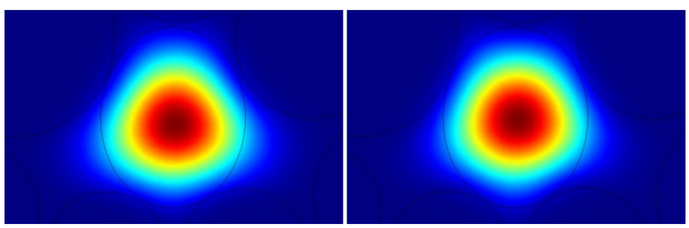

Fig. 3. Intensity distributions of the x- (left) and y- (right) polarized fundamental modes for model structure of the fabricated HB MSF with two wider bridges.

To quantify the asymmetry of the fiber mode shape, we use a parameter w defined as the ratio of the difference between the mode sizes to their average: $w = 2(W_x - W_y)/(W_x + W_y)$, where W_x and W_y are the mode sizes (full width at half intensity) along the x- and y-axes, respectively. For the x- and y-polarized fundamental modes we determined $w_x \approx 0.037$ and $w_y \approx 0.043$, respectively. These values are of the order of magnitude smaller then the w parameters of the usually used highly birefringent microstructured fibers [3]. Consequently, these HB MSFs may be coupled with circular core fibers or with circular laser beams without additional power losses. Thus, the fibers developed hold promise for practical applications.

4. References

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[2] A. N. Denisov, A. E. Levchenko, S. L. Semjonov and E. M. Dianov, "Highly birefringent microstructured fibers with low mode field asymmetry", 2011 Conference on Lasers and Electro-Optics Europe (CLEO/Europe 2011), paper CE.P.32-WED.

[3] K. J. Lee, K. S. Hong, H. C. Park and B. Y. Kim, "Polarization coupling in a highly birefringent photonic crystal fiber by torsional acoustic wave", Opt. Express **16**, 4631-4638 (2008).