Polarization Couplers in Fibers with Different Core Shapes

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ABSTRACT

We report the rocking filter formation in a circular, a bow tie and in an elliptical core optical fiber by the technique of internal light exposure. The visible Argon ion laser lines in 488.0 and 514.5 nm, with circular polarization, are used as the writing beam source, and the obtained filters shown coupling efficiency between 2.5 and 60.0 %. For similar exposure parameters, elliptical core fiber lead to higher efficiency couplers as compared to the stress induced birefringent fibers.

Keywords: rocking filter, polarization coupler, optical fiber

1. INTRODUCTION

It is well known that the refractive index is changed permanently in many types of doped optical fibers after a convenient exposure of the core to intense optical field [1]. The origin of this photoinduced effect is not yet fully understood; however, it can be used in a variety of practical devices in the field of optical communications and sensing, such as WDM (Wavelength Division Multiplexing) devices [2], wavelength selective switches and temperature, stress or pressure sensors [1,3]. In this way, fiber photosensitivity has been used to fabricate both Bragg gratings [3] and rocking filters in polarization maintaining (PM) optical fibers after exposure to green, blue or UV radiation. One important issue is that the change can also be birefringent, leading to polarization couplers (rocking filters). The rocking filter or polarization coupler is a fiber optic device that couples two modes of orthogonal polarization in a specific wavelength band. This coupling is based on the resonance between a periodic birefringent refraction index modulation and the propagation constant mismatch of the involved modes. The rocking filter is obtained by internal or external light exposure techniques. In the internal method, a periodic grating inside the fiber is induced due a periodic evolution of the polarization state of a light beam circularly polarized launched into the fiber. As the light propagates the polarization state evolves through left-circular, linear (orthogonal to the incident direction), and right-circular back to the initial linear state. This pattern repeats at the beat period of the birefringent fiber. The perturbation induced by exposure is axially periodic and, when probe light in the correct wavelength band is later launched in the fiber core, permits that the component of the electric field in the fast (slow) mode to radiate into the orthogonal slow (fast) mode at positions where the two modal fields are in phase. The result is phase-matched power conversion between the polarized modes.

2. EXPERIMENTS AND RESULTS

For the experiments we used samples of: a circular core optical fiber model F-SA, mode field diameter of 3.7 μm, cutoff wavelength around 380 nm (purchased from Newport Corporation); a bow tie PM fiber, model WF71 (WaveOptics), mode field diameter of 2.9 μm, and cutoff wavelength < 450 nm; and an elliptical core optical fiber, model AD137, core diameter of 3.24 μm with an ovality of 46%. The last one is monomode above 750 nm and contains germanium and aluminum as dopants.

The light source used was a linearly polarized CW Ar^+ laser beam at 488.0 nm (for F-SA and WF71 fiber) and at 514.5 nm (for AD137 fiber). Figure 1(a) shows the experimental writing setup used for the rocking filter formation. The quarter wave plate (QWP) converts the linearly polarized laser light in circularly polarized light, which is coupled into de fiber using a M40x objective lens (L). Using this method, equal excitation of the polarization modes is guaranteed. A power meter (PM) is used for monitoring the power coupled to the fiber during the exposure since misalignments are common, probably caused by the thermal expansion of the fiber coating. The coupling spectrum is measured using the reading setup shown in figure 1(b). The white light is launched into the fiber and the output signal, dispersed by a monochromator, is detected by a photomultiplier.

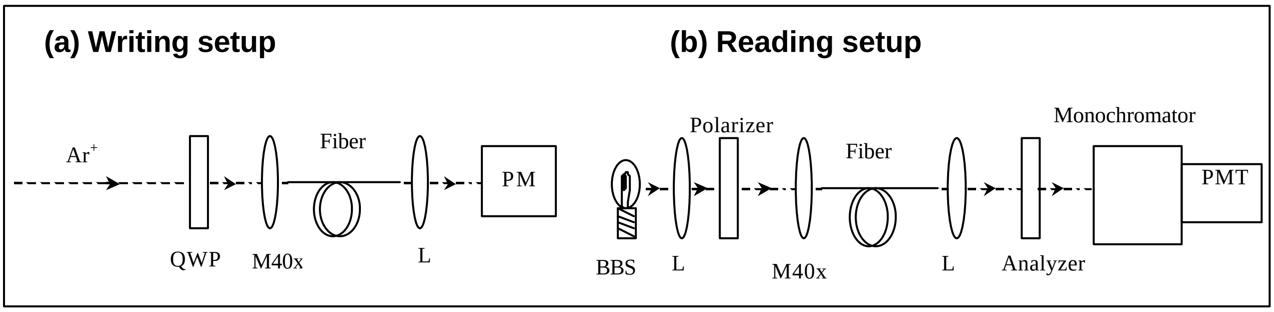

Fig.1: Experimental setup to writing and reading the filters

Birefringence was induced in the circular core fiber by winding it around a 0.62 cm diameter cylindrical mandrel [4]. The bending-induced birefringence B, is given by

$$B = -\alpha\left(\frac{r}{R}\right)^2 \tag{1}$$

where r is the fiber cladding radius, R is the mandrel radius, and α=0.133 for fused silica [5]. Eq. 1 gives a birefringence of 5.4 x 10^{-5}, resulting in a modal beat length, $L_B=\lambda/B$, about 9.0 mm at 488.0 nm. The intrinsic birefringence of the F-SA, WF71 and AD137 fibers was measured before the exposition using the technique described in ref. [6] by Rashleigh, and the obtained values allow fiber beat length $L^*_{B0}=\lambda/B^*$ be calculated at the writing wavelength. The results are shown in table 1.

For rocking filter fabrication, we expose 52 cm of the F-SA fiber to an input power of about 1W at 488.0 nm during 10 minutes. This sample shows a light output of only 50 mW during the exposure, due to scattering and the high bending losses. Figure 2(a) shows the division between the transmitted output through the fiber after exposition and before exposition. The most efficient coupling between the two orthogonal polarization modes occurs around 488.0 nm, the writing wavelength.

A 50 cm long sample of the bow-tie fiber (model WF71) is exposed to 1W input power in 488.0 nm for 40 minutes, with a measured fiber output signal of 450 mW. The coupling spectrum obtained is shown in figure 2(b).

The AD137 fiber used is 80 cm long, being singlemode only above 750 nm. The fiber is exposed to an intracore intensity of 150 mW at 514.5 nm for 30 minutes. Figure 2(c) shows the coupling spectrum filter for this fiber. The filter efficiency is also measured with the setup shown in figure 1(b), with the source replaced by a proper laser line and the polarizer angle is set parallel to one of the birefringence axis of the fiber. The sum of the crossed polarized components at the fiber output corresponds to the total intensity launched into the fiber (apart from fiber losses).

The efficiency of the coupler, $\eta(\%) = I_x/(I_x+I_y)$, corresponds to the percentage of the total intensity in the fiber core, which couples to the crossed polarization at the resonance wavelength, where I_x and I_y are the intensity measured for the coupler with the analyzer placed respectively perpendicular and parallel to the input polarizer at the resonance wavelength. The efficiency was calculated to be 17% at 488.0 nm (F-SA fiber), 2.5% at 488.0 nm (WF71 fiber), and 60% at 514.5 nm (AD137 fiber). In figure 1 is also plotted a theoretical fit to the expression obtained by Russell at al in ref. [7],

$$\eta = \frac{\kappa^2}{\kappa^2+\left(\frac{\theta}{2}\right)^2}\, sin^2\left[L\sqrt{\kappa^2+\left(\frac{\theta}{2}\right)^2}\right] \tag{2}$$

where η is the conversion efficiency, $\kappa = \left[\pi\,\Delta\beta_i/4\lambda\sqrt{n_f n_s}\right]$ is the coupling constant, $\theta = \left[2\pi\,\Delta\lambda/L_{B0}\,\lambda_0\right]$ is the dephasing parameter and L the interaction length. The parameter $\Delta\beta_i$ is the anisotropic changes induced by optical exposure, λ_0 is the central wavelength of the filter and L_{b0} is the beat length. Table 1 shows, besides the measured values (with the superscript *), the adjusted ones for some relevant parameters.

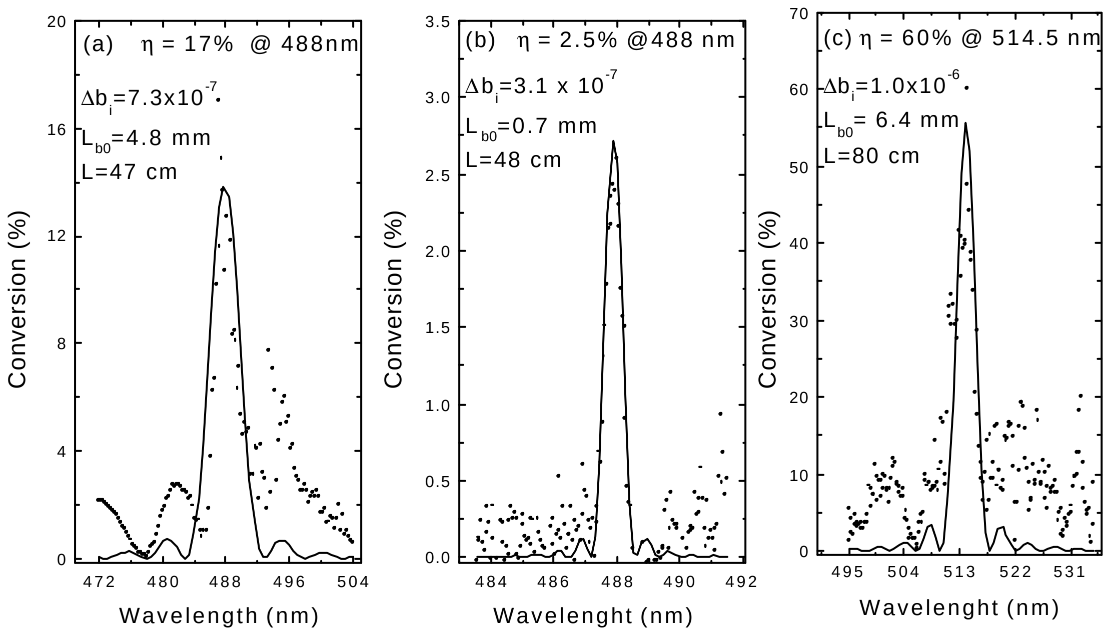

Fig.2: Rocking filters written in the F-SA, WF71 and AD137 fibers.

Fiber	l_0 (nm)	P(mW)	t(min)	h(%)	B^*	L^*_{b0} (mm)	L^* (m)	L_{b0} (mm)	L (m)	D_{bi}
F-SA	488.0	50	10	17.0	$5.1x10^{-5}$	9.5	0.52	4.8	0.47	$6.8x10^{-7}$
WF 71	488.0	450	40	2.5	$8.5x10^{-4}$	0.6	0.50	0.7	0.48	$3.1x10^{-7}$
AD 137	514.5	150	30	60.0	$7.9x10^{-5}$	6.5	0.80	6.4	0.80	$1.0x10^{-6}$

Table 1: Some relevant parameters for the written filters

3. CONCLUSION

We had shown that the one important factor in writing efficient polarization couplers is the origin of the intrinsic birefringence. The use of both F-SA and WF71 fibers, where the birefringence is due to stress effects, leads to less efficient couplers when compared with the AD137 fiber. In this fiber, the birefringence is due to the elliptical core shape. The filter efficiency in AD137 fiber was three times the efficiency for the filter in F-SA fiber, in despite of their comparable intrinsic birefringence values. It is also important to note that the higher efficiency was obtained using a writing wavelength of 514.5 nm, that is non-resonant with the two photon absorption process in Ge defects. For the F-SA and WF71 fibers, we observed that higher values of stress induced birefringence results in lower values of efficiency, in despite of the use of higher light intensities and exposure times.

The expression for the efficiency fits well the experimental data, and the optically induced birefringence values agrees with direct measurements of conversion efficiency. The low adjusted value for the F-SA fiber length reflects the high bending losses, and corresponds to a lower effective interaction length, suggesting that the coupler was more efficiently written in the beginning of the fiber. For the WF71 and AD137 fibers, the adjusted values of fiber length and the measured ones are in good concordance.

Furthermore, both the measured and the adjusted beat length values agrees well, unless regarding to the F-SA fiber, where the low adjusted value may be due to the increase in average birefringence along the whole fiber caused by the irradiation. This effect is not observed in the WF71 fiber, where the magnitude of the optically induced birefringence change, Db_i, is less significant when compared with the intrinsic birefringence, B^*. In the AD137 fiber, where the birefringence is due to the elliptical core shape and not to stress effects, no increase in the average birefringence was detected. More experiments to study of the dynamics of the process are necessary to understand the influence of the stress in the average birefringence.

4. ACKNOWLEDGEMENTS

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