High-Extinction Coiled-Fiber Polarizers by Careful Control of Interface Reinjection

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Abstract—**Taking account of the reinjection at the clad/coating interface, we are able to substantially improve the performance of polarizers made by coils of hi-bi fiber. We obtain reproducibly 45 dB of extinction with a 4-turn coil of selected radii, with no kinks in attenuation and a limited insertion loss.**

I. Introduction

MANY applications, e.g., in optical communications and fiberoptics sensors, require high performance all-fiber polarizers with low insertion loss for the desired linear state polarization and high extinction loss for the other, orthogonal state of polarization.

By taking advantage of the different bending losses of the two orthogonally-polarized fundamental modes in a high-birefringence fiber, all fiber polarizers achieving ~30 dB of extinction loss and <2 dB of insertion loss have been demonstrated since ten years ago [1]–[3], in form of coils of several turns of hi-bi fiber.

Attempts to improve extinction have included the design of a special fiber (the so called SP-single polarization fiber) with one polarization mode at cut-off [4]–[6]. This approach is interesting because even a few meter of straight fiber acts as a good polarizer [7]; however to obtain a compact device a winding is necessary and the arguments developed below are relevant.

Recently, it has been shown [8], [9] that the bending loss experienced by a coated fiber is strongly affected by the reinjection in the core of light reflected at the clad/coating interface. This effect can be also described as a synchronous coupling between the guided fundamental mode and the so-called whispering gallery mode. As the outward evanescent field in the bent fiber is reflected by the clad/coating interface and coupled back (in phase or out of phase) to the guided field, large oscillations are found in the bending loss of the coil as a function of both radius of curvature r and wavelength λ.

Theoretically, the injection loss have been calculated [10], [11] for an ideal cylindrical (symmetric) fiber with infinite coating, a simple model which nicely accounts for the oscillation superimposed on the monotonic exponential trend of the bending losses and is in good agreement with the experimental results on a wide range of r and λ.

Though the theory for an asymmetric, hi-bi fiber is considerably more difficult to treat analytically and will not be dealt with here, the same trend of oscillation due to injection is found experimentally in hi-bi fibers. The amount of oscillation is sufficient to justify the kinks observed in the extinction loss curve of coiled hi-bi fibers (see, e.g., [3, Fig. 1]), and explains the limited values of extinction achieved as well as the poor repeatibility of the polarizer.

Manuscript received March 20, 1995; revised May 19, 1995. This work was supported by a MURST 40% contract.

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IEEE Log Number 9414270.

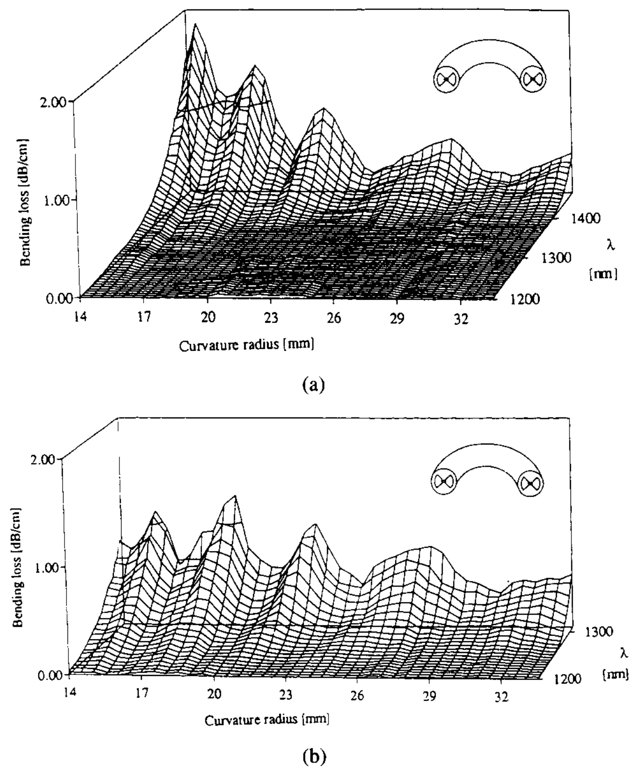

Fig. 1. Measured bending losses as a function of radius and wavelength for the (a) fast axis and (b) slow axis of the hi-bi fiber.

In this letter, we show that, through the measurement of the bending losses of a standard commercial hi-bi fiber versus r and λ, one can identify ranges of such parameters in which reinjection effects are exploited to improve the extinction ratio up to the limit set by the minor cross-polarized field component of the mode [12] in a hi-bi fiber (i.e., about 50 dB).

II. Experiment

A commercial high-birefringence fiber (York HB800 bow-tie type, λ_c = 750 nm, beat length 2.1 mm, MFD_x = 8.29 μm and MFD_y = 11.1 μm, α = 2 dB/Km @ 1300 nm) has been characterized by means of a polarization-resolved spectrophotometer.

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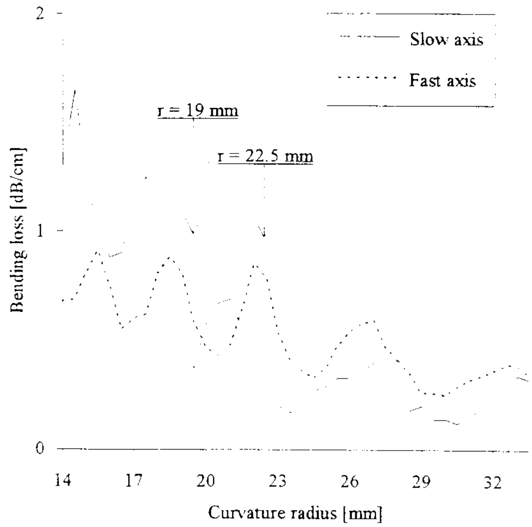

Fig. 2. Comparison of the bending losses for slow axis at 1460 nm and fast axis at 1300 nm versus curvature radius. Arrows show the selected radii.

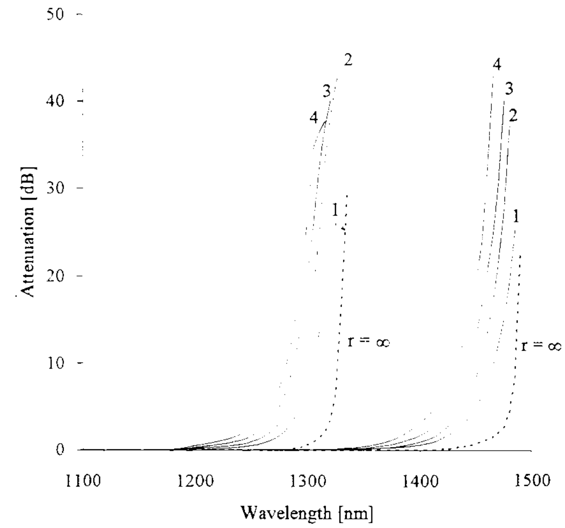

Fig. 3. Attenuation for the 22.5-mm radius polarizer measured for $n = 1$–4 number of turns (solid line) and loss for the straight fiber (dashed lines).

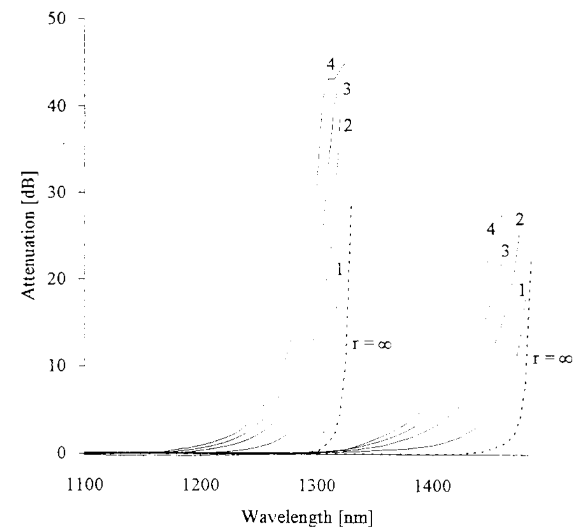

Fig. 4. Attenuation for the 19-mm radius polarizer measured for $n = 1$–4 number of turns (solid line) and loss for the straight fiber (dashed lines).

The instrument, described elsewhere [13], allows to measure in single-mode fibers attenuations up to 45 dB (at $S/N = 1$) on the 800–1600 nm interval. Two calcite Glan Thompson cubes (>50 dB extinction) at the fiber ends where used as polarizer and analyzer. Spectral attenuations P_r/P_{0r} were measured as a function of wavelength λ for several curvature radii r. The reference level of attenuation was taken as the measured value P/P_0 for the fiber laid straight, without changing the launch condition.

Fig. 1 shows the attenuations measured for the fast and slow axes of the fiber wound in a half-turn curve, for radii going from 13.5 mm to 34.5 mm in steps of 0.5 mm, and with the bow-tie sectors oriented parallel to the coil plane.

Nearly the same diagrams were found when the bow-tie was oriented perpendicular to the coil plane, except for a shift of both (fast and slow) curves of about 150 nm toward shorter wavelengths.

From Fig. 1, the optimum radius can be selected as follows: given a wavelength range of operation for the polarizer, for example 1300–1400 nm as in our intended application, one chooses a fast-axis curve below 1300 and a slow-axis curve above 1400 and plots them like in Fig. 2. If a radius can be found giving a large difference in attenuation, possibly not too sharp in r, this will be a good choice. The procedure is carried out easily because the peak position is not strongly dependent on λ. As an example, from Fig. 2 the preferred values of r are 19 and 22.5 mm.

Several polarizers with these radii were wound and measured. The orientation of the fiber with respect to the bow-ties was first checked to avoid unintentional [14] 180° rotations, by comparing the bending loss curve to those of representative (good) coils with the bow-tie sectors oriented parallel and perpendicular to coil plane. In the windings, the tension of the fiber was kept to a minimum, just to balance the curvature force.

The attenuations vs wavelength, measured for $n = 1 - 4$ complete turns of the two selected radii are reported in Figs. 3 and 4. For $n = 4$, the 22.5-mm coil has an insertion loss <0.5 (1) dB up to 1360 (1370) nm and gives an extinction ratio larger than 40 dB for $\lambda > 1310$ nm; the 19-mm coil has an insertion loss <1 dB up to 1340 nm and its extinction ratio tops to 45 dB for $\lambda >$1320 nm. Also shown in Figs. 3 and 4 is the contribution of attenuation due to mode cutoff in the straight fiber (dotted line), which is negligible up to specified wavelengths. Note that, as the instrumental limit of our setup is 45 dB, at some wavelengths the extinction may even surpass this figure. Data for $n > 4$ (not shown in Figs. 3, 4) show a worsening of both extinction and insertion loss.

Worth to note, the above described polarizers curves were found very reproducible in a batch of several ($N > 10$) samples, opposedly to previous hi-bi coils with uncontrolled reinjection, and exhibited no kinks along the curves.

One point of concern with the 1300-nm polarizer made by 750-nm cutoff fiber was the splice loss in joints with a standard communication fiber. However, we were able to reduce it to 0.6–0.7 dB routinely simply by multiple arc-heating of the hi-bi fiber before arc-splicing to the standard fiber in our commercial arc-fusion machine.

Last, we have analyzed the temperature dependence of the extinction attenuation, following the analysis of Ref. [15]. For our fiber polarizer, the temperature period for the clad/coating injection is $T = 500$ K. This means that thermal effects are negligible in the range $T = 10$–50 °C as observed experimentally.

III. Conclusion

By taking account of reinjection effects we have demonstrated an all-fiber polarizer at 1300 nm, made with commercially available hi-bi fiber, that attains high extinction ratio with good reproducibility. Extension to other wavelength of operation is achieved by appropriate scaling of the cutoff wavelength of the hi-bi fiber used in the coil.

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