Optical properties of a low-loss polarization maintaining microfiber

Yongmin Jung, Gilberto Brambilla, and David J. Richardson
Optoelectronics Research Centre, University of Southampton, Southampton, SO17 1BJ, UK

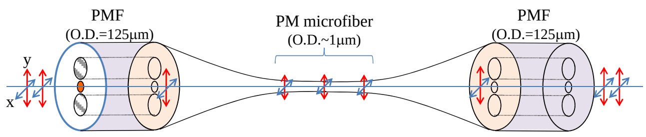
***Abstract*—A polarization preserving single-mode microfiber was successfully fabricated by a flame brushing method. A polarization extinction ratio of 16dB is typically maintained through the device with excess loss of 0.2dB.**

I. Introduction

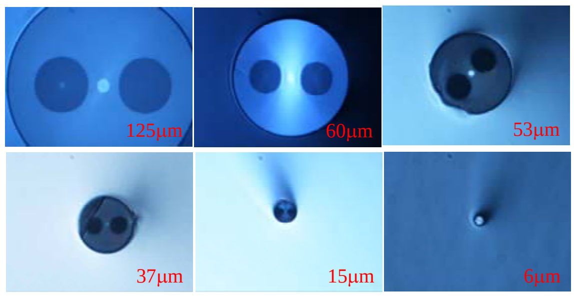
With recent advances in micro- and nanophotonics, optical Micro-/Nanofibers with diameters close to the wavelength of guided light have attracted considerable attention as promising building blocks for a variety of photonic applications [1-2]. The most interesting issue is the fabrication of polarization maintaining (PM) microfibers since unwanted changes in the polarization of the propagating signal induce a considerable deterioration of micro-system sensitivity. There are two principle approaches for the manufacture of PM microfibers. The first approach uses non-circular fibers such as side-flat fibers. By breaking the circular symmetry observed in conventional optical fiber tapers, a strong form birefringence can be achieved. The second approach involves the use of commercial PM fibers such as panda and bow-tie fibers. By carefully controlling the parameters of microfiber manufacture, it should be possible to control the diffusion of dopants in the tapered region and minimize the anisotropic external perturbations for preserving a given state of polarization. In this paper, a commercial panda fiber was employed as a host fiber to preserve the plane of polarization of the light and was tapered into a very thin waist (~1µm) microfiber. The optical properties of the PM microfiber were examined by observing the polarization extinction ratio and state of polarization measurement.

II. Fabrications and Optical Characterizations

Figure 1(a) shows the schematic configuration of the proposed polarization maintain microfiber. A short section of panda fiber was heated and stretched into a very thin microfiber similar to previous well-established bi-conical fiber taper [2]. In the adiabatic taper transition, the local fundamental core mode (LP_{01}^{core}) is continuously mode converted to a guided cladding mode (LP_{01}^{clad}) in the taper waist by the down-taper and then coupled back into fundamental core mode (LP_{01}^{core}) of the fiber by the up-taper [3]. In this type of polarization preserving fiber stress applying parts induce tensile stress to the core and cause a difference in the refractive indices between the linearly polarized components that are parallel to the fast and slow axes. The linear polarization of those two lights is maintained while they propagate in the fiber, even when the fiber is bent or twisted. The main focus of this study is how well the input polarization state is preserved during the tapering process. First, the taper cross section was inspected under optical microscope using a conventional cleaving tool (diamond scribe). As shown in Fig. 1(b), the fiber geometry is well preserved and the stress applying parts are well observed even though the outer diameter is less than 10µm.



(a)



(b)

Fig. 1. (a) Schematic of an adiabatically tapered PM microfiber, (b) microscope images of the fiber cross section along the taper.

To investigate the modal guidance, in-situ transmission spectra of the PM microfiber were recorded for various outer diameters during the tapering process. An incoherent white light source and an optical spectrum analyzer were used to measure the spectral characteristics of the PM microfiber. Figure 2 shows the spectral output

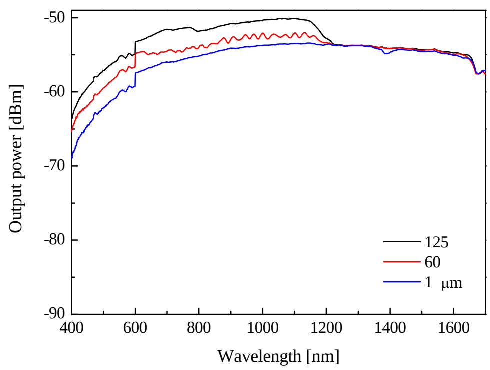


Fig. 2. Transmission spectra of the proposed PM microfiber

of tapered PM fibers for different diameters in the uniform waist region. Just as in similar previous experiment on high-order mode filtering in a standard telecom fiber [3], the transition region is adiabatic for fundamental mode but non-adiabatic for higher-order core mode. Note that for the microfiber with a=1μm the optical loss in the single mode region is negligible (< 0.2dB at λ=1.55μm).

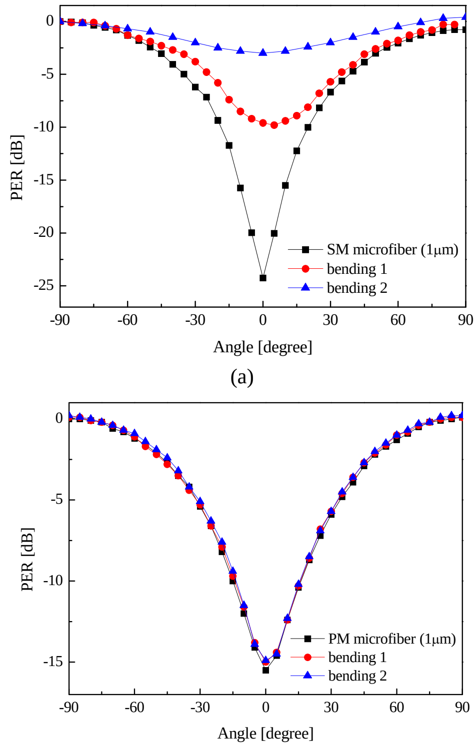


Fig. 3. Polarization extinction ratio with respect to input polarizer angle for (a) SM microfiber and (b) PM microfiber

To verify the polarization maintaining property of PM microfibers, we compared them with regular single mode (SM) microfibers with the approach of polarization extinction ratio (PER) measurement. The PER is defined as PER= 10log(P_{max}/P_{min}) and a cross-polarizer method was adapted. In this method, polarized light is launched into the core of the constituent fibers through a polarizer of which the polarization axis is aligned to one of the principal axes of the fiber. The output light is measured through an analyzer. To achieve good measurement accuracy, we chose a broadband ASE source with bandwidth up to 60nm and accurately aligned the principal polarization axes to the input PM fiber.

As shown in Fig. 3(a), single mode (SM) microfiber can exhibit a high PER at a certain angle, where one of the birefringent axes is well aligned with the polarization direction of incident light. However, transmission in regular SM microfiber was easily changed by external perturbations such as bending and twisting and the PER value was significantly deteriorated. For the PM microfiber, when stress was applied, the PER with respect to input polarization angle showed a nice polarization maintaining characteristics with a tolerance of bending stress, as shown in Fig. 3(b).

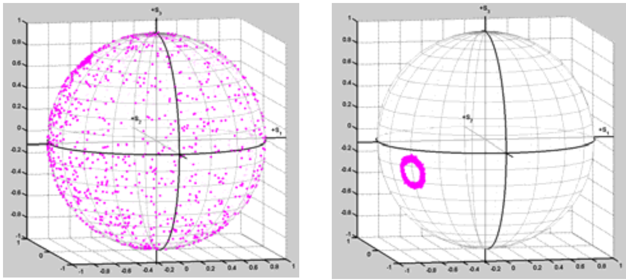


Fig. 4. Polarization mapping onto the Poincare' sphere with respect to some bending conditions for (a) SM microfiber and (b) PM microfiber

Fig. 4 is the state of polarization (SOP) trace measured with some bending conditions for both SM and PM microfibers. As can be seen in Fig. 4(a), the entire Poincare' sphere was covered by the trace, which means that the SOP of SM microfiber is easily affected by the external disturbance. For comparison, the SOP trace at the output of the PM microfiber was localized to a certain point and did not changed. The small circle of the Poincare's sphere is due to the small misalignment of the direction of the linear polarized beam relative to the input PM fiber axes and can be minimized with further precise alignment. The output from the PM microfiber is a stable linearly polarized light with PER >16dB.

III. Conclusions

We have verified the polarization maintaining property of PM and regular SM microfibers with approach of PER and SOP measurements. Both microfibers exhibit a good capability to maintain linear polarization. However, under the presence of external perturbations such as bending, the PM microfiber exhibits consistent PM characteristics, while the SM polarization maintaining capabilities deteriorate. Therefore, PM microfibers have the potential to introduce an additional degree of control in micro-/nanophotonics.

Acknowledgment

The authors thank the Engineering and Physical Sciences Research Council UK (EPSRC) for financial support; GB gratefully acknowledges the Royal Society (London, UK) for his University Research Fellowship.

References

[1] L. Tong, R. R. Gattass, J. B. Ashcom, S. He, J. Lou, M. Shen, I. Maxwell and E. Mazur, "Subwavelength-diameter silica wires for low-loss optical wave guiding," *Nature*, vol. 426, pp. 816-819, December 2003.

[2] G. Brambilla, F. Xu, P. Horak, Y. Jung, F. Koizumi, N. P. Sessions, E. Koukharenko, X. Feng, G. S. Murugan, J. S. Wilkinson, and D. J. Richardson, "Optical fiber nanowires and microwires: fabrication and applications," *Adv. Opt. Photon.*, vol. 1, pp. 107-161, Jan. 2009.

[3] Yongmin Jung, Gilberto Brambilla and David J. Richardson, "Broadband single-mode operation of standard optical fibers by using a sub-wavelength optical wire filter," *Opt. Express.*, vol. 16, pp. 14661-14667, Sep. 2008.