Angular orientation of micro-structured fiber by side imaging analysis

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Abstract- A side-imaging technique (SIT) for orienting the azimuthal angle of micro-structured fiber (MSFs) is proposed and demonstrated. Scattering is reduced by using the incoherent light as illuminating source. Side images are measured and analyzed while the fiber is rotated. The peaks pattern of the side-images, unique to each MSF, are experimentally demonstrated to be correlated closely with the symmetry in the cladding structure of MSFs. The unique correspondence between the peaks and the azimuthal angle is determined by numerical simulations.

Keywords—Micro-structured fiber; Angular orientation; Side image; Pattern analysis

Micro-structured Fibers (MSFs) have attracted highly intensive attention, since the first invention by Russell in 1991[1]. The guiding properties of such fiber are essentially governed by the topology of periodic refractive index array in the cross-section of the fiber cladding. In fabrication of MSFs based device, such as grating and coupler, fiber angular orientation is the key factor to the device performance. To respond the requirement of quality inspection and MSFs orientation, side-scattering techniques have been employed.

In this letter, we propose a novel approach to determinate the MSFs angular orientation based on side imaging technique. Incoherent light is illuminated perpendicularly on the MSFs, and images formed by the light transmitted through the fiber are recorded as the fiber rotating. The peaks intensity in the images present a strong dependence to the fiber azimuthal angle. Numerical simulations are performed to demonstrate the angular orientation of three kinds of micro-structured fiber.

Figure 1 depicts the schematic diagram in our simulation. We illuminate collimated light perpendicular to the axial of MSF from one side of the cross section. The effect of MSF cladding structure on the light can be divided into two parts. The whole outer silica cylinder acts as a cylindrical lens, while the micro-structure channels in the micro-structured cladding acts as a cubic scattering array. Here we take a hexagonal lattice MSF (ESM-12-01, NKT Photonics) as an example, as most MSFs feature a hexagonal lattice configuration. Since the hexagonal lattice MSF has a 60° rotational symmetry, we set the the 0° orientation corresponding to the ΓK direction of the hexagonal lattice. The MSF was held in a fiber chuck , which was in turn mounted on a motorized rotation stage with a rotation step size of 0.50°. We adopted the ray tracing method by running the commercially available software of RSOFT. The total amount of light rays was 400 000.

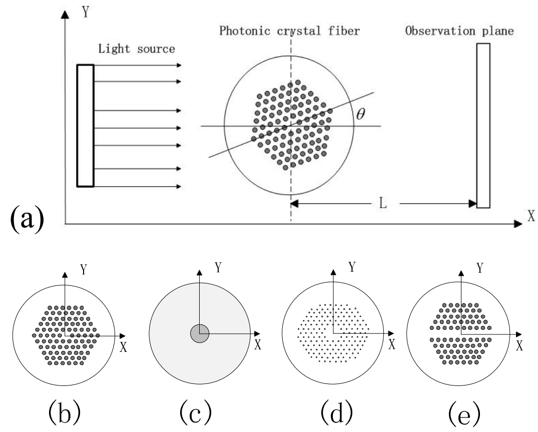

Fig. 1 (a) Schematic diagram of side-imaging technique. Cross sections of sample fibers and definition of azimuthal angles. (b)hexagonal, (c)single mode fiber, (d) larger mode area and(e) hybrid lattice MOF.

Figure 2 (a) shows the images of MSFs (the right column) and the horizonal light intensity distribution (the left column) at different azimuthal angle. When the light passes through the micro-structured area, the part of light striking on the air holes is scattered due to the inhomogeneity of refractive index, and the other part of light goes through the gaps between the rows of the airholes with no scattering or less scattering. The latter part forms two high intensity zones, P1 and P2, in the focal plane and are recorded by CCD camera. At the angle of 0°, two peaks appear clearly and symmetrically in intensity. As the fiber being rotated, the amount of un-scattered light will decrease, which leads to the decease of the peaks intensity and their symmetry. When the rotation angle comes to 60°, the appearance of the two peak repeats back like that at 0°.

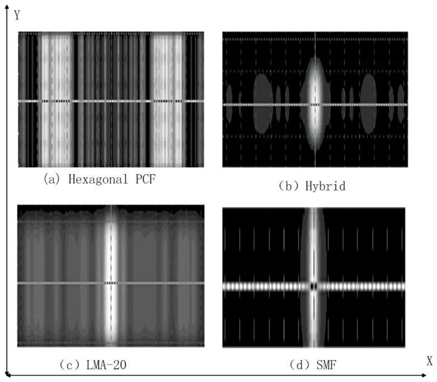

Fig 2. Side image of (a)hexagonal PCF, (b) hybrid PCF, (c) LMA-20 and (d) single mode fiber.

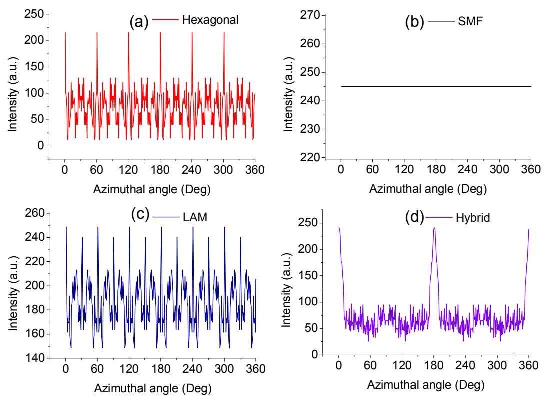

Fig. 3 Simulation results for measured intensity of P_1 at varying azimuthal angle for different fiber. (a) Hexagonal lattice MSF. (b) Single mode fiber. (c) Large area mode MSF. (d) Hybrid lattice MSF. The right column are the cross section of the corresponding fiber.

Since the two peaks show symmetry in intensity and position, we can choose either of them for further analysis. The dependence of the peak intensity on azimuthal angular rotation is shown in Figure 3. A six fold symmetry is presented with period of around 60°. Besides, between each 60°cycle, a 30°symmetric waves can also be found. These minor periodic waves are not apparent in experimental results, because the distortions in fiber structure and perturbations in rotating motor. Even though, they provide important information for MSF precise structure analysis.

As a control, we perform measurements on a standard single mode fiber (SMF), a hybrid micro-structured fiber and a large area mode fiber (LAM) with the same procedure dealing with the hexagonal MSF. Figure 2 (b) show SMF presents a flat respondence to the azimuth angle change, because of the absence of micro-structured cladding in SMFs.

Side-imaging measurements present a few features, such as topology, and filling ratio, unique to the micro-structured cladding of different types of MSFs. Fiber angular orientation can be realized by finding the ΓK direction firstly and rotating the desired angle. The scattering is greatly reduced in SIT by using incoherent light as the illuminating source and subsequently the necessity of filling refractive index matching fluid is avoided. This feature benefits SIT in a non-contamination, full nondestructive, and in-line angular orientation during the fabrication of MOFs based devices.

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