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The Identification Method of the Photonic-Crystal Fiber Mode Field Diameter Maximum Position: Experimental Researches

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Abstract **– The research results of the determine method of the position of the mode field diameter maximum of photonic-crystal fiber are represented in this article. Using of this method will lead to decrease of the optical losses in connection of two identical PCF due to their precise positioning on mutual rotation angle. Image of mode field is analyzed by the near-field technique.**

Keywords – photonic crystal fiber; mode field; position identification; optical fiber connection; near-field technique

Last years in electronic engineering are increasingly used photonic-crystal fiber (PCF). These are fibers in which cladding is a dimensional photonic crystal formed by symmetrically arranged around the core hollow capillaries in a round or hexagonal densely packed dielectric tube, creating a cross-section periodic macro lattice [1].

Depending from the type PCF, the size of the diameter of the holes in the cladding and their relative position, there are different specialized passive and active elements of functional electronics based on them.

PCF with large core diameter can be used as a transmission medium high intensity light streams. The limits of nonlinear effects are reduced in PCF with small core sizes and this is of great interest to create effective Raman lasers, amplifiers, optical switches and generators super continuum - a source of white light with very high energy brightness. These sources can be used in systems DWDM. Due to its unique dispersion properties, PCF are used as dispersion compensators in fiber communication systems.

During the application of PCF it is necessary to connect them together. This leads to loss of optical power in the joints. Besides the usual factors such as transverse and longitudinal shifts, angular inclination of axes, non-parallel ends face, on the quality of the connection of two PCF impact of mutual rotation angle [2, 3]. Fig. 1 shows a model developed by PCF (left) and calculated of mode field (right). Due to the presence of holes in the cladding the mode field is complex and flow into between the holes on the cladding. If during of two PCF connection did not take into account the relative angle of rotation around the longitudinal axis, it is possible to lose some signal which passes between the holes. That is desirable achieved to air holes in the cladding of a PCF coincide with the holes in the cladding of another PCF. This will increase the area of overlap both mode field fibers, which minimizes the signal loss. In the worst case, losses may amount to 10%.

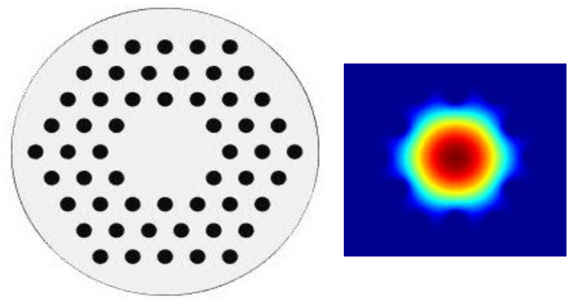

Fig. 1. Constructed PCF model and calculated distribution of fundamental mode

Purpose of this study is to determine the position of the crossing with a maximum diameter of PCF mode field. To achieve the purpose should be to solve the following problem [4]:

- to obtain the image of PCF mode field;
- to calculate the distribution center of mode field, through which will pass crossing;
- to determine the intensity distribution of radiation at each crossing with one degree increments;
- to determine the maximum diameter and appropriate to it angle of inclination of crossing.

There are several methods of the mode field diameter measurements, one of them - a near-field technique - allows to measure not only mode field diameter, but also to determine the geometric parameters of fiber. The method is based on measurements of mode field diameter at the output end face of the fiber by using of focused optical radiation power distribution of the fiber end face, transmitting on matrix sensor platform. The most accurate measurement results with small errors can be obtained from the use of detectors with high dynamic range and carefully prepared ends face of the fiber.

Typical setup for realization of near-field method includes optical system, multi element CCD photodetector, the ADC and control PC (fig.2). Step of the CCD-matrix photosensitive elements location determine the resolution of the measuring system. It’s necessary to use the high aperture lens system, which increases the fiber end face image that is scanned by CCD-camera.

The precision calibration and alignment optics are needed

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for implementation of accurate measurements. The great numerical aperture of optical systems it is important in this method: optics with a low aperture can do inadmissible cutoff in spatial and frequency areas, causing large errors in the determination of the refractive index profile. For this reason, should be used optics with NA>0,5. Dynamic range of control systems based on NF-method should be more than 40 ... 45 dB.

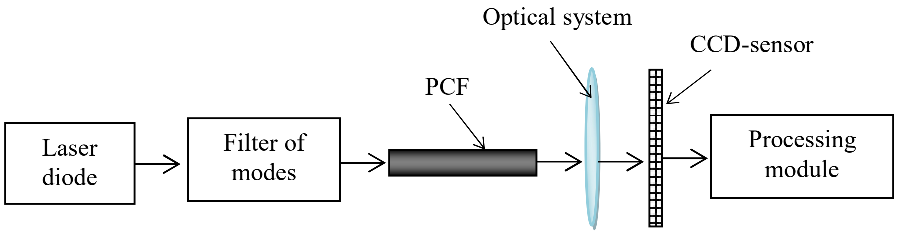

Fig. 2. Measuring scheme of PC-fiber parameters by near field technique

Fig. 3 shows the measured PCF mode field with a core diameter of 40 microns at a wavelength of 1.55 microns.

Measured image except the useful signal includes different high frequency noise components caused by errors of measurement systems and PCF end face conditions. It needs the image filter in order to increase the accuracy of calculations. The Butterworth low pass filter is the best filter to exclude high frequency noise in this case. Experimentally found that the filter has to be the twelfth order and have a normalized cutoff frequency w=0.5π rad/sample. Fig. 4 shows the measured one-dimensional distribution of PCF mode field and filtering result.

The distribution center is found after the filtering operation of entire mode field image by the auto convolution method. Further the mode field diameter in each crossing of that passes through the center in increments of one degree is calculated. Algorithm for determining of the distribution center and mode field diameter is described in [4]. Result of calculations in the form of graph dependence of mode field diameter change at the rotation angle of crossing $D(\alpha)$ shown in Fig. 5.

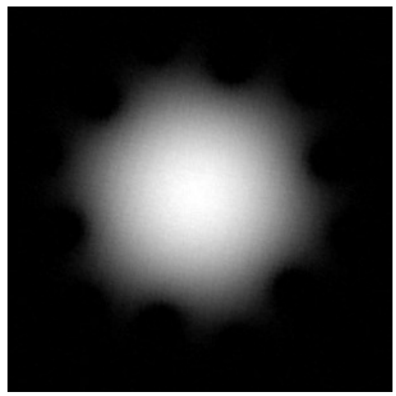

Fig. 3. Measured PCF mode field

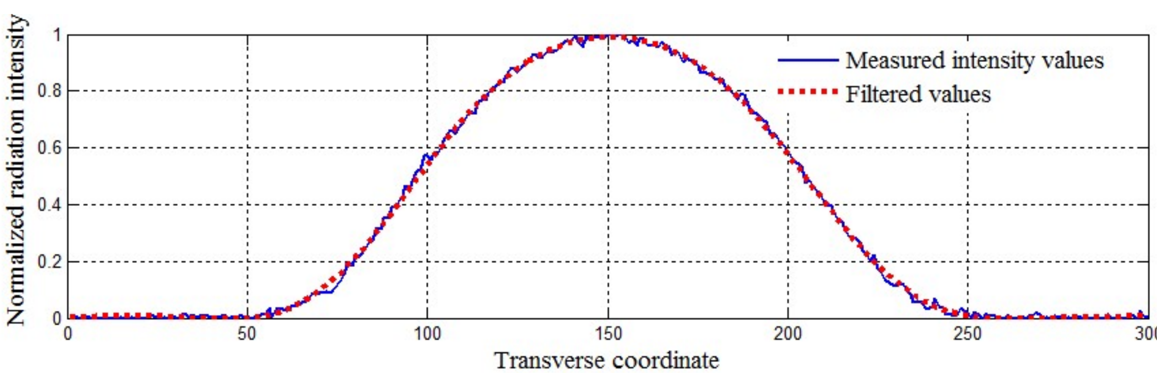

Fig. 4. One-dimensional image of measured mode field distribution before and after filtration

The derivative of the resulting dependence $D(\alpha)$ for determine of the maximum diameter is calculated. It is known that derivative in the maximum point is zero and will change its sign from positive to negative. As a result the five peaks, where the mode field diameter reaches its maximum, were obtained from calculations. Numerical data of research are presented in Table. 1. The small difference between the obtained values of maximum diameters allows carry out PCF positioning on any of them.

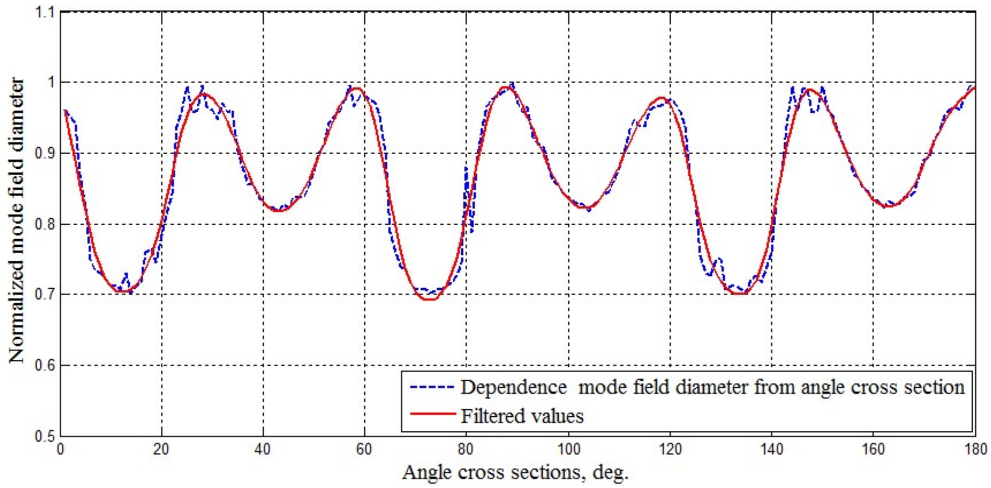

Fig. 5. Change of mode field diameter depending on the rotation angle of crossing $D(\alpha)$

TABLE I
RESULTS OF CALCULATIONS

The rotation angle of crossing, deg.	31	60	89	120	148
Normalized values of mode field diameter	0,9888	0,9955	0,9955	0,9924	0,9917

Thus, the proposed method of determining of the maximum diameter position of mode field allows a more precise positioning of two identical PCF during connection. The main requirement is the presence of even number of holes in PCF cladding first round.

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