THE SYMMETRY OF OPTICAL FIELD IN PHOTONIC CRYSTAL FIBRE WITH TRIGONAL SYMMETRY

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Summary Some photographs of intensity of optical field of a photonic crystal fibre are presented in the contribution. Presented photographs document that the symmetry of photonic crystal creating the cladding of fibre is manifested in the symmetry of distribution of the optical field intensity. In case when more modes are excited in the fibre the symmetry of the generated field can be different as the symmetry of the eventual modes. How the symmetry may be changed is illustrated by a model example.

1. INTRODUCTION

A photonic crystal is a transparent medium with a periodic arrangement of the refractive index inhomogenities. These inhomogenities can be distributed in such structure which (due to Bragg scattering) does not allow to some optical waves (the waves with some wave vectors) to propagate through the medium. This means, that some regions of energies (wavelengths) and wave vectors are permitted others forbidden. It is similar to behaviour of solids where exist regions of allowed energies of electrons and regions with forbidden energies. These energetic regions are, in solid state physics, named as *valence* and *conducting band* for allowed values of energies and as *the bandgap* for forbidden energies, respectivelly. In analogy, also the region of wavelengths of light which can not propagate throught the optical structure is named as bandgap – the *photonic bandgap* [1].

It is possible to prepare a 2D photonic crystal, which contains a long ”defect” (inhomogenity of the photonic crystal) with small cross section (Fig. 1). If the cross-section is small, but great enough to allow that an optical wave with the wave vector from forbidden region can propagate along it, the defect behaves as the core of a optical fibre, because light of these wavelengths cannot leave the area of the defect. It means that the structure serves as a optical fibre – the *Photonic Crystal Fibre* (PCF).

The structure of the photonic crystal fibre determines the fibre properties [2], including phase velocity, dispersion and also the distribution of the light intensity in the “core” of the fibre. The dispersion and the difference of the phase velocities of the first and second modes we have described in our previous papers [3,4]. In this paper we present some results of investigation of the optical field pattern of the photonic crystal fibre made by *CENTAURUS Technologies, Sydney*. The investigated fibre is performed by a set of airholes in silica glass with trigonal arrangement and his core is performed by a missing hole in the centre of the fibre [3]. The arrangement of the air holes can be seen in the photograph given in Fig. 3.a. The diameter of the hole is 2,6μm and the pitch is 7,1μm. The investigated fibre belongs to the group of PCFs called *index-guiding* PCFs. This name is related to the fact that the refractive index of fibre core is higher than average index of the cladding region, created by photonic crystal with periodically distributed airholes. Therefore, in the first approximation, for the characterisation of these fibres can be used the theory of step-index fibres with the refractive index of the “cladding” equal to average value in the surrounding structure [5]. Beside the index-guiding fibres there are also so called *band-gap guiding* PCFs [6]. The refractive index of the core in these fibres is smaller than average index of cladding. The structure of the photonic crystal surrounding the core of such fibres can cause sufficient reflection of the waves impinging from the core also when the cladding is realised as an air hole structure.

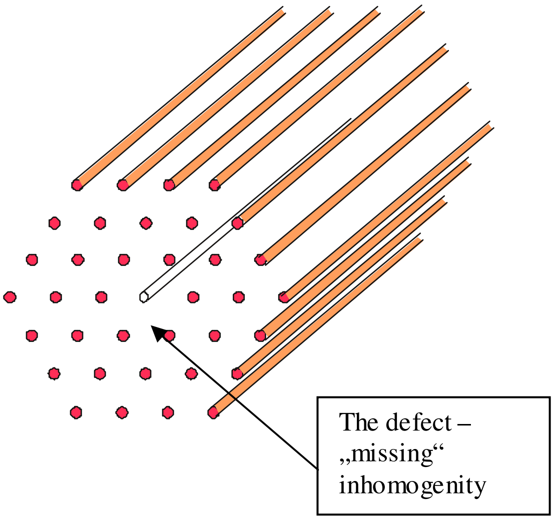

Fig. 1 A scheme of photonic crystal with a long defect.

2. DESCRIPTION OF EXPERIMENT AND RESULTS

The investigation of profile of the optical field in the fibre we realised by photography of the end face of the fibre after its magnification by an appropriate microscope.. The used setup is shown in Fig. 2.

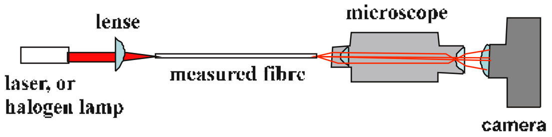

Fig. 2 Setup of the experiment.

The illumination of the front face of the fibre was changed during the investigation by changing its position in the focal plane of the illuminating system. It led to different amplitudes of excited modes and gave quite broad variety of observed optical field shape in the fibre. Between obtained pictures there were pictures of field, which has evident sixfold symmetry. Such symmetry of the field at the end of fibre excited by halogen lamp and by He-Ne laser, respectively, are shown in Fig. 3. In the used region of wavelengths (visible light) two modes can propagate in the fibre. In order to show the field orientation with respect to the fibre structure, the end face of the photographed fibre was illuminated by white light (Fig. 3.a). That is why the airholes are displayed as small black circles. Note, the photograph gives the pattern of optical field intensity i.e. the square of the electrical field of the wave. Due to the symmetry of the threefold symmetry of the optical field the picture is sixfold one. But this does not mean that sixfold symmetry of the intensity must be involved by threefold symmetry of the field.

The optical field of the fundamental mode in a PCF have the same phase in all cross-section like LP_{01} mode of a step-index fibre which field is circularly symmetric. The sixfold symmetry of this mode can be simple a result of the existence of the fibre inhomogenities (holes), positions of which are shown in Fig. 3.a. However, besides fields with sixfold symmetry we observed also field with significant threefold symmetry (Fig. 4).

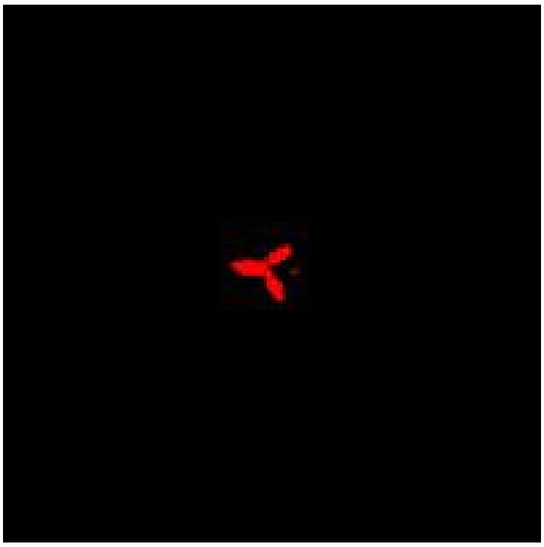

Fig. 4 The photography of field with threefold symmetry.

The existence of such field can be explained as follows: A change of the phase of the field in the fibre is given by its phase velocity (the phase constant of the particular mode). As it can be seen from Fig. 5 the phase velocity is 1/cos (α) multiple of speed of a planar wave in that medium, where α is the angle between the direction of particular waves forming the optical mode and axis of the

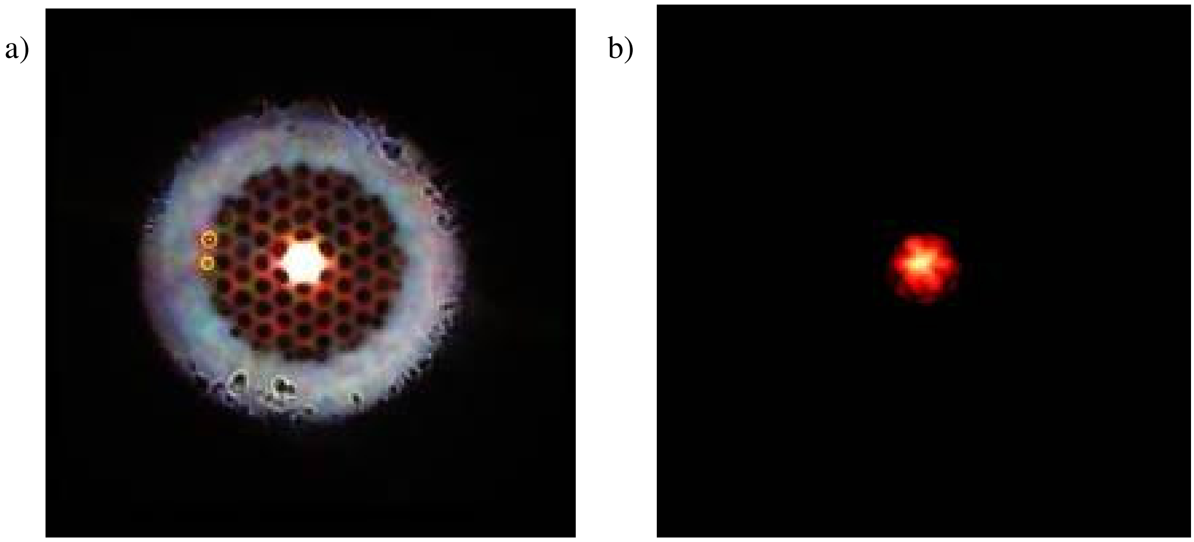

Fig. 3 Photographs of the optical field at the end face of PCF when fibre was excited by halogen lamp (a) and by He-Ne laser (b), respectively.

fibre. Because these angles have different values for particular modes, phase constants of these modes are differed, too.

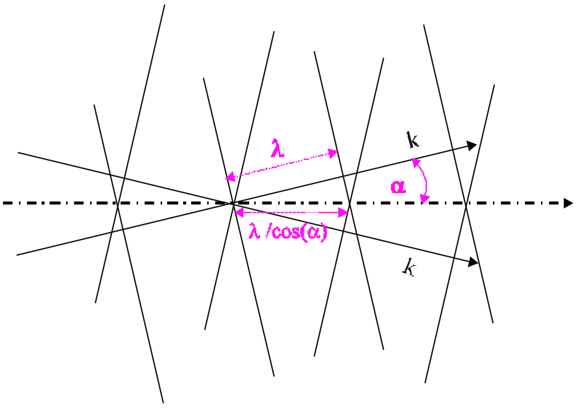

Fig. 5 Illustration of phase constant dependence on direction of wave propagation.

In the case of optical field formed by particular symmetrically distributed plane waves the phase of the field depends on coordinate by the same way. It means that the dependence of the phase constant on angle α illustrated in Fig. 5 is valid outside the fibre, as well as inside it. Only the angle α is greater in comparison with angle inside the fibre because of the difference of refractive indexes inside and outside the fibre. So, the relative phase of the fields formed by the particular modes near the end face of the fibre depends on the distance from the fibre end. That is why defocusing the microscope, i.e. changing the distance between microscope objective and the fibre end, causes the changes of the shape of the imagined optical field for the appropriate position change of the microscope. The change can be so significant that the sixfold field symmetry can be transformed to threefold one.

For illustration of this effect let us assume that two modes are generated in fibre: fundamental mode with circular symmetry and threefold symmetry mode. Field distribution of these modes in 3D graph, as welltheir intensity distribution are shown in Fig. 6.

It follows from an elementar calculation that in the places where phases of the fields of the first and the second mode are shifted by (n+1/2)π the intensity of their sum is the sum of the particular intensities (Fig. 7).

In the place where modes have equal or opposite phases the amplitudes of the interfering modes should be summed up algebraically. For an appropriate ratio of their amplitudes it can be radically manifested in distribution of the intensity of the final field. It illustrates the intensity distribution shown in Fig. 8.

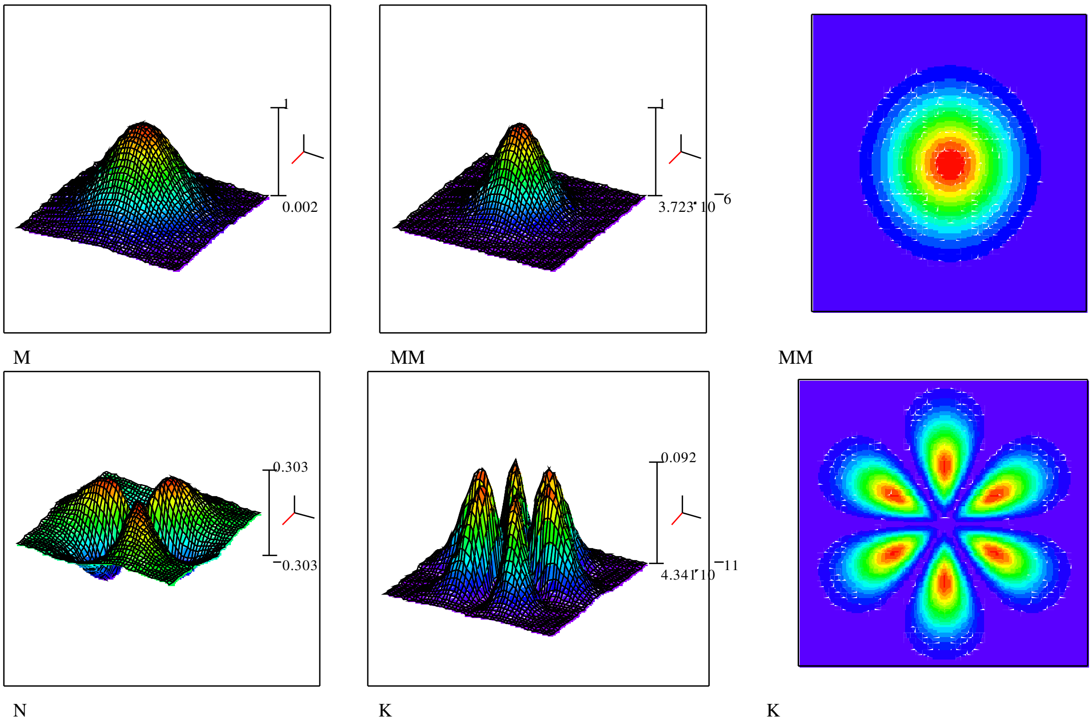

Fig. 6 Pattern of fundamental mode (M) and his intesity in 3D (MM) and 2D plot (MM) and pattern of mode with trigonal symmetry (N) and his square (K).

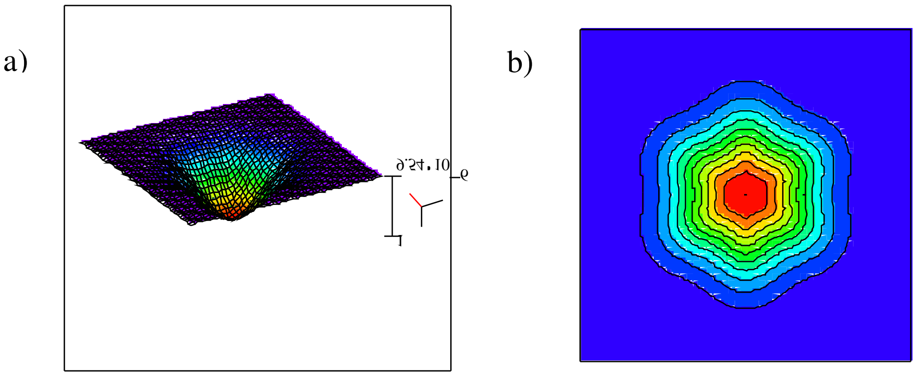

Fig.7 Intensity distribution when phase difference of fundamental and the trigonal mode is π/2 shown in 3D (a) and 2D graph (b).

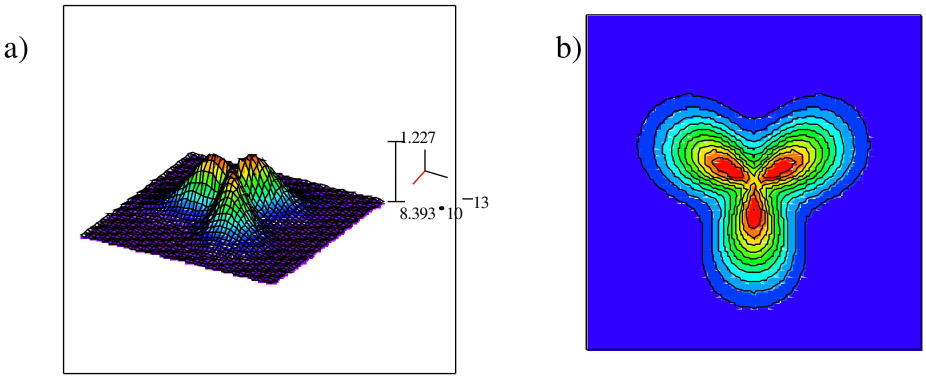

Fig.8 Intensity distribution when both modes have the same phase in 3D and 2D graph.

The photographs given in Fig. 3 and Fig. 4 show that for appropriate position of the scope (appropriate focusing of the microscope) both situations shown in Fig. 7 and Fig. 8 can be observed.

3. CONCLUSION

The pictures of modal field distribution presented in this contribution show that the optical field in the investigated fibre has not cylindrical symmetry. The field distribution is significantly influenced by trigonal arrangement of airhole of the PCF structure. This result documents that the fibre attributes PCF are determined by properties of photonic crystal reflecting the light waves propagating through the fibre core also when the fibre is index-guiding one. It documents that the name *"index guiding fibres"* does not reflect the fibre properties and should be accepted really only as a name of kind of photonic crystal fibres.

Acknowledgement

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