THE LIMITATION OF USING THE AVERAGE REFRACTIVE INDEX MODEL IN PHOTONIC CRYSTAL FIBRES

D. Káčik, I. Turek

Department of Physics, Faculty of Electrical Engineering, University of Zilina
Univerzitna 1, 010 26, Zilina

Summary Results of investigation of dependence of transmission function of so called "index guiding" photonic crystal fibres on mechanical bending is presented in this paper. The bending was realised in two differently oriented planes. In both cases the influence of the bending differs from the influence in conventional fibres. The obtained results show that properties of the fibre can not be explained using model based on average refractive index.

1. INTRODUCTION

In conventional optical fibres, the electromagnetic modes are guided by total internal reflection in a core/cladding boundary. For this purpose the refractive index of the material of the core is higher than the refractive index of the cladding. Refractive index of the core is increased usually by doping of the base material.

In photonic crystal fibres (PCFs), the core is surrounded by photonic crystal i.e. by medium with suitable periodic structure of the refractive index. The medium is obviously composed by periodic arrangement of cylinder airholes, or cylindrical regions of higher refractive index. The light wave in PCF is guided by a photonic bandgap effect, what means that the periodic structure of the refractive index in the cladining does not allow propagation of the optical wave.

In the literature [1,2,3] it is usually presented that two distinct guiding mechanisms are possible:

- The light is guided in the core with a higher refractive index than average refractive index of the cladding by an similar effect to total internal reflection (often termed modified total internal reflection or just index-guiding),
- The ligth can be trapped in the core with lower average refractive index than the cladding region by a photonic bandgap effect.

The existance of these two possible types of fibres is one of the reasons for the versatility utilization of PCFs.

In this contribution we will concern about so-called index guiding PCFs. As it was mention before, the light is guided in the fibre core of higher refractive index than average value of the refractive index of the cladding. Due to this it is often interpreted as a mechanism similar to total internal refrection in conventional fibres.

A common design, easily fabricated by stacking capillary tubes, is shown in Fig.1. The cladding region consists of a periodic array of airholes, with a missing one or more airholes representing the core.

A qualitative understanding of some basic properties of index guiding PCFs may be obtained by

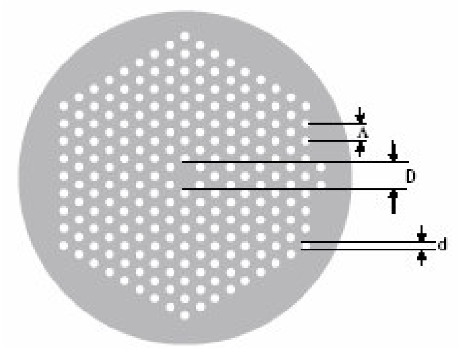

Fig.1 A common photonic crystal fibre design. White areas are airholes while dark areas are silica. D is core diameter, d is average hole diameter and Λ is a pitch

considering the effective index model [3] depicted in Fig.2. Here, the photonic crystal fibre structure is approximated by step index fibre with core refractive index coresponding to refractive index of base material (e.g. silica), and refractive index of cladding defined as effective refractive index (average value of refractive index of base material and airholes).

Using this approximation it can be written similar relation of normalised frequency to conventional

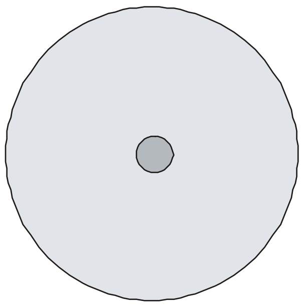

Fig.2 Effective index model of design inFig.1

fibres [3]

$$V_{eff} = k\Lambda F^{1/2}\left(n_0^2 - n_a^2\right)^{1/2} \qquad (1)$$

where k is wave number, n_a and n_0 are refractive index of air (or whatever is in the holes) and base material respectively, Λ is pitch and F is the air filling fraction. It follows from this, that large holes make the fibre to be multimoded whereas the gaps between the holes are narrow and the core is strongly isolating from the cladding. By contrast, small holes make single mode guidance but the decrease in effective index difference (or in numerical aperture) makes the fibre more susceptible to bend loss.

However, as it will be seen later, this approximation does not interpret all properties of photonic crystal fibres.

2. EXPERIMENT

We experimentally investigated bend influence on fibre transmission characteristic in experimental arrangement similar to describing in [4,5]. The bend influence on the transmission function of PCF was measured in fibre labeled as ASC014_B5a made by Optical Fibre Technology Centre University of Sydney, Australia. The investigation has been made in region of the wavelength from 0.9 µm to 1.4 µm because the singlemode regime of the fibre starts at 1 µm as it was confirmed by intermodal interference measurement [6]. The cross section of the fibre imagined by electron microscope is shown in Fig. 3.

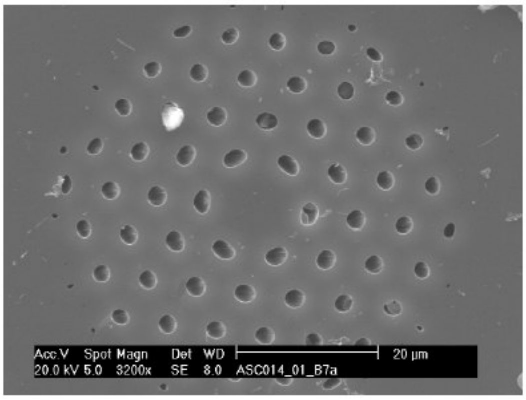

Fig.3 Triangular structure of photonic crystal fibre

3. RESULTS

The measurement of transmission function of photonic crystal fibre was performed for single twist on rod of diameter 15 mm. For comparison the measurement of transmission function of "straight" fibre was done, too.

In the first case of the bend of the fibre, the bending plane was directed at hole in second ring as it is shown in inset in Fig.4. To be sure that the result is correct, the measurement was repeated after the fiber was turned for 60 degrees, to the equivalent position.

As it is seen from the figure, the measured transmission functions are practically the same in the both cases.

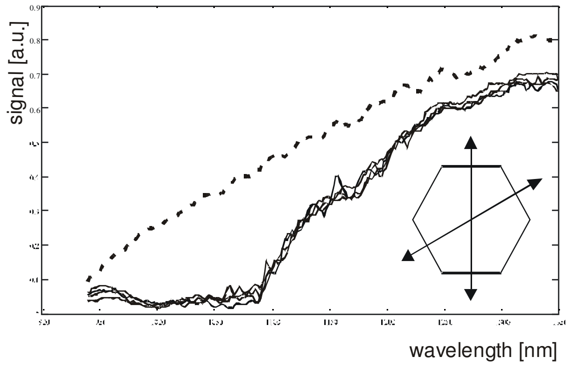

Fig.4 Spectral dependencies of transmission function. Dash curve is for straight fibre, and the others are for bend radius 7.5 mm

In the next, the measurement was done for bending plane directed at hole in the first ring as it is shown in inset in Fig.4.

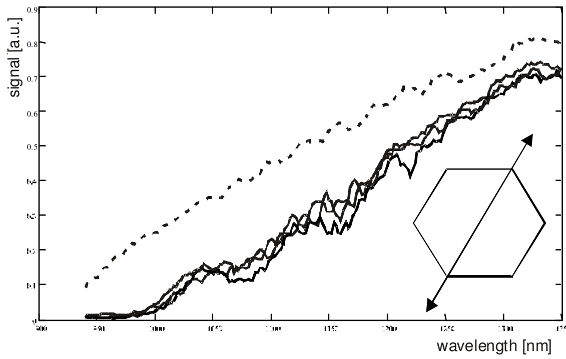

Fig.5 Spectral dependencies of transmission function. Dash curve is for straigth fibre, and the others are for bend radius 7.5 mm

The comparison of measured transmission functions depending on bending plane and measured transmission function of straigth fibre is shown in Fig.6.

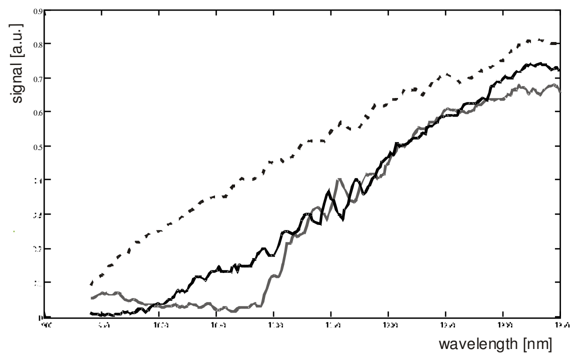

Fig.6 Comparision of spectral dependencies of straigth (dash) and bending fibres

This figure clearly shows that the transmission function depends on the fibre bending and their changes also depend on orientation of the bending plane.

It follows from the figure that using of modified total internal refraction model is not justifiable. By using this model it is not possible to explain the different behaviour of fibre due to bending plane.

Also, the fact that transmission function of photonic crystal fibre is influenced mainly in the short wavelength side of its monomode region, while the bending influences transmision function of conventional fibre mainly in the long wavelength side (Fig.7) cannot be explained by the index quiding model.

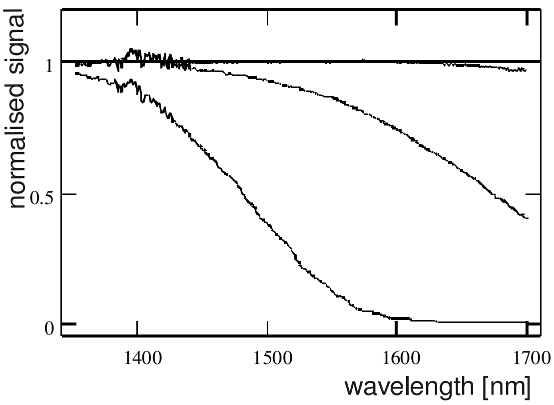

Fig.7 Transmission functions of step-index fibre with different curvatures in the range 1350-1700 nm

And this model cannot explain the central difference between PCFs and conventional fibres: the PCFs can support only one mode over wide spectrum of wavelenghs (endlessly singlemode fibers [3]).

4. CONCLUSION

Presented results of the bending dependence of the transmission function of so called „index guiding fibers“ show that the properties of such fibers cannot be explained using the average refractive index of the cladding because such scalar value cannot leads to dependence of the transfer function on orientation of the bending plane.

Also, different influence of the bending on transmission function of the conventional fibers and PCF documents that properties of the PCF are not based on the total reflection on core/cladding boundary with different refractive indexes.

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