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Section of gradient index multimode fiber as an elementary fiber grin lens

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In the work presented below it has been demonstrated that the section of the multimode fiber with gradient refractive index distribution in the core spliced to a singlemode fiber modifies the path of rays in a manner analogous to the GRIN type lens. Using a small section of graded-index optical fiber as a lens provides several advantages, including: small size, well matched fiber-lens diameter, stable fiber-lens interface, and a comparatively low cost of fabrication of an elementary fiber lens. The aim of the present paper is to discuss the technological process that enables fabrication of elementary fiber lenses with different lengths, and the measurement system for analysis of optical power density distribution in the light beam modified by an elementary fiber lens.

Keywords: gradient index lens, singlemode fiber, multimode fiber, optical power density distribution, beam diameter.

1. Introduction

The aim of the present work has been to prove that the section of the multimode (MM) optical fiber with gradient distribution of the refractive index in the core spliced to a singlemode (SM) fiber modifies the course of rays in a manner analogical to the GRIN lens. Formation of the distribution of the optical power in the transverse cross-section of the light beam at the exit of the elementary optical fiber lens depends on the length of the optical fiber section in relation to its basic parameter called period. On that relation depend basic technical functions that can be realized by an elementary optical fiber lens, such as collimation, focusing or image transfer [1].

Advantages resulting from the use of the section of the optical fiber MM as the elementary optical fiber lens are connected with its small size, with the fact that the diameter of the lens and the diameter of the singlemode optical fiber are perfectly matched, with mechanical stability of the joint of the interacting optical fiber elements (optical fiber splicing), relatively small outlay on fabrication of the optical fiber lens [2, 3].

The present paper discusses the technological process leading to the fabrication of elementary optical fiber lenses of different lengths and describes the experimental setup for analysis of the optical power distribution in the light beam modified by the lens. It also presents experimental results illustrating the change in the diameter in the transverse cross-section of the light beam in the length function of the elementary optical fiber lens.

2. Section of multimode optical fiber as an elementary lens

Later on in this work the technological procedures will be discussed that lead to modification of the light beam at the exit of telecommunication singlemode optical fiber using the elementary optical fiber lens. The elementary optical fiber lens is a section of multimode optical fiber [4], which has been spliced to a singlemode optical fiber [4] with the RXS X75 Siemens fusion splicing machine (see Fig. 1**a**). The next step included bonding joint optical fibers to a glass capillary measuring: internal diameter 2.5 mm and length 20 mm, using optical thermosetting adhesive glue Epo-Tek 353ND (Fig. 1**b**). The excess of multimode optical fiber was removed by means of a diamond wedge scriber (Fig. 1**c**). Afterwards the frontal end face of the multimode fiber was ground and polished. As a result of those processes, a good quality end surface of the multimode optical fiber was obtained (which means the surface of the elementary fiber lens) and the change of its length (Fig. 1**d**).

In the first phase of grinding, in order to remove the excess of optical fiber MM 15 μm abrasive paper was used. In order to obtain smooth and free from scratches surface of the frontal area of the glass capillary and the elementary optical fiber lens, 1.5 and 0.3 μm papers were used. However, microscopic observations that followed revealed defects of the surfaces in the shape of scratches. To reduce their size (length and depth), the next phase included polishing them wet with the use of polishing

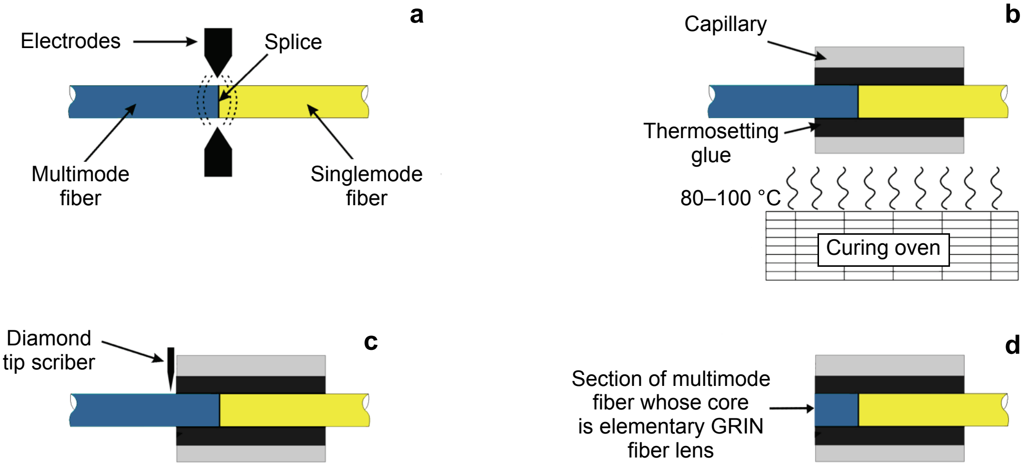
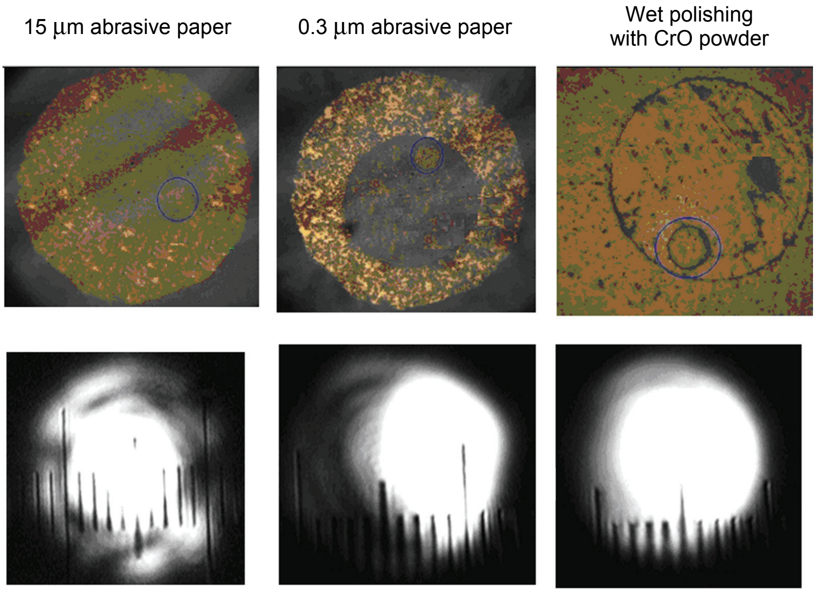


Fig. 1. Phases of fabrication of an elementary GRIN optical fiber lens (see text for explanation).



15 µm abrasive paper

0.3 µm abrasive paper

Wet polishing with CrO powder

Fig. 2. Quality of the frontal surface area of the elementary GRIN lens and optical power distribution in the transverse cross-section of a light beam.

powder (CrO) and distilled water. The change in quality of the frontal surface area of the multimode optical fiber functioning as an elementary lens is presented in Fig. 2.

Photographic documentation kept throughout the experiment shows that the change in the grain of abrasive paper and polishing material results in the improvement in the quality of frontal surface area and in consequence leads to reduction in the number and size of surface defects. Registered intensity distributions in the transverse cross-section of the light beam under investigation are to a lesser degree disrupted by diffraction and diffusion occurring on the surface imperfections.

3. Setup for measuring optical power distribution in the transverse cross-section of the light beam

The setup for measuring optical power distribution in the transverse cross-section of the light beam is presented in Fig. 3. The setup is block built, which facilitates possible failure removal and allows carrying out consecutive optimizations effectively.

The basic blocks of the measuring setup are as follows:

– source of light (laser diode RLD-65PC) with power system supply and SM optical fiber integrated with an elementary fiber lens;

– measurement module (0.01 microscopic plate etalon, measuring microscope with 5× objective and CCD camera);

– registration unit (thin film transistor liquid crystal display (TFT-LCD) and TV tuner connected to a laptop).

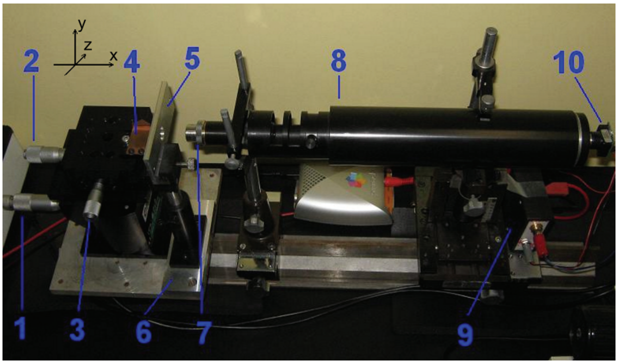


Fig. 3. Measurement module: 1, 2, 3 – positioning screws in axes *x*, *y*, *z*, 4 – grips holding capillary in place, 5 – 0.01 microscopic plate etalon, 6 – transition slab, 7 –microscope objective, 8 – measuring microscope, 9 – CCD camera power supply and video output, 10 – CCD camera.

Figure 3 presents a photograph of part of the measurement system comprised among others of such elements as: 0.01 microscopic plate etalon, measuring microscope with 5× objective and CCD camera.

The section of the singlemode optical fiber under investigation topped with an elementary lens was plugged into an RLD-65 PC diode working in the laser mode, which emits radiation whose length equals $\lambda = 656$ nm and full width at half maximum FWHM = 2.9 nm.

To ensure repeatability and the possibility of comparing measurements of light beam diameters, observations and registrations of optical power distributions were made in the plane of the microscopic plate etalon. By moving the microscope objective along the microscope axis it was possible to effect a sharp reproduction of plate etalon scales on the surface of the CCD camera. As the next step, micrometer screws were used to move the capillary with optical fibers so that the frontal surface area of the capillary found itself in direct contact with the microscopic plate etalon. Optical power distribution in the microscopic plate etalon plane was registered with the monochromatic CCD camera mentioned above. Camera image was watched on the TFT-LCD (thin film transistor liquid crystal display), and transmitted via TV tuner to the computer to be registered.

4. Measurements of optical power distribution in the transverse cross-section of a light beam

Tentative evaluation of the light beam diameter in the output plane of the elementary optical fiber lens was carried out using the microscopic plate etalon whose scale interval (minimum graduation) equals 10 μm. Because of the limited precision of such an evaluation, digital processing of the optical power distributions registered was conducted using GWYDDION 2.14 (www.gwyddion.net). Out of the programs menu a function was singled out thanks to which it was possible to produce intensity chart

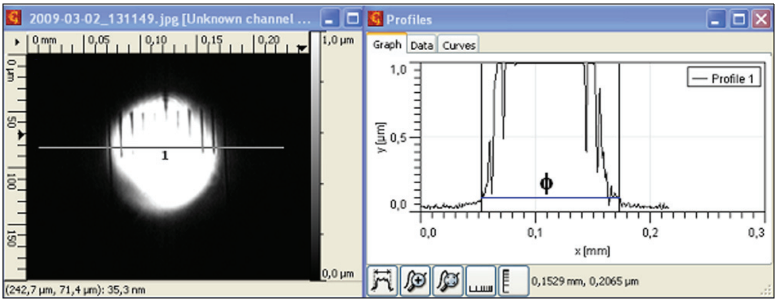


Fig. 4. Analysis of light intensity distribution using GWYDDION 2.14 program and designation of light beam diameter.

for a read in image in the form of the shades of grey (white color 100% intensity, black color 0% intensity) – see Fig. 4.

In analyses that were carried out it was assumed that the light beam diameter is designated by the section for which the drop in intensity equals 10% of the maximum value. For each of the registered power distributions intensity analysis was carried out in four axes and the end value of the light beam was defined as their arithmetic mean.

The graph presented in Fig. 5 illustrates changes in the light beam diameter in the function of the changing length of the elementary optical fiber lens.

It should be noted that precise determination of the length of an elementary fiber lens is encumbered with an error caused by ambiguous location of the plane of fusion splicing between SM and MM fibers. Fusion splicing of the fiber requires heating both fibers up to a temperature of 1600 °C in which thermal diffusion of the dopant takes place. In accordance with what has been said above, the value presented on the horizontal axis in Fig. 5 should be interpreted as a relative change in the length of the elementary fiber lens.

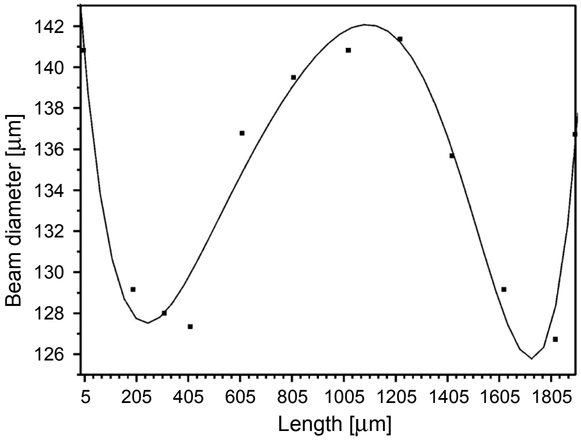


Fig. 5. Change in the light beam diameter in the function of the changing length of the elementary lens GRIN.

The analysis of the chart permits observing the periodicity of changes in the light beam diameter in its length function. Pitch value for an elementary optical fiber lens designated on the basis of the chart may be assumed in the order of 1600 μm. Theoretical considerations [5] indicate that the course of rays in centers with gradient distribution of the refractive index is described with a sinusoidal function whose period equals:

$$P = 2\frac{\Pi}{\sqrt{A}} \tag{1}$$

where: A – parameter of distribution of refractive index in GRIN lens equaling $A = g^2$, g – distribution constant represented by

$$g = \frac{\sqrt{2\Delta}}{r} \tag{2}$$

where: Δ – difference between refractive indexes for the core and clad of the optical fiber, r – radius of the optical fiber core.

In accordance with [4] catalogue data for the Corning optical fiber, the period length was designated as equal to 1739.5 μm. The difference between the value designated empirically and a theoretical one is mainly caused by imperfections occurring on frontal surfaces of the fabricated elementary fiber lenses.

5. Conclusions

Experimental results presented in this paper indicate that a section of a multimode optical fiber can function as an elementary optical fiber lens. Improvement in the precision of measurement of the light beam diameter can be achieved by introducing better technologies of polishing and grinding that will ensure greater smoothness of the frontal surface area of the lens, modification in intensity distributions caused by the presence of scales of the design pattern, elimination of the saturation effect of the registering camera, and limitation of the external influence of the disturbing light source.

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References

[1] EMKEY W.L., JACK C.A., *Analysis and evaluation of graded-index fiber lenses*, Journal of Lightwave Technology **5**(9), 1987, pp. 1156–1164.

[2] Chanclou P., Kaczmarek C., Mouzer G., Gautreau O., Thual M., Grosso P., *Design and demonstration of a multicore single-mode fiber coupled lens device*, Optics Communications **233**(4–6), 2004, pp. 333–339.

[3] Rawson E.G., Herriott D.R., McKenna J., *Analysis of refractive index distributions in cylindrical, graded-index glass rods (GRIN rods) used as image relays*, Applied Optics **9**(3), 1970, pp. 753–759.

[4] http://www.corning.com/opticalfiber/products/index.aspx.

[5] Szustakowski M., *Elementy techniki światłowodowej*, Wydawnictwa Naukowo-Techniczne, 1992 (in Polish).

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