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Microlenses formation by electric arc at the end of optical fibres, preserving the polarization of optical radiation

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Abstract. In this paper, the use of tapered optical fibers with preservation of radiation polarization for the fabrication of microlenses is considered. The contraction of the fibers is achieved by stretching optical fiber under the influence of the electric arc the splicing machine. This method allows to fabricate microlenses with a mode field diameter at the focal point of up to 2 μm and with a polarization extinction ratio (PER) coefficient of radiation at the output of the microlens of up to 40 dB. At the same time, the drop in the PER coefficient in the microlens is no more than 3 dB.

Keywords: fiber microlens, tapered fiber, fiber with preservation of polarization, polarization extinction ratio, focal length, mode field diameter

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Формирование микролинз с помощью электрической дуги на торце оптических волокон, сохраняющих поляризацию оптического излучения

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Аннотация. В настоящей работе рассматривается применение суженых конических оптических волокон с сохранением поляризации излучения для формирования микролинз. Сужение волокон достигается путем растяжения оптического волокна под воздействием электрической дуги сварочного аппарата. Данный способ позволяет получать микролинзы с диаметром поля моды в точке фокуса до 2 мкм и с коэффициентом поляризационного затухания излучения на выходе из микролинзы до 40 дБ. При этом падение коэффициента поляризационного затухания в микролинзе составляет не более 3 дБ.

Ключевые слова: волоконная микролинза, коническое волокно, волокно с сохранением поляризации, коэффициент поляризационного затухания, фокусное расстояние, диаметр поля моды

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Introduction

Optical constrictions, in the form of tapered fibers, are of great interest for a variety of applications. One of the first applications for such fibers was the creation of fiber-optic splitters and connectors. Over time, tapered fibers began to be used in medicine, chemical and biological sensing, construction, and engineering industries as sensors for physical quantities [1].

Currently, optical constrictions are produced using two main methods: chemical etching [2, 3] and thermal methods [4]. Chemical etching with hydrofluoric acid allows you to achieve the desired geometry by controlling several parameters, including the percentage concentration of the acid, the temperature during the etching process, the time of etching, and the amount of acid applied to the surface being etched. The main disadvantages of this method are the negative effects of acid on human health, as well as the requirement for special equipment for chemical etching.

The thermal method of producing tapered conical fibers is one of the most commonly used. This method involves an electric arc the fiber fusion splicer to soften the glass of the optical fiber. The advantages of this method include the high speed of producing the elements and their relatively low final cost. In this method, the following parameters are controlled: the power and duration of the electric arc, the rate of fiber stretching, and the time over which the stretching process occurs. In this paper, a method for the fabrication and measurement of microlenses parameters using optical constrictions on fibers while maintaining the polarization of optical radiation is proposed [5].

Fabrication method

The Fujikura FSM-100P the fiber fusion splicer is used to create microlenses using optical constriction. This device is designed for splicing optical fibers in laboratory conditions. As an additional option, it is possible to create optical constrictions with different geometric dimensions. The general process of creating fiber microlenses is illustrated in Fig. 1.

At the first stage, the cleaned optical fiber is placed in the fiber fusion splicer. Using the standard Fujikura FSM-100P mode, the next step is to fabricate a constriction (Fig. 1, *a*). The formation of an optical constriction is a process that involves several steps. First, the two ends of the fiber are connected by splicing. Then, with continuous exposure to an electric arc, the fiber is softened and stretched until a constriction with the desired geometric parameters is achieved. In the absence of an electric arc, a rupture occurs in the tapered area of the constriction. The result of the rupture is two segments of optical fiber with conical ends (Fig. 1, *b*). To form a hemispherical surface from two segments, one of the segments is chosen that does not contain a splicing site for the two fibers. The resulting tapered surface at the end of the fiber is additionally melted by the electric arc of the fiber fusion splicer. The fused section of the optical fiber, under the action of surface tension forces, forms a symmetrical convex surface that acts as a microlens (Fig. 1, *c*).

Measurement of microlenses characteristics

The focal length is the distance between the end of the lensed fiber and the point where the light beam focuses. The microlens converts the outgoing Gaussian beam into a converging beam at a certain distance, which is known as a necking. The focal length is directly related to the

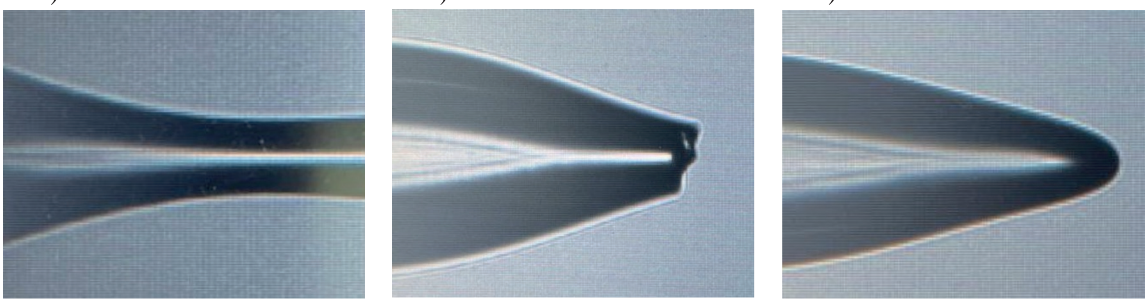

Fig. 1. Process of creating fiber microlenses: fabrication a constriction (*a*); rupture in the tapered area (*b*); fiber microlens (*c*)

length of the necking formed. The most widely used precision method for measuring focal length is the Fabry-Perot method [6], in which an outgoing beam of optical radiation is reflected from a mirror and returns back to the fiber, while experiencing interference. The value of the output power is fixed, and as a result, an optical power distribution is achieved, which depends on the length of the Fabry-Perot cavity.

The mode field diameter (MFD) in an optical fiber determines the area through which the main part of the optical radiation energy is transmitted. The MFD, for a fiber with a microlens at the end, is located in the area of the constriction formed at the focal length from the edge of the lens. An infrared profilometer is used to quickly and relatively accurately estimate the size of the MFD fiber microlens. It is a high-resolution infrared camera that uses a lens to capture images and a software suite to process the recorded signals. Measurement of the MFD of a fiber microlens is performed by image processing with power distribution of the optical signal coming out of it.

The polarization extinction ratio coefficient is the most important parameter for optical fiber-based microlenses while maintaining radiation polarization. The numerical value of this coefficient is used to evaluate the ability of the microlens to maintain the polarization of radiation. To date, the method of cross-polarization of PER measurement is known [7, 8]. It is based on the principle that polarized light is guided into the core of a single-mode optical fiber through a polarizer. The axis of polarization of the polarizer is aligned with one of the principal axes of the fiber, ensuring that the polarization of the radiation is maintained. The light that comes out of the fiber passes through the analyzer, where the proportion of output signal power is measured. This power is linearly polarized along two axes, called the fast (P_{max}) and slow (P_{min}) axes. The PER coefficient value is calculated using the formula:

$$\text{PER} = 10\lg\left(\frac{P_{max}}{P_{min}}\right) \quad (1)$$

In this paper, a meter FIBERPRO ERM 2200 is used to evaluate the PER coefficient fiber microlenses. This device allows you to measure the numerical value of PER coifficient in real-time. The decrease in the PER coefficient of the lensed fiber is the difference between its value at the microlens entrance and its value at the exit.

Results and Discussion

Produced domestically optical fibers with polarization preservation of radiation were used to create a small batch of fiber microlenses. Unlike foreign analogues, these fibers have the property of preserving the PER coefficient up to 40 dB. During the manufacturing process, 10 lensed fibers were obtained and the repeatability of their parameters was evaluated.

The focal length of the obtained fiber microlenses varied in the range from 20 to 26 microns. The values of the mode field diameter at the focus point ranged from 2.0 to 2.5 microns. The optical losses introduced by a single microlens were no more than 3 dB. With all the above characteristics, the resulting products retained the radiation polarization. The decrease in the PER coefficient was not more than 3 dB. Based on the numerical values of the key characteristics of the microlenses obtained, it can be concluded that using an electric arc for creating batches up to 10 units is acceptable.

Conclusion

In this article, the use of optical constrictions for the formation of fiber microlenses while maintaining radiation polarization was considered. Using the electric arc of the fiber fusion splicer, lenses were formed using optical fibers with a spot size of 2 microns at the focal point. This method allows us to obtain microlenses with a PER coefficient of up to 40 dB at the output and a polarization drop of no more than 3 dB in the lens.

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