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Threshold temperature optical fibre sensors

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ABSTRACT

This paper presents a new approach to manufacture a threshold temperature sensor based on a biconical optical fibre taper. The presented sensor employs the influence of variable state of concentration of some isotropic materials like wax or paraffin. Application of the above- mentioned materials is an attempt to prove that there is a possibility to obtain a low-cost, repeatable and smart sensor working as an in-line element. Optical fibre taper was obtained from a standard single mode fibre (SMF28®) by using a low pressure gas burner technique. The diameter of the manufactured tapers was 6.0 ± 0.5 µm with the length of elongation equal to 30.50 ± 0.16 mm. The applied technology allowed to produce tapers with the losses of 0.183 ± 0.015 dB. Application of materials with different temperature transition points made it possible to obtain the threshold work at the temperatures connected directly with their conversion temperature. External materials at the temperatures above their melting points do not influence the propagation losses. For each of them two types of the protection area and position of the optical fibre taper were applied.

1. Introduction

HE development of optical fibre technology over the last century is significant. This technology can be divided into two parts: telecommunication [1] and non-telecommunication [2] application. The telecommunication part is of special importance today and is oriented towards increasing the transmission data capacity. In a non-telecommunication area the scientific research is oriented towards manufacturing sensors and set-ups made form optical fibres. Nowadays, there is an increasing interest in low-cost, in-line optical fibre sensors of a variety of physical quantities like temperature, pressure ET. Large expectation for a fast development of optical fibre sensors led to elaboration of photonic crystal fibres (PCF) [3–5], however the cost of their production is much higher than the standard ones. Additionally, PCF fibres are not prepared for the direct connection to the most of accessible equipment which requires making a splice to the standard structures [6]. However, the process of splicing with low losses is well-elaborated, an extra process using a splicer designed for PCF is required. The detectors employing PCF fibres present a structure of air holes which can be filled with materials sensitive to the external factors.

Since the taper allows controlling a light beam propagation in a fibre, there is a very interesting possibility of connecting such a structure with the external material characterized by variable state of concentration. Thus, different interferometric temperature sensors using the phenomenon of multimodal interference in tapered region and based on an optical fibre taper have been proposed [6–9,20]. Another way of sensors' designing is covering the taper waist with noble metal layers [6,8,9], (platinum, gold etc.). In these case the phenomenon of a surface plasmon resonance effect is used [12–15]. For the main advantage it can be noticed that thin layers (20–100 nm) give possibilities to change many parameters like: dispersion, sensitivity, phase difference etc. [12]. However, a thin layer of metal introduces a high attenuation in dependence on the optical fibre taper and thickness of metal which can be over dozen of dB. From the technological point of view manufacturing of metal layers generates the highest cost of production.

The well-known method of manufacturing sensors is also the use of fibre Bragg gratings [16]. The advantages of such solution is sensitivity of a measurement factor. In spite of well know how of this technology all process is more expensive than presented in this paper.

It should be mentioned that for all mentioned above sensors, the wave range is narrow – of dozen of nm and for a different wavelength it has to be redesigned. Solution presented in this paper gave possibility to work in a wide range of over few hundred nm along with the low cost.

The idea of making research presented in this paper was based on the use of different materials with a changeable state of matter connected with the tapered standard optical fibre SMF28®.

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In this paper we present the results of a new approach to the technology of the low cost threshold temperature sensors. In Section II the applied technology and technological view of a set-up for manufacturing of the biconical optical fibres' taper is described. An approach to protect such a structure, as well as a possibility of combining it with external materials is proposed. In Section III the experimental results using the manufactured sensor with a commercial available external materials in two different ways of packing of the tapered fibre are presented. Section IV contains conclusions and additional information about the development of the presented works.

2. Tapering process

The most important and interesting task in a non-telecommunication application is a method to obtain a direct access and possibilities for influence and to change the propagation parameters of the optical beam run in an optical fibre. All manufactured optical fibres, the standard ones, as well as the photonic ones guide an optical beam using material or geometrical properties. Additionally, the manufacturing process is oriented towards obtaining the propagation losses as small as possible. These properties require an adequate dimension of the core and cladding which does not allow propagation of optical beam outside the fibre's structure. Manufacturing of an optical fibre with an external diameter below several micrometers is very expensive (i.e. the method of protection of such a fibre) and there does not exist an absorptive market for that product.

The tapering technology is relatively easy and gives a possibility to obtain a continuous monitoring of the changes in the light propagation through the fibre during its tapering [11,17–19].

The set-up developed in the laboratory of the Institute of Applied Physics at MUT for biconical taper manufacturing FOTET II– Fibre-Optic Taper Element Technology [18] (Fig. 1) is based on a fibre's elongation in a low-pressure gas burner. Fibre's heating up to its melting temperature is obtained in a propane-oxygen flame whereas the fibre's elongation is realized by uniform fibre axial stretching in two points located symmetrically outside the heating point.

The main advantage of FOTET II is a possibility of its application for manufacturing different types of biconical tapers (point, short or long length of taper region) for all types of fibres including telecommunication, photonic crystal fibres, as well as plastic fibres. The above types of tapers are connected with a flame brush movement: point – punctual fibre heating by placing an immobile flame under the fibre, short waist – an oscillating flame brush moves along the determined fibre distance with the oscillation amplitude correlated with the taper waist length, and long waist – an increased distance of the flame brush travelling during the tapering process with a constant oscillation amplitude equal to the length of the taper waist [17]. Process of the fibre elongation can be controlled by the flame movement connected with speed of two stretching engines. The required length of the taper waist can be obtained, as well. The set-up allows manufacturing elements of the length of the taper's main region up to 200 mm with the waist diameter even below one micrometer. The taper's elongation system was designed to avoid the fibre's damage (especially breaking) and to get a perfect biconical taper which is achieved by a permanent monitoring of the light propagation through a fibre and the application of a special antigravitation unit for controlling the flame distance from the taper. Extra-units for fibre holding and positioning allow manufacturing some advanced elements based on the biconical taper like X type couplers with a required output light power distribution, the in-line polarization switcher and the in-line optical fibre polarizer.

From the point of view our investigations the most interesting ones are the tapers with a long taper waist region with a diameter of about few single micrometers. Another important property of the manufactured tapers is a possibility to obtain very low insertion losses which can be achieved by a proper forming of the taper region including the area of connection of an unstretched fibre with the taper waist region. The scheme of a taper region is presented in Fig 2.

The fundamental parameters of the biconical taper which have direct influence on light beam propagation in the structure are: radius of the taper waist (r_w), length of taper waist (L_w) and length of taper transition (z_o). Whereas the first two parameters have influence on the access to the light in the fibre's structure for its intentional modifications, the ratio of the two last parameters have influence mainly on the structure's loss. Below is presented the general relation between above parameters for long waist biconical structure:

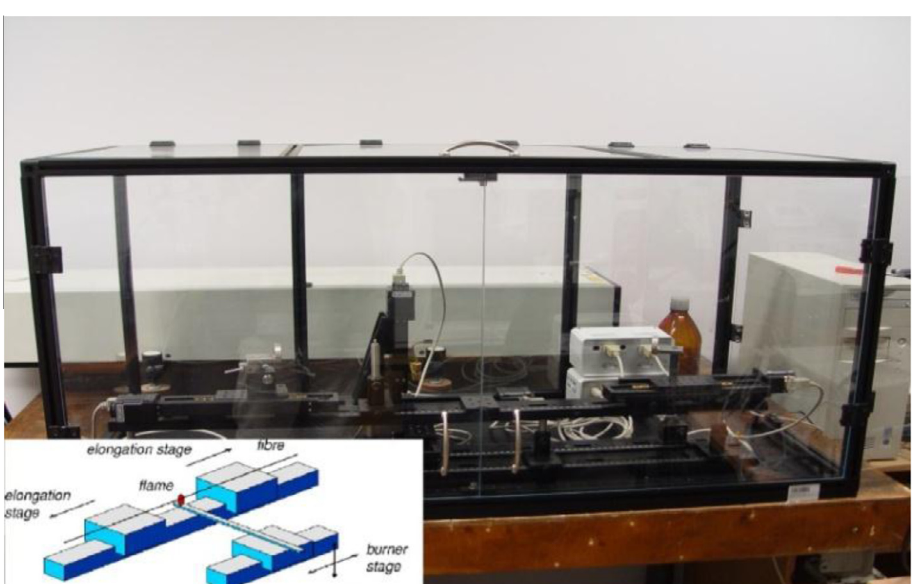

Fig. 1. Set-up for manufacturing biconical fibre tapers and a functional FOTET scheme [18].