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Optical power 1 × 7 splitter based on multicore fiber technology

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ABSTRACT

Multicore and microstructured fibers open a new door for designing all-fiber telecom components. In this article we propose a design of an optical power splitter based on the phenomenon of power coupling in the tapered splice between a single-core (SMF-28) and a seven core fiber (MCF-7), which was originally developed for spatial division multiplexing telecommunication systems. Comprehensive numerical analysis is presented and backed up with an experimental demonstration.

1. Introduction

The optical power splitter is an important element of every optical fiber communication network. However there are no versatile solutions available. Optical power splitter technologies used commercially consist of fused biconical tapering (FBT) [1,2] and a planar lightwave circuit (PLC) [3,4]. FBT splitters have a limited number of output ports due to technological difficulties related to manufacturing splitters with more than 4 outputs. What's more, the production of such splitters is not automated and carries a high risk of failure. On the other hand, PLC splitters have a greater number of outputs, but due to the need to connect planar and fiber technology, PLC splitters are more vulnerable for external factors (like temperature) which can induce loss caused by the fiber misalignment [5].

Besides these two commercially used technologies, other approaches are proposed in the literature. They aim to eliminate the drawbacks of existing solutions. One of the proposals presented is based on applying the specially designed multicore fibers with coupled cores [6,7]. Also designing planar structures based on polymer waveguides [8] or photonic crystals [9] in order to develop an optical power splitter has already been presented. A different approach, based on tapering the splice between a single core and a multicore fiber, was reported by L. Yuan [10]. In this solution the light couples from a standard single mode fiber to all cores of the multicore fiber which allows a splitter with a high number of outputs to be designed in all-fiber technology. The construction is uncomplicated and durable and the technology required to fabricate the device is available. However, the first results presented by L. Yuan [10] showed that the splitter fabricated within this technology exhibits high loss and poor uniformity (understood as a ratio of minimum and maximum power levels in specific cores of the multicore fiber), as well as, poor stability (understood as a difference of power level in specific core while tapering a splice) basing on the graphs presented in [10].

The aim of this paper is to present a comprehensive description of light the propagation phenomenon in the tapered splice between single-core and multicore fibers and the optical power splitter based on it. We report the design of a 1 × 7 optical power splitter and provide the numerical analysis of this design which explains the observed features. The validity of the numerical analysis was confirmed by an experimental demonstration of the fabricated element.

2. Principles

The concept of the optical power splitter presented in this paper is based on a microstructured seven core optical fiber [11–13]

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designed for spatial division multiplexing (SDM) systems (Fig. 1). Unlike in the paper presented by L. Yuan [10] where 3 and 4-core fibers with coupled cores were used, in the fiber presented here, air holes are used to isolate the cores, resulting in low cross-talk between cores (less than −30 dB @ 1550 nm) and high stability of the proposed element. What is more, the fiber is insensitive to twisting and bending, thanks to the fiber microstructure which enables uncoupled propagation in the seven separated cores.

A hexagonal arrangement of the cores and air holes enables the fiber to be produced using the stack-and-draw method. Additionally, in order to connect the new components with existing fiber networks, performing low loss splices is required. To guarantee that, the diameter of the cores and the outer diameter of MCF-7 are comparable with the ITU-T G.652 recommendations. This means that low loss splices between SMF-28 and MCF-7 can be made with standard single mode fibers.

Fig. 2 presents the scheme of the tapered splice between the SMF-28 and MCF-7. Light is introduced into the core of the SMF-28 (Fig. 2A) where is guided without loss (apart from attenuation loss which are neglected) to the taper region, which propagation loss are considered later in the article. In the taper region (Fig. 2B and C) the difference in refractive indices between the cores and the cladding of both fibers is not sufficient to provide light confinement in the core area. Consequently, light propagates also in the cladding in the tapered region. This effect is desirable as it effects in light splitting into all the cores of the multicore fiber. In the untapered region the rebuilt MCF-7 structure (Fig. 2D) ensures uncoupled propagation in each of the seven cores, so the 7-fold power distribution is retained. The taper transition regions are sufficiently long to fulfill adiabatic conditions of the taper length, which was calculated by eigenmode expansion method in order to ensure low loss light propagation (i.e. lower than 0.02 dB) through the splitter.

In the splitter based on MCF-7, power transfer occurs only in the tapered region, where the air holes are collapsed and the fiber's diameter is decreasing and is relatively small. After applying taper protection the power distribution of the splitter is retained and light propagation through the splitter is stable. This feature makes the presented solution both exceptional and promising as it results in the power coupling effect only being observed in the tapered region. The light does not couple between the cores of the untapered fiber, unlike in previous studies.

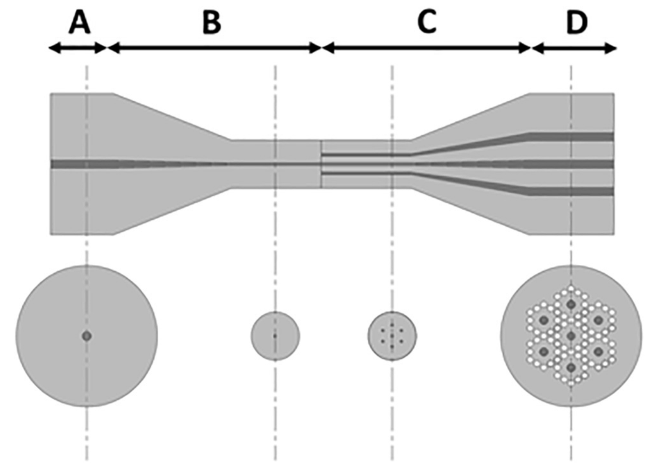

Fig. 2. Scheme of the tapered region and the splice between the SMF-28 and MCF-7 and cross-sections of the fiber's structure at points along the fiber taper. A- the SMF-28. B- the tapered SMF-28. C- the tapered MCF-7. D- the MCF-7. Dimensions on the scheme do not reflect real sizes.

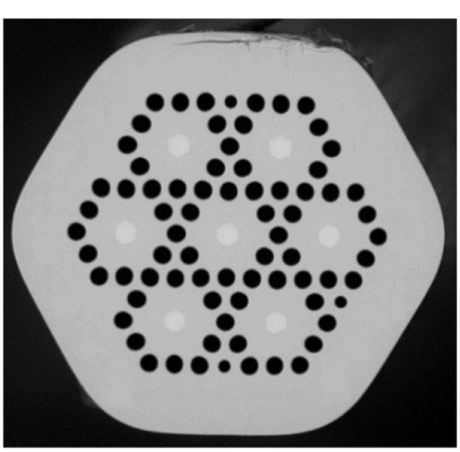

Fig. 1. Scanning electron microscope (SEM) image of MCF-7. The measured fiber dimensions are: d_{core} = 6.2 μm, Λ = 7.6 μm, d_{hole} = 5.6 μm and the clad diameters equal 121 μm and 130 μm. GeO_2 doping of the core is 4% mol.

3. Numerical simulation results and analysis

We carried out a simulation of the tapered region of the splice (Fig. 3). We used the eigenmode expansion method, which is suitable for strongly varying photonic structures. All simulations were performed for a 1550 nm wavelength. Simulations were carried out for three dimensional structures but for the sake of clarity only two of the external cores are visible in the images presented (Fig. 3a).

Fig. 3a shows the distribution of electric field amplitude in the tapered splice of the SMF-28 and MCF-7. Fig. 3b shows the characteristics of the power level in the cores at the output of the multicore fiber as a function of the taper waist length. The simulated taper (Fig. 3) had taper transition regions equal to 5 mm, taper waist length equal to 5 mm and tapered waist diameter equal to 23 μm. Our simulation shows that most of the power stays in the central core, and hence the splitter based on this taper would suffer from low uniformity. The theoretical loss in the simulated taper equals 0.2 dB and uniformity, understood as power ratio between the minimum and maximum power in the specific cores of the MCF-7 (for the case presented in Fig. 8 the uniformity is the ratio of power levels in the core 1, maximum power level, and 2, minimum power level and equals 6.1 dB). What is more, changing the taper waist length would not influence the output power distribution (Fig. 3b).

Low uniformity is inevitable as a fundamental mode, propagating in the SMF-28, is recreated in the tapered multicore structure, and hence most of the power stays in the central core. In this case power transfer between the cores is allowed only in the up-transition tapered MCF-7 region which is not long enough. Decreasing the taper waist diameter will not improve the performance of the splitter. It is caused by the fact that as soon as light is not guided in the core of SMF area but by the fundamental mode of taper region at the glass/air boundary the power division in the taper waist region remains constant. The only place where power distribution between cores can be influenced is the up-transition taper region where supermodes are excited. What is more, as the cores are not guiding, light in the taper waist region propagates on the edge of the air and glass which makes this kind of taper highly sensitive to any external factors.

It is possible to improve splitter's performance through increasing the taper waist diameter. In this case, our simulation (Fig. 4) unveils that even though the taper diameter was significantly