Optical microfibers: fundamentals and applications

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Abstract: Transmission properties and applications of single mode optical microfibers are reviewed.

OCIS codes: (060.2340) Fiber optics components; (060.2370) Fiber optics sensors; (999.9999) microfibers.

1. Introduction

The interest in optical microfibers has been recently renewed [1-14] giving rise to the development of microfiber photonics. Very low-loss optical microfibers are usually fabricated by tapering the conventional silica optical fibers [1,2,4,11]. Microfiber photonics uses microfibers as building blocks for the fabrication of optical devices. It is feasible that, eventually, the microfibers can be assembled into complex multi-functional low-loss photonic circuits. At present, the simplest devices composed of microfibers have been demonstrated experimentally and/or considered theoretically. This paper reviews several theoretical and experimental results on optical microfibers and microfiber-based devices, concentrating on the results obtained at OFS Laboratories. Primarily, the linear transmission properties of single mode optical microfibers and their applications are considered.

2. Fundamentals

The ideal optical single mode microfiber (MF) is straight, uniform, and cylindrically symmetric. For such a microfiber, the Maxwell equations are separable and the linear theory is well developed [15,16]. The deviation from the ideal shape may cause propagation losses, polarization effects, and non-trivial behavior of the evanescent field. The evanescent field can significantly expand with the decreasing of the MF diameter [15,16] and is very sensitive to smallest perturbations. An adiabatically deformed MF has exponentially small losses [17]. The simplest types of deformation are bending and axially symmetric tapering (Fig.1(a), (b)). In adiabatically bent MFs, radiation loss is defined as a tunneling rate through an effective barrier, which exponentially vanishes with a bend radius (Fig. 1(a)) [15]. A similar effective barrier can be defined for adiabatic MF tapers in exceptional cases only [18]. However, the loss in adiabatic MF tapers can be determined quite simply with exponential accuracy [17]. Low-loss coupling between adjacent MFs is easier to achieve if the MFs are adiabatically tapered and the contact region contains a cross-section of equal propagation constants (Fig. 1(c)). In this case the transmission power between MFs is determined by the Landau-Zener formula [19,20]. Similarly, in multimode adiabatic tapers having complex cross-sectional refractive index distribution, the mode transition takes place primarily near points of pseudo-crossing of the propagation constants.

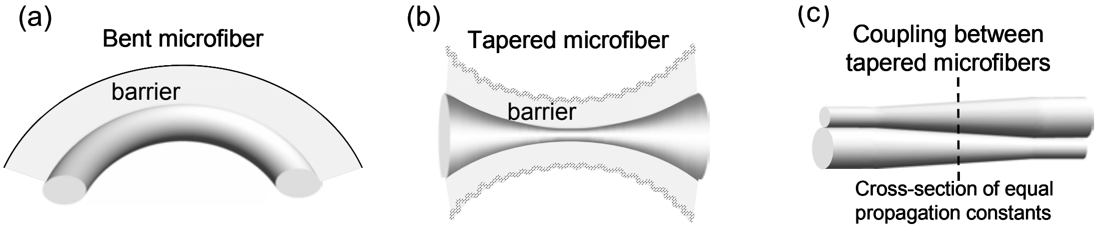

Fig. 1. (a) – Bent microfiber; (b) – Tapered microfiber; (c) – Coupling between tapered microfibers.

3. Applications

An important application of a MF is the generation of the supercontinuum [21,22,4,8] which is based on the strong confinement of radiation in MFs causing enhancement of non-linear effects. The first demonstration [21] employed a MF in the form of a micron-sized core surrounded by air holes in a photonic crystal fiber. A MF secured inside the photonic crystal fiber is more robust than a free MF and can be used for fabrication of tunable filters, polarizes, and sensors [23,14]. A direct application of a thin MF is using it as a sensor of the ambient medium by probing the environment with the evanescent field [12,13]. In particular, a MF was implemented as a very accurate sensor of the optical fiber diameter using the setup illustrated in Fig. 2(a) [24,25]. Engineering the MF shape with appropriate evanescent field distribution may be used for atom trapping [6]. Coiling a MF into a high quality factor self-coupling loop resonator enhances the MF sensitivity to ambient changes and represents the simplest device of microfiber-based photonics [11] (Fig. 2(b)). A more advanced multifunctional MF device is a microfiber coil theoretically investigated in [3,26] and shown in Fig.2(c). The MF enables almost lossless excitement of the high quality factor whispering gallery modes in optical microcavities [27,28], which are extremely sensitive to changes of the ambient medium and can be used as sensors as well. In particular, Fig. 2(d) shows a setup for local optical surface characterization, which employs a MF and a microsphere resonator [29]. Simplest MF photonic devices, e.g., a MF

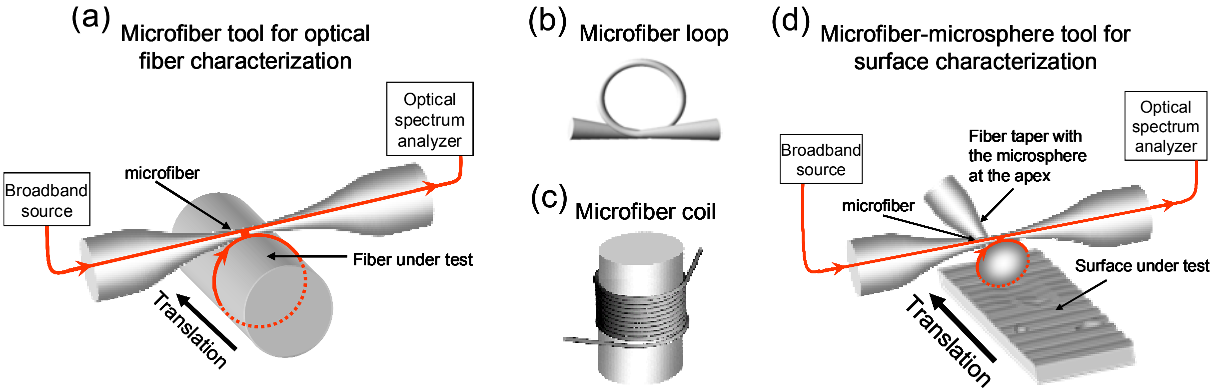

Fig. 2. (a) – Microfiber loop; (b) – Microfiber coil; (c) – Microfiber tool for optical fiber characterization; (d) – Microfiber-microsphere tool for surface characterization.

loop resonator, can be realized in air [11]. Prospectively, the creation of complex MFs structures needs the development of a robust assembling technology based on the lower index substrate material with high optical transparency. The low-loss silica MFs positioned at the aerogel surface have been demonstrated in Ref. [9]. The fabrication of the low-loss higher-index compound-glass MFs, which could be used for assembling MFs at regular silica substrates, was reported in Ref. [10].

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