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Regular Articles

Space-efficient fiber ribbon composed of reduced-cladding single-mode fibers

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ABSTRACT

We develop a space-efficient single-mode fiber (SMF) having a cladding diameter of only 82 μm. This SMF has the depressed-cladding index profile and its mode-field diameter, cutoff wavelength, and macro bending loss are designed to be similar to those of the conventional step-index SMF. We fabricate this reduced-cladding SMF and measure its optical and mechanical characteristics. The results show that this fiber satisfies major specifications of the ITU-T G.654 recommendations. We also fabricate a fiber ribbon by using twelve of these reduced-cladding SMFs. Compared to a commercial fiber ribbon made of twelve standard SMFs having 125-μm cladding diameter, this fiber ribbon can improve the spatial efficiency by ~75%.

1. Introduction

Recently, the space-division-multiplexing (SDM) technology has emerged as a promising solution to the upcoming capacity crunch problem by drastically increasing the capacity of an optical fiber. Various types of multi-core fiber (MCF) and multi-mode fiber (MMF) have been developed for this purpose [1–4], and ultra-high-capacity transmission experiments have been already demonstrated by using these optical fibers [5–8]. However, this technology is still in its infancy as there are many remaining issues for the use in practical systems. In particular, it is difficult to imagine that this technology can solve the imminent space constraints of the cost-sensitive data center and access networks in the near future [9]. A straightforward alternative to alleviate this problem before the SDM technology becomes mature would be the use of optical fibers having reduced physical size. The outer diameter of the standard optical fiber used today is 250 μm including the buffer coating, while its cladding diameter is 125 μm. Previously, there have been some efforts to reduce this physical size of the optical fiber and cable by reducing the thickness of buffer coating [10,11] or packing the bend-insensitive fibers tightly into a cable [12]. However, to further improve the spatial efficiency, it would be necessary to reduce the physical dimension of optical fiber itself too.

In this paper, we attempt to minimize the cladding diameter of an optical fiber. We demonstrate that the cladding diameter of an SMF can be reduced to 82 μm without sacrificing the optical and mechanical characteristics by using the depressed-cladding index profile. The results show that this fiber satisfies all the major optical and mechanical specifications of the ITU-T G.654 recommendations. We also fabricate a fiber ribbon by using twelve of these reduced-cladding SMFs. The fabricated fiber ribbon has ~75% higher spatial efficiency than a commercial fiber ribbon made of standard 125-μm SMFs. Thus, we expect that this new fiber ribbon can be used for the development of a space-efficient fiber-optic cable having small diameter and high packing density.

We note that there have already been some efforts to develop the reduced-cladding fiber with a cladding diameter of 80–100 μm for the use as a compact dispersion-compensating fiber (DCF) [13]. Its primary objective was to minimize the physical dimension of the DCF module. In comparison, we develop the reduced-cladding SMF for the use as the transmission fiber. Thus, although both of these fibers have similar cladding diameters of ~80 μm, the optical and mechanical requirements of these fibers as well as their index profiles are different from each other. In fact, to the best of our knowledge, this is the first report indicating that the reduced-cladding SMF can satisfy the major optical and mechanical specifications of the transmission fiber listed in ITU-T G.654 recommendations. It is also demonstrated for the first time that a fiber ribbon can be fabricated by using such proposed reduced-cladding fibers to improve the spatial efficiency of fiber-optic cables.

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2. Design of reduced-cladding SMF

Our objective is to minimize the cladding diameter of SMF. However, the fiber becomes more susceptible to macro bending as the cladding diameter is reduced. Thus, to make the fiber insensitive to the bending, it is necessary to decrease the mode-field diameter (MFD). However, this approach is not desirable since it can increase not only the splicing loss with the conventional SMF due to the MFD mismatch, but also fiber nonlinearities. On the other hand, the depressed-cladding fiber is known to be less sensitive to the bending than the step-index fiber when their MFDs are similar [14,15]. Thus, we attempt to minimize the cladding diameter of SMF having a depressed-cladding index profile.

Fig. 1 shows the refractive index profile of a depressed-cladding fiber used for the design of the reduced-cladding SMF in this work. In this index profile, the refractive index of the inner cladding (i.e., the cladding immediately surrounding the core) is lower than that of the outer cladding. Here, we denote the core diameter, outer cladding diameter, index difference between the core and outer cladding, and index difference between the inner and outer claddings by d_{co}, d_{cl2}, Δ_1, and Δ_2, respectively. The refractive index and thickness of the coating are assumed to be 1.477 and infinite. We first design the diameter of the inner cladding (d_{cl1}). Fig. 2(a) shows the macro bending loss of the depressed-cladding fiber as a function of d_{cl1}. We estimate the imaginary refractive indices of the fiber under bent condition by using the finite element method (FEM) while varying d_{cl1}, and then calculate the bending losses. In this calculation, d_{co}, Δ_1, Δ_2, and d_{cl2} are set to be 9 μm, 0.4%, 0.04%, and 80 μm, respectively. We also assume that the bending radius and wavelength are 10 mm and 1625 nm, respectively. The results show that the bending loss is decreased as d_{cl1} increases, but it levels off when d_{cl1} is larger than 45 μm. To explain this behavior of bending loss, we illustrate the equivalent refractive index profile of the fiber under bent condition in Fig. 3. It shows two exemplary

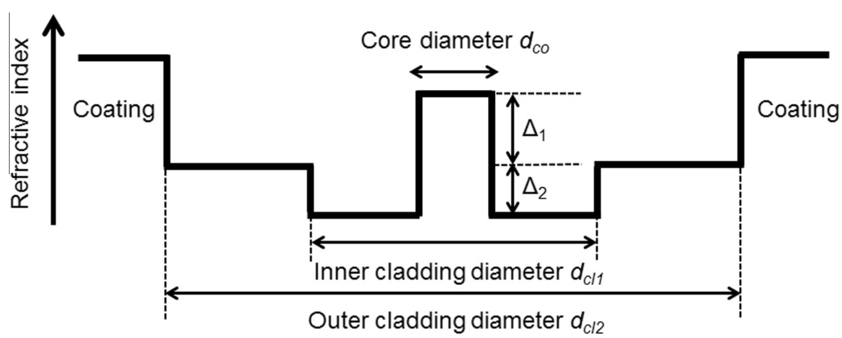

Fig. 1. Refractive index profile of the depressed-cladding fiber.

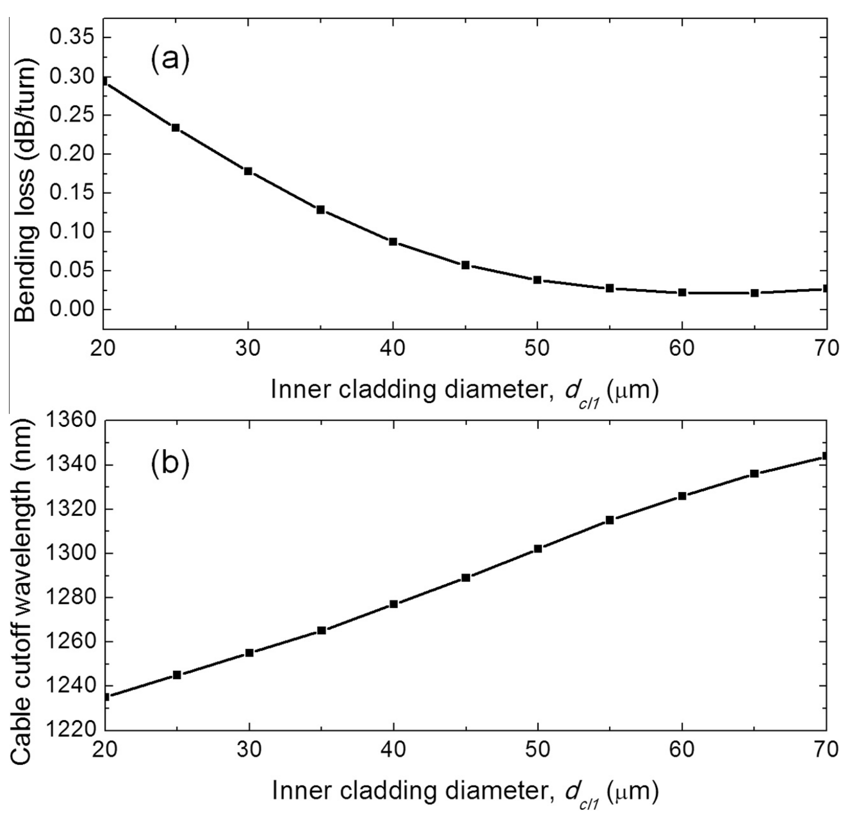

Fig. 2. (a) The macro bending loss calculated at a bending radius of 10 mm (@ 1625 nm) as a function of the diameter of inner cladding. (b) The cable cutoff wavelength versus the diameter of inner cladding.