Extended Abstract



# Design of Holey Optical Fibers Insensitive to Bending Used in FTTH Networks

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**Abstract:**

Fiber-to-the-home (FTTH) technology provides the ability to transmit telecommunication data at a maximum level. In order to achieve this technology, fibers with the lowest bending and splice losses are required. In this paper, the losses of bending and splice joints in single mode optical fibers have been investigated with a variety of designs, such as holey fibers, nanoscale optical fibers, and micro structured optical fibers. By comparing the losses of these fibers, we chose the best fiber with the lowest losses in designing FTTH that is used for two purposes of reducing costs and improving optical network performances. These fibers have advantages such as low bending radius, wavelength and mode field diameter, which can be effective in minimizing bending losses.

**Keywords:** FTTH, Holey and micro structured optical fibers, nanoscale optical fibers, bending loss and radius, splice loss

## 1-Introduction

Bend-insensitive single-mode optical fibers are well suited for use in fiber-to-the-home (FTTH) networks, as they can minimize installation costs [1]. For in-home installation and wiring, the optical fibers employed must exhibit a minimum bending loss of less than 0.1 [2]. To reduce the bending loss of single-mode optical fibers, hole-assisted fiber designs have been proposed [3,4]. In this paper, we compare three types of low-bending-loss fiber designs used in FTTH systems. Based on the reported measurements, we present the minimum bending loss of each fiber along with its dependence on fiber parameters—including bending radius, mode field diameter, and wavelength—and finally introduce the optimal fiber design for application in FTTH technology.

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## 2- Investigation of the Design of Bend-Insensitive Optical Fibers

For applications in fiber-to-the-home (FTTH) networks, the optical fiber must exhibit low bending loss, a short cut-off wavelength at higher-order modes, and a mode field diameter (MFD) matched to that of standard optical fibers. These characteristics are achieved by HF fibers.
Recently, photonic crystal fibers, known as holey fibers or microstructured optical fibers, have attracted particular attention. These types of optical fibers possess unique properties that are not present in conventional optical fibers.

### 2-1 Splice Loss Between Single-Mode Fiber and Holey Fiber

In this section, we aim to demonstrate that the holey fiber (HF) can be connected to the single-mode fiber (SMF) with minimal splice loss. The holey fiber has been selected for splicing because the mode field diameters (MFDs) of the two fibers match, resulting in lower installation losses.According to the calculations performed using the following equation:

$$L_s = -20\log_{10}\frac{2w_{SMF}w_{HF}}{w_{SMF}^2 + w_{HF}^2} \qquad (1)$$

where $W_{SMF}$is the mode field diameter of the SMF and $W_{HF}$is the mode field diameter of the HF. In Figure (12-2), the splice loss of the holey fiber is calculated and plotted as a function of the mode field diameter, where the mode field diameter of the SMF is assumed to be 2.5 μm.

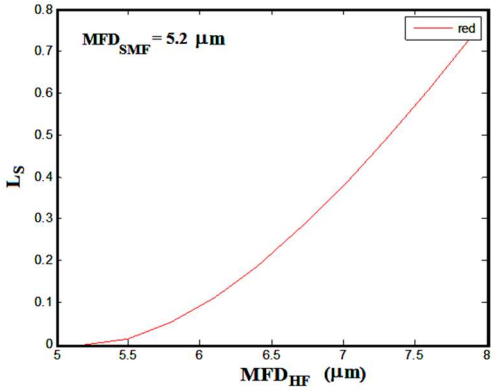



**Figure 1.** Splice loss versus mode field diameter of the holey fiber [8].

Holey fibers are a suitable option for splicing with SMF, as they possess all the essential parameters required to achieve minimum bending loss and splice loss. These parameters are presented in Table (1) [8].

**Table 1.** Parameters related to the splicing of single-mode fiber to holey fiber [8].

| | |
|---|---|
| Splice loss | 0.08 |
| Bending loss(mm) | 0.011 |
| Bending radius(mm) | 5 |

| | |
|---|---|
| Cut-off wavelength(μm) | 1.1 |
| Operating wavelength(μm) | 1.55 |
| Mode field diameter(μm) | 9.3 |

## 2-2-Investigation of the Design of Nanoscale-Engineered and 12-Hole Microstructured Optical Fibers

The nanoscale-engineered optical fiber is a new technology that has been added to the conventional optical fiber design space. This fiber consists of a germanium-doped core and a nanoscale-engineered ring in the cladding. The ring is composed of nanometer-scale air lines along the fiber, which are processed into the glass around the fiber and merged into one. These air rings have diameters of several hundred nanometers and are designed to be filled with air segments

A microstructured optical fiber with novel features and outstanding optical components can exhibit bend-insensitive characteristics; and if designed, as shown in Figure (2), a 12-hole microstructured optical fiber can minimize the bending loss to its lowest value.

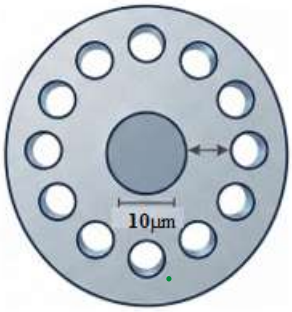



Figure 2. Optical structure of the 12-hole optical fiber [4]

In Table (2), the bending loss is presented for different bending radii and different numbers of turns at a specific wavelength.

**Table 2.** Parameters related to the bending loss of the 12-hole microstructured optical fiber [4]

| Bending radius (mm) | Number of turns | Wavelength (nm) | Bending loss (dB) |
|---|---|---|---|
| 2 | 1 turn | 1550 | 0.89 |
| | | 1625 | 0.86 |
| 3 | 10 turns | 1550 | 0.73 |
| | | 1625 | 0.044 |
| 5 | 1 turn | 1550 | 0.049 |
| | | 1625 | 0.047 |

**3-Discussion and Investigation**

Figure (3) shows, both experimentally and theoretically, the bending loss characteristics of the HF as a function of bending radius at a wavelength of 1.55 μm. It is observed that the bending loss of the HF is much lower than that of the SMF, particularly for a small bending radius of 5 mm at 1.55 μm, where its value is 0.011.

Nanoscale-engineered optical fibers have been fabricated with nanometer dimensions. The obtained results are consistent with the OVD process. The optical characteristics of this type of optical fiber are presented in Table (3). The properties of this optical fiber have been investigated at wavelengths of 1310 and 1550 nm.

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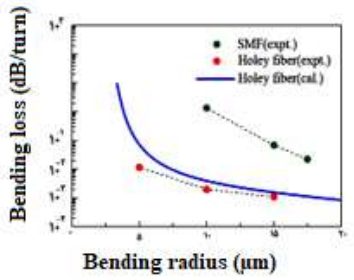



**Figure 3.** Bending loss behavior versus bending radius for HF and SMF at 1.55 μm [9].

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**Table 3.** Optical characteristics of the nanoscale-engineered optical fiber [12].

| | | |
|---|---|---|
| Dispersion slope (ps/nm²·km) | 0.09 | 0.09 |
| Zero-dispersion wavelength (nm) | 1315 | 1315 |
| Cable cut-off wavelength (nm) | 1225 | 1225 |
| Attenuation coefficient (dB/km) | 0.20 | 0.34 |
| Dispersion (ps/nm·km) | - | 17.6 |
| Mode field diameter, MFD (μm) | 9.7 | 7.8 |
| Wavelength (nm) | 1550 | 1310 |

The bending loss of the microstructured optical fiber was calculated as a function of bending radius for 1, 10, and 30 turns, and is shown in Figure (4)

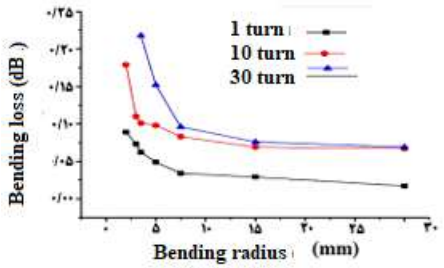



**Figure 4.** Bending loss versus bending radius for different turns at a wavelength of 1.55 μm [11].

In another figure, the attenuation of the microstructured optical fiber at wavelengths of 1310 and 1550 nm was calculated as a function of wavelength and is shown in Figure (5) [12].

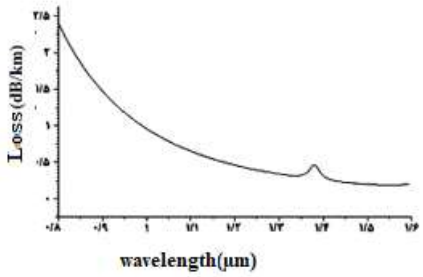



**Figure 5.** Spectral attenuation of microstructured optical fibers [12].

A summary of the comparative analysis is presented in Table (4) [4, 7, 5].

**Table 4.** Comparison of nanoscale-engineered, holey, and 12-hole optical fibers [8, 7, 5].

| Fiber type | Bending radius (mm) | Wavelength (nm) | Bending loss (dB) |
|---|---|---|---|
| Nanoscale-engineered fiber | 5 | 1550 | ~0.1–0.3 |
| Holey fiber | 5 | 1550 | 0.011 |
| 12-hole fiber | 5 | 1550 | 0.049 |

**5-Conclusion**

We examined three selected optical fibers in terms of their optical structure, advantages, and applications in fiber-to-the-home networks, and compared their bending losses with one another at the same wavelength and bending radius.

Based on the analysis of the conducted investigations, all three types of optical fibers exhibit different bending losses at a bending radius of 5 mm and a wavelength of 1550 nm. The 12-hole optical fiber, with a bending loss of 0.049 dB, has a lower bending loss than the other two fibers at the specified wavelength and bending radius. Therefore, it can be the most suitable option for application in fiber-to-the-home networks.

For further investigation, in order to reduce the bending loss of single-mode optical fibers used in fiber-to-the-home networks, reducing the mode field diameter (MFD), using a compact cladding, reducing the air-filling fraction, and new designs of holey fibers can be investigated.

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