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Ultra-compact highly nonlinear fiber module technologies

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Abstract

We summarize the state of the art down-sized HNLF modules and their applications. This paper provides the theoretical limits of reducing cladding diameter of HNLF. Also, ultra-compact HNLF modules and SC light generation using this module is introduced.

1 Introduction

Highly nonlinear fiber (HNLF) [1] is a key component holding great promises in applications in the all-optical signal processing [2] [3], broadband light sources [4], optical pulse compressors [5] etc., which are essential for future high-speed transmission systems.

To produce commercially viable HNLF requires more compact modules. Previously it was possible, using 90μm HNLF, to develop a module size of a 3.5-inch floppy disk [6], but any further reduction in module sizes would require even finer fiber. Since HNLF has an extremely small mode field diameter (MFD), it is advantageous in terms of down-sizing but any major reduction in cladding diameter would require investigation of the theoretical design.

In this paper, we report our study of theoretical limit of down-sizing of HNLF and characteristics of fabricated down-sized HNLF and HNLF modules. Furthermore, we introduce our experimental result of supercontinuum (SC) generation by the fabricated compact module.

2 Theoretical approach to down-sized design

Transmission in optical fibers occurs generally by utilizing the difference in refractive index between the core and the cladding to confine the light in the area of the core. The intensity of this light decreased exponentially as the distance from the core becomes greater, but when the cladding diameter (cladding thickness) is insufficient, the transmission mode reaches the interface between the cladding and the coating and large leakage loss occurs. Thus in reducing cladding diameter it is necessary to clarify the cladding diameter required with respect to the design of the core.

By means of simulation using the finite element method (FEM), we analyzed the relationship between cladding diameter and leakage loss. In this simulation we used the refractive index profile of the core actually adopter in HNLF and that used in ordinary SMF. For each core design, simulations were carried out for leakage loss when cladding diameter was changed with no change in core diameter.

Figure 1 shows the relationship between cladding diameter and leakage loss obtained by simulation, demonstrating that the thinner the cladding diameter the greater the leakage loss. Comparing HNLF and SMF we can see that even an HNLF with a cladding diameter of 40μm has lower loss than 125μm SMF.

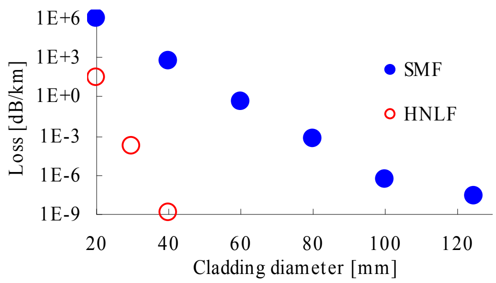

Fig.1 Cladding diameter and leakage loss

Figure 2 shows the leakage loss under macro bending. It should be noticed that as the cladding becomes thinner and light confinement weaker, the ability to withstand bending changes. However, it can be seen that an HNLF having a core designed for extremely strong light confinement will be only slightly susceptible to the effects of bending, and even when the cladding is thinner the ability to withstand bending will not change to any degree.

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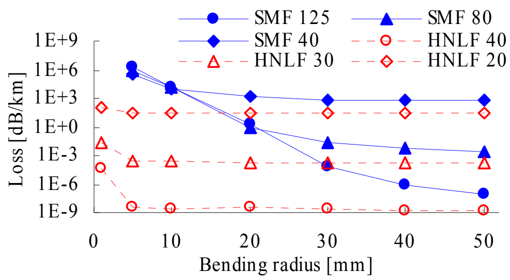

Fig.2 Leakage loss with macro bending

Thus we may conclude that for HNLF, as long as cladding diameter is 40µm or more, leakage loss characteristics will be as good as or better than SMF with a cladding diameter of 125µm

3 Characteristics of down-sized HNLF

Table 1 shows the characteristics of one of our prototype down-sized HNLFs designed and fabricated based on study of down-sizing. Cladding diameter of this HNLF is 51µm and sufficient cladding thickness is realized. Coating diameter is 85µm by the effect of down-sized cladding, and volume of this HNLF is reduced to 1/10 comparing to conventional fibers with 250µm coating. The basic optical characteristics shown in Table 1 are similar to those for an HNLF with a cladding diameter of 125µm having the same core design.

Table1 Characteristics of down-sized HNLF (@1550nm)

Cladding diameter	[µm]	51
Coating diameter	[µm]	85
Dispersion	[ps/nm/km]	-0.78
Dispersion slope	[ps/nm^2/km]	0.017
λ_0	[nm]	1610
γ (SPM)	[W^{-1}km^{-1}]	13.8
Attenuation loss	[dB/km]	1.14
PMD	[ps/km$^{1/2}$]	0.05

Bobbin size can be reduced drastically by small cladding and coating diameter of HNLF. Figure 3 shows small bobbins for down-sized HNLF. 400m of HNLF can be accommodated in the coin sized bobbin.

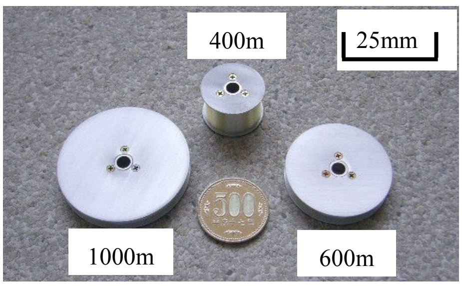

Fig.3 Down-sized bobbins and ¥500 coin.

4 SC generation by down-sized HNLF

We conducted SC light generation experiment using fabricated ultra-compact module achieved by means of down-sized HNLF. SC light generated in the normal dispersion domain of HNLF is low noise, and since it has a good SNR, it is promising for applications in optical signal processing or as a broadband light source.

SC light generation experiment was carried out using the fabricated 1000m HNLF module shown in figure3. In this experiment, the repetition rate of the pulse source was set at 10GHz, the pulse width was 2.1ps. Figure 4 shows the SC spectrum at an input power of 100mW. The spectrum bandwidth at the points where power decreased 20dB form peak power was 32nm, and ripple around the pump wavelength was sufficiently small at about 3dB.

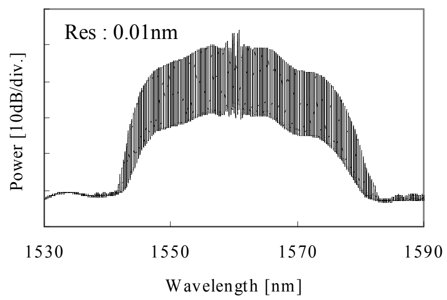

Fig.4 SC spectrum of ultra compact HNLF

5 Summary

We introduced recently reported down-sized HNLF. Theoretical discussion of the limits of reducing cladding diameter and characteristics of ultra-compact HNLF modules realized by means of this theory are briefly reviewed. We also show the result of SC light generation experiment which is carried out using fabricated ultra-compact modules, and satisfactory characteristics are confirmed.

6 References

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