Improvement of FWM Conversion Efficiency by SBS-suppressed Highly Nonlinear Dispersion-Decreasing Fiber with a Strain Distribution

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Abstract

We demonstrated 8dB SBS-suppression and a uniform dispersion simultaneously by down-sized dispersion-decreasing HNLF applying distributed strain. FWM wavelength conversion efficiency of -2dB was achieved with single CW pumping.

Introduction

Optical signal processing utilizing nonlinear effects occurring in optical fibers, such as four-wave mixing (FWM), have been well studied and reported. In these applications, Silica-base highly nonlinear fibers (HNLFs) which have enhanced nonlinearity and precisely controlled dispersion characteristics have been widely used since an efficient nonlinear process can be achieved [1]. Even though the HNLFs can be used as an effective nonlinear medium, higher pump power is required to improve the efficiency of nonlinear process. However, the maximum pump power is limited by stimulated Brillouin scattering (SBS) [2]. Therefore, the SBS suppression has been strongly demanded.

In this paper, we propose a novel HNLF and a technique to suppress SBS for an efficient nonlinear process and report the characteristics of the SBS-suppressed HNLF and results of FWM wavelength conversion experiments.

Design of SBS-suppressed HNLF

For SBS suppression, several techniques such as changing core diameter along the length of the fiber [3] or using Al_2O_3 doped core [4] have been reported. However, changing core diameter is not necessarily suitable for the aspect of dispersion control of the HNLFs, while a HNLF with Al_2O_3 doped core has a very large attenuation loss at this moment.

The Brillouin gain spectrum (BGS) can be shifted to higher frequency by applying the strain to the fiber [5]. By this effect, the BGS can be dispersed by giving distributed strain to the fiber and SBS suppression is expected. Down-sized HNLFs [6] are particularly useful for this purpose because an efficient strain distribution is realized with lower tension.

When a HNLF is stretched by applying a tension, the core diameter was changed by this effect, results in the change of dispersion properties [7]. Therefore, dispersion characteristics of HNLF are distributed by distributing the strain. To compensate the dispersion distribution, we designed dispersion-decreasing HNLF (HNL-DDF) to realize uniform dispersion after applying the strain distribution.

Characteristics of fabricated HNL-DDF

Table 1 shows the characteristics of fabricated HNL-DDF. A cladding diameter is reduced to 71μm for an effective strain distribution, and changed at the rate of 0.4μm/100m to realize dispersion decreasing structure. Figure 1 shows the calculated dispersion characteristics of the fabricated HNL-DDF. Dispersion of the input end (0m) of this fiber was 0.5ps/nm/km at 1550nm. The Dispersion was gradually decreasing toward the output end (120m) and the dispersion of the output end was -0.1ps/nm/km.

Cladding diameter (IN)	[μm]	71.7
Cladding diameter (OUT)	[μm]	71.2
Dispersion (average)	[ps/nm/km]	0.17
Attenuation loss	[dB/km]	0.39
Nonlinear coefficient	[$W^{-1}km^{-1}$]	12

Table 1 : Characteristics of HNL-DDF (@1550nm)

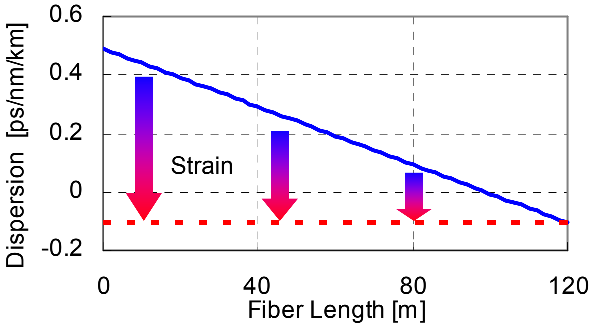

Figure 1: Calculated dispersion of HNL-DDF (@1550nm)

Strain distribution experiment

We carried out a strain distribution experiment using the fabricated down-sized HNL-DDF. A strain distribution was realized by winding HNL-DDF into the bobbin while changing spooling tension. The maximum tension applied was 1% stretching level at the input end. The Applied tension was changed gradually to the lower level toward the output end. An average dispersion of the HNL-DDF was changed from 0.17 to -0.11ps/nm/km as designed after applying the strain distribution.

Figure 2 shows the measured BGSs of the original and the strain distribution setting. The FWHM line

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width of the 1st peak of the BGS was broadened to 320MHz from the original spectrum of about 20MHz due to the strain distribution effect. In this spectrum, the Brillouin peak gain was decreased and SBS suppression was expected. In case of the strain distributed setting, the BGS was flattened, which indicates that the constant stress variation along whole length of the HNL-DDF was realized.

Figure 3 shows the results of SBS threshold measurement. The CW light at 1550nm with a line width of 200kHz was used in this measurement. As shown in the Fig.3, SBS threshold was improved by 8dB with the strain distributed HNL-DDF.

We measured the dispersion characteristics, BGS and SBS threshold of the strain distributed HNL-DDF after 6 months from the fabrication. We confirmed that these characteristics were not changed and the stable strain distribution had been maintained.

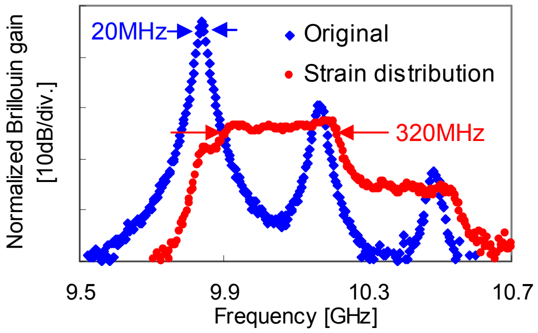

Figure 2: Measured BGS of HNL-DDF

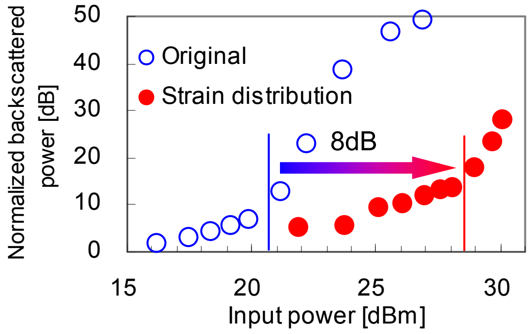

Figure 3: Measured SBS threshold of HNL-DDF

Wavelength conversion experiment

Wavelength conversion experiments were performed with the fabricated strain distributed HNL-DDF. First, we measured zero dispersion wavelength (λ_0) by FWM method. The measured λ_0 was 1559nm, and pump wavelength (λ_P) was set to this wavelength. The intensity of pump and probe light were set to 18dBm and -2dBm, respectively.

Figure 4 shows the measured normalized conversion efficiency. The 3 dB bandwidth of 40nm was observed. From this result, we confirmed that a uniform dispersion was realized under the strain distribution setting. Figure 5 shows the dependences of the conversion efficiency on the pump power (P_P). Signal wavelength and power (λ_S, P_S) were set to 1554nm and 0dBm, respectively. An Output idler power (P_I) obtained by changing P_P was plotted as conversion efficiency

P_P is limited to less than 21dBm without SBS suppression. Therefore, conversion efficiency is also limited to around -20dB in the conventional setting. On the other hand, in case of the strain distribution setting, P_P was increased by the SBS suppression and conversion efficiency became proportional to the P_P even for higher pump power region over 21dBm. As the result, conversion efficiency was increased over 16dB, and the maximum conversion efficiency of -2dB was obtained.

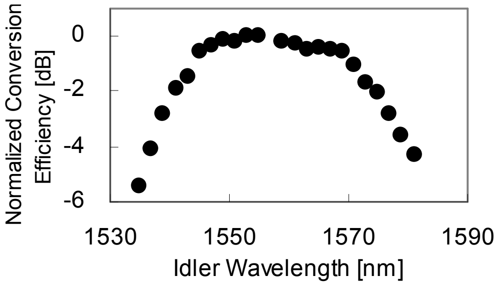

Figure 4: Normalized wavelength conversion efficiency of strain distributed HNL-DDF

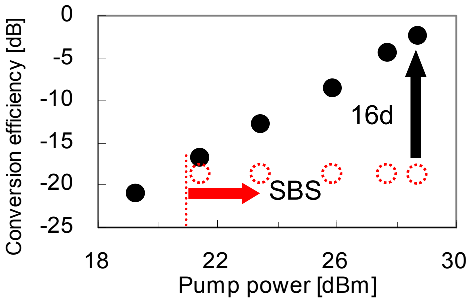

Figure 5: Conversion efficiency of HNL-DDF

Summary

Down-sized HNL-DDF which was designed to realize a uniform dispersion under a strain distribution was successfully fabricated. SBS of 120m HNL-DDF was suppressed by 8dB by applying the strain distribution and the uniform dispersion characteristics were confirmed by the FWM wavelength conversion experiment. Conversion efficiency was increased drastically by the SBS suppression, and the maximum conversion efficiency of -2dB was obtained.

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