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Effective stimulated Brillouin scattering suppression by phase modulation in fibers

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Brillouin gain spectrum (BGS) and Brillouin frequency shift (BFS) of different fibers are measured by self-heterodyne detection. The stimulated Brilloin scattering thresholds (SBSTs) of fiber are measured with different lasers. The effect of the length of fiber on SBST is considered. The SBST is improved by 17.65 dB with phase modulator (PM) at three different frequencies. Moreover, the influences of the core dopant and the uniform of the core diameter along the length of fiber on SBST are also discussed. These results are particularly important for fiber optics parametric amplifier (FOPA) and the effect of slow light.

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1. Introduction

In recent years, the suppressed stimulated Brillouin scattering (SBS) in optical fibers has attracted extensive attention due to that is harmful fiber optical communication systems. SBS is a significant nonlinear effect caused by the interaction that occurs between acoustic waves and light waves in optical fibers [1]. The most prominent origin of SBS is a physical phenomenon called electrostriction, which manifests itself in a variation of medium's density by action of light [2]. When the continuous wave pumps (CW) pumps with power close to the Watt level are launched in highly nonlinear fibers of a few hundred meters long, the SBS process is easily excited, and as a consequence, the backscattering power increases dramatically, so the input power was limited very low values and then any amplification or conversion process would be canceled. In order to increase the SBS threshold (SBST) several methods have been demonstrated. Some known passive techniques, such as air gaps [3], stress distributions [4], tapered cores [5], isolators [6], based on cross-phase modulation process [7], or using thermal noises [8] could perhaps be used for this purpose. Some promising approaches are to design fibers for which the overlap between the optical and acoustic modes of interest is smaller than for conventional fibers. Such as creating a sinusoidal strain variation in a fiber, creating a staircase strain distribution in an highly nonlinear fiber (HNLF), bismuth oxide fibers have an advantage compared to silica-based fibers when it comes to SBST [9] and heavy core doping with aluminum oxide and change the structure parameters of photonic crystal fibers (PCF) [10-18]. The general way of increasing the SBST can be found in Ref. [19].

Here, we experimentally investigate the BGS of various fibers using a self-heterodyne detection [20]. And BFS is measured by a high resolution optical complex spectral analyzed (OCSA). The influence of the length of fiber and the linewidth of laser on SBST is also considered. The SBST is improved 17.65 dB by phase modulator (PM) with three frequencies. Our results show that the length zero dispersion wavelength of fiber are not affect BFS. And the levels of spectrum of laser are more flat, the effectives of increasing SBST are more obviously. Those may useful for suppressing SBS and slow light based on SBS.

2. Theory

The approximate solution of spatial evolution of the pump input pump P_p and the back reflected Stokes P_s wave can be described as [2, 21]:

$$P_s(0) = \frac{4\pi}{3}\Theta e^{q/2}\left\{q\left(1+\frac{e^{-\alpha L}}{2}\right)\left[I_0\left(\frac{q}{2}\right)-I_l\left(\frac{q}{2}\right)\right]-(1-e^{-\alpha L})I_l\left(\frac{q}{2}\right)\right\} \quad (1)$$

where I_l are the modified Bessel functions of the order

$l,q = \kappa(1-e^{-\alpha L})$, κ Boltzmann's constants，L is the length of fiber, α is the optical loss coefficient of the fiber, $\Theta = \frac{\kappa T v_p w_1}{2 v_1}$ is the effective noise power per pump polarization state in the bandwidth corresponding to the BGS of the dominant acoustic mode, T is the fiber temperature, $v_p = c/\lambda_p$ is the pump frequency, λ_p is the pump wavelength, *c* is the speed of light, v_1 and w_1 are the frequency shift and the FWHM width of the 1th line in the BGS, respectively.

The SBST power is common defined with $\mu = 1$ or $\mu = 0.01$. Here, we use the value $\mu = 0.01$ to calculate the SBST. Thus, the SBST condition is

$$P_s(0) = \mu P_0 \tag{4}$$

where the $P_s(0)$ nonlinearly depends on the input pump power P_0 according to Eq.(1).

By Eq.(4), the threshold power can be illustrated as:

$$P_{th} = \frac{q}{\gamma L_{eff}} \tag{5}$$

where $L_{eff} = \frac{1-e^{-\alpha L}}{\alpha}$ is the effective length of the fiber.

3. Experimental setup

The experimental setup is sketched in Fig. 1. The TL is a tunable laser source with a high coherence, and an isolator served to protect the laser oscillator from radiation back reflected. A polarization controller is used to control the polarization of the laser. The optical spectrum is broadened and the SBST is increased by the phase modulator (PM: COVEGA LN65S), radio frequency amplifiers (RFA) and radio frequency signal (RFSG). A high power EDFA was used to ensure that the power was high enough to reach the SBS threshold. The power of the EDFA can up to 35dBm. The amplified spontaneous emission (ASE) noise was filtered using the optical bandpass filter (OBPF) with a full-width at half-maximum (FWHM) bandwidth of 0.9 nm. The launching power could be adjusted using the variable optical attenuator (VOA). The input and reflect power of the high nonlinear fibers (HNLF) can be measured by optical power meter (OPM). TL and Brillouin backscattering are detected in the fast-response photodiode (Hewlett-Packard PDT0313). The electric signal from detector is analyzed by the Electric Spectrum Analyzer (ESA, Agilent E4440A). The spectrum of TL and the SBS are analyzed by the OCSA (Apex AP2443B).

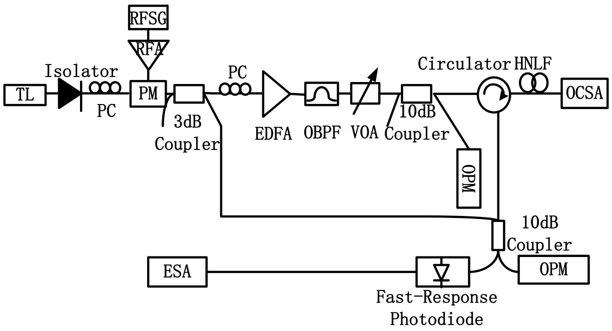
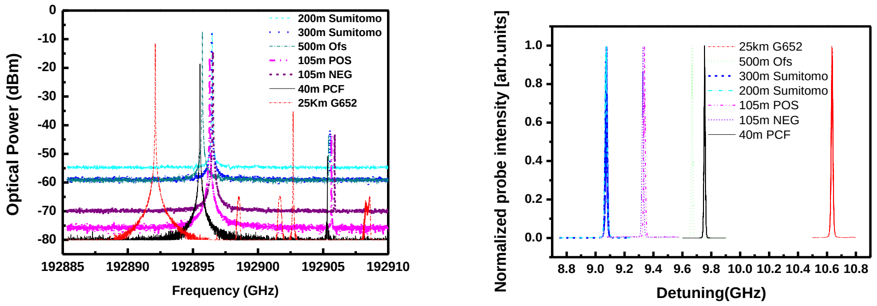


Fig. 1. The configuration of the experimental setup TL, tunable laser; PC, Polarization controllers; RFA, radio frequency amplifiers; RFSG, radio frequency signal; PM, phase modulator (COVEGA LN65S); EDFA, high power erbium fiber amplifier; OBPF, 0.9 nm optical bandpass filter; VOA, variable optical attenuator.

First of all, we measure the BFS and BGS of fibers. Secondly, two TLs (Ando AQ4321D and Santec TSL 510H) are used to analyze the influence linewidth on the SBST. Thirdly, OCSA is used to analyze the different between PM on and off. Fourthly, choosing the best modulation frequency and power, we remark the SBST between the PM on and off.

4. Results and discussions

We characterized a range of different fibers including 200 and 300 m Sumitomo HNLF, 500 m Ofs HNLF, 105 m Yogc NEG fiber, 105 m Yogc POS fiber, 25km Yogc G652 fiber and 40 m photonic crystal fiber (PCF). The BFS and BGS of the fibers are shown in Fig. 2 and Table 1.



(a) (b)

Fig. 2. The BFS and BGS of fibers (a) BFS (b) BGS.

Table 1. The BFS and BGS of fibers (a) BFS (b) BGS.

Fiber Types	200m Sumitomo	300m Sumitomo	500m Ofs	105m POS	105m NEG	40m PCF	25km G652
BFS(GHz)	9.114	9.114	9.694	9.346	9.346	9.771	10.546

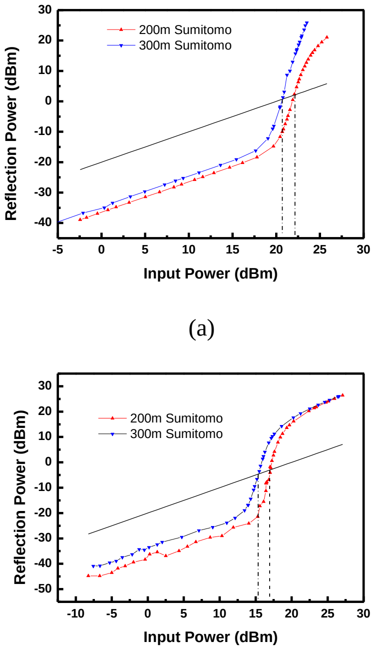
(a)

Fiber Types	200m Sumitomo	300m Sumitomo	500m Ofs	105m POS	105m NEG	40m PCF	25km G652
BGS(MHz)	15.489	12.31	9.809	12.574	11.361	8.98	14.253

(b)

As seen from Fig. 2 (a) and Table 1 (a), the BFS of different fibers. Comparing 200 m and 300 m Sumitomo HNLFs, the BFS is not related with the length of fiber. Comparing 105 m POS and 105 m NEG, the BFS is also not related with the dispersion of fiber. These agree with Eq.4. A high germanium concentration decreases ν_A and increases the nonlinear parameter. In Fig. 2 (b) and Table 1 (b), the BGS of different fibers. Comparing 200 m and 300 m Sumitomo HNLFs, though the FWHM value of gain bandwidth is inherent to particular fiber [22] and the FWHM of BGS depend on the numerical aperture of fiber [23], due to the drawback production technical of fiber, the FWHM of 200 m and 300 m Sumitomo HNLFs are different.

Laser linewidth and the length of fiber play a significant role in SBST. To investigate the effects of laser linewidth and the length of fiber on SBST, two different lasers and different lengths of Sumitomo fiber are used to measure SBST. The results of experiments are shown in Fig. 3.



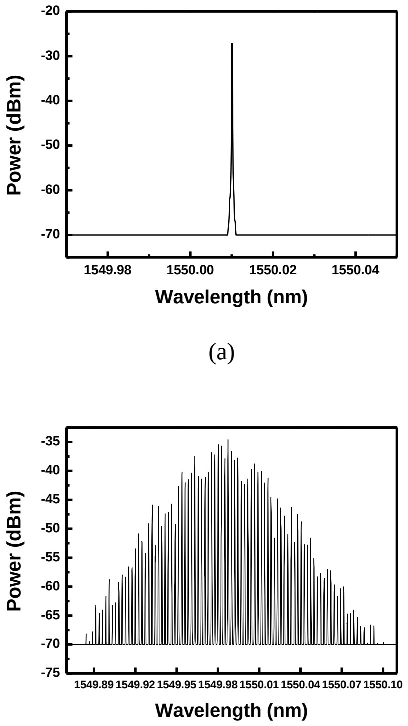
(a)

(b)

Fig. 3. Reflected power measured as a function of input power for different fibers and lasers. The SBST can be obtained from definition (20), which is shown by a black solid line ($\mu = 0.01$), (a) Ando AQ4321D laser and (b) Santec TSL 510H laser.

The linewidths of Ando laser and Santec laser are 100 MHz and 50 MHz. For different lasers, the difference of SBST is about 5 dB. For different lengths of fibers, the difference of SBST is about 1.6 dB. These results agree well with Eq.21. So broadening the linwidth of laser is an effective way to increasing SBST.

PM is used to broad the linwidth of laser and high-resolution OCSA is used to measure the spectrum of laser. The results are shown in Fig. 4.



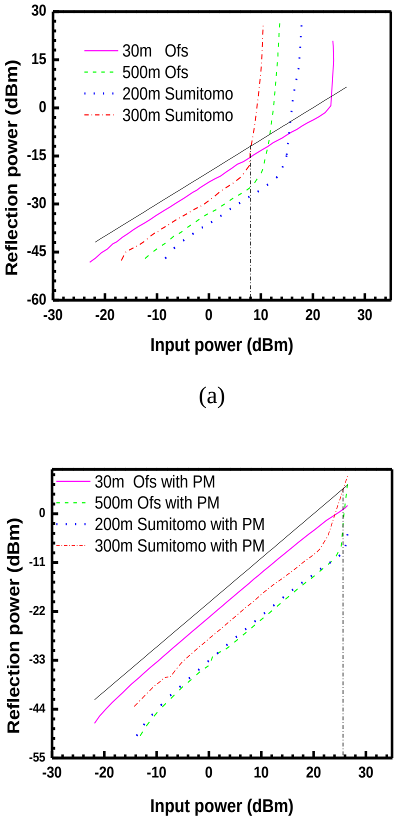
(a)

(b)

Fig. 4. (a) The spectrum of laser (b) the spectrum of laser after PM.

In Fig. 4, the frequencies of RFSG are 294, 896, and 2702 MHz. By PM the spectrum of laser is obviously broadened. So the SBST can be effectively increased. For easily seeing the improvement of SBST by PM, we use the narrow type of Ando laser, the linwidth of laser can less than 1MHz. The difference SBSTs between without PM and with PM are illustrated in Fig. 5.

In Fig. 5, when the PM is not used, the SBST of 30 m Ofs HNLF, 500 m Ofs HNLF, 200 m Sumitomo HNLF and 300 m HNLF are 7.98 dBm, 11.78 dBm, 15.70 dBm and 23.54 dBm, respectively. However, when PM is used, the SBST can be increased obviously, and then the SBST of 500 m Ofs and 300 m HNLF reach to 26.5 dBm and 25.63 dBm, respectively. Due to the limit of the EDFA and the loss of OBPF and coupler, the SBST of 30 m Ofs and 200 m Sumitomo HNLFs cannot be measured. Comparing 30 m and 500 m Ofs HNLFs, the fiber is longer, the SBST is lower, which is well agree with (21). In Fig.5 (a), the SBST of 300 m HNLF is lower than the SBST of 500 m Ofs HNLF, because the SBST are co-coused by the length of fiber, the core dopant, the uniform of the core diameter along the length of fiber and so on, especially for different kind fibers. Due to different dopants may modify the refractive index of pure silica and may lead to affect the acoustic guiding, SBST can be changed by dopants. F-doped silica has a smaller refractive index than pure silica. If used it as the cladding material, the acoustic velocity in F-doped silica is also reduce. And GeO2-doped core is also can reduced reduce acoustic velocity [24]. The SBST can be improved by dopants or changing the uniform of the core diameter along the length of fiber that the acoustic velocity is slightly lower in the cladding than in the core.



(a)

(b)

Fig. 5. (a) Reflected power measured as a function of input power for different fibers without PM (b) Reflected power measured as a function of input power for different fibers without PM. The SBST can be obtained from definition (20), which is shown by a black solid line $(\mu = 0.01)$.

5. Conclusions

In summary, the self-heterodyne detection is used to measure BGS. BFS is measured by a high resolution OCSA. The influence of laser pulse width and the length of fibers on SBST are investigated. We experimentally demonstrated that the SBST are improved 17.65 dB by PM with three frequencies of RFSG. A high SBST may find extensive applications in FOPA and the effect of slow light.

Acknowledgments

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