Lightwave Signal Processing Using Tellurite Fibers

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Abstract

Tellurite glasses are known as one of highly nonlinear fiber materials. We shows new potential of tellurite fibers as lightwave signal processing media by demonstrating applications of stimulated Raman and Brillouin scattering, and supercontinuum generation.

Introduction

Many efforts have been devoted to materials development and design for optical fibers, waveguide devices, fiber lasers and amplifiers to meet the demands of present and future telecommunication systems and other data transmitting services. There is still a strong need and interest to explore fiber materials in order to develop various fiber devices including fiber lasers, amplifiers, optical signal processing devices, etc. Silica fibers are currently used as major waveguide materials in telecom technology. However, they have limited performance if they are applied to active fiber devices. For example, they have a very low Raman gain response and limited usable spectral bandwidth of around 5THz for single pump excitation. This leads to research focused on new Raman gain materials using non-silica glasses. Among non-silica glasses, such as heavy metal oxide and non-oxide glasses, tellurite glasses are promising materials for photonic applications, as they combine (i) a wide transmission window, (ii) good glass stability and durability, (iii) high refractive index, (iv) increased nonlinear optical properties, and (v) relatively low phonon energies[1]. In addition, tellurite glasses have low glass transition temperatures (*T*g) and high thermal stability against crystallization which are primary factors for successful fiber fabrication.

We have focused on research of tellurite fibers, covering research of new fiber material, waveguide structures and applications, as lightwave signal processing devices. In this paper, we will present a new prospect of tellurite fibers for lightwave processing including Raman and Brillouin amplification, and broadband light source

Broadband Raman amplification

Figure 1 shows the gain coefficient spectra of two TBSN glasses added with WO_3 and jointly added with WO_3 and P_2O_5 compared with gain coefficient spectrum of silica and that of a standard tellurite glass, TeO_2-Bi_2O_3-ZnO-Na_2O. The $68TeO_2$-$3.5BaO$-$10.5SrO$-$8Nb_2O_5$-$10WO_3$ (mol%, TBSNW) and $56TeO_2$-$3.5BaO$-$10.5SrO$-$8Nb_2O_5$-$6WO_3$-$16P_2O_5$ (mol%, TBSNWP) glasses have the maximum (6.82×10^{-12} m/W) and minimum (4.52×10^{-12} m/W) gain coefficients among the present glasses, respectively.

The Raman gain coefficient of TBSNW was ~42 times higher that in the silica glass. The total gain bandwidth and Raman shifts achievable in fiber Raman amplifiers are also considerably greater in the present glasses than those in silica glass. One may observe that gain spectra of the glasses developed by our study is superior in terms of gain bandwidth even compared with other tellurite glasses. The bandwidth of TBSNWP was more than twice that of the conventional TeO_2-Bi_2O_3-ZnO-Na_2O glass and 70% larger than that of silica glass[2].

The net-gain-flattened profile of S+C+L bands TBSNWP FRA pumped at 8 wavelengths has been simulated. The effective gain bandwidth of the TBSNWP FRA is expanded to 208 nm with 8 wavelength pumpiung. It is easily understood that for a multi-wavelength pumped FRA, supposing the longest pump wavelength is 1460 nm, the effective bandwidth of such a FRA is nearly equal to the usable Raman shift pumped at 1460 nm. It means that for multi-wavelength pumped gain-flattened FRA, the fiber Raman gain medium with broader usable Raman shift and bandwidth gives larger effective gain bandwidth. As above mentioned, TBSNWP glasses showed the broadest usable Raman shift and bandwidth so far achieved in tellurite glasses, so we believed that multi-wavelength pumped gain-flattened TBSNWP FRA could give quite large effective gain bandwidth[3]. These results indicate that the TBSNWP glasses are promising candidates for ultra-broadband band fiber Raman amplifiers in photonic systems.

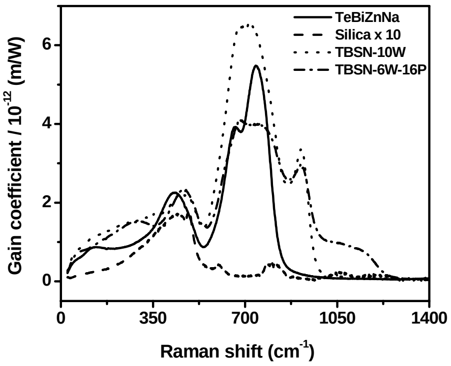

Fig. 1 Raman gain coefficient spectra for tellurite glasses.

Slow light generation

The Brillouin gain coefficient of tellurite fiber is 1.61×10^{-10} m/W at the peak and about one order of magnitude larger than that of silica fibers. The Brillouin shift is 7.96 GHz and a 3 dB Brillouin gain linwidth is 22.23 MHz.

Figure 2(a) shows the measured time waveforms of the probe pulses for different pump power, where the pulse delay and pulse widening (or distortion) due to gain filtering effects were clearly observed. Figure 2(b)

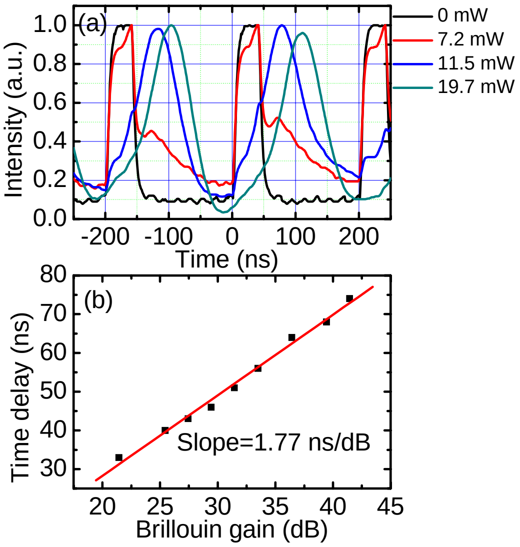

Fig. 2 (a) The measured time waveforms of the probe pulses for different pump power, (b) the dependence of the pulse delay on the Brillouin gain.

shows the dependence of the pulse delay on the Brillouin gain. As we can see, a time delay of 74 ns and its corresponding broadening factor of ~1.785 were achieved for an input pulse of 40 ns width and a Brillouin gain of 41.4 dB, corresponding to a pump power of 19.7 mW, in a 200 m long fiber, which gave the highest value (~3.76 ns/mW) of the time delay per unit power ever reported, to our best knowledge. By linearly fitting the data in Figure 2(b), a time delay slope of 1.77 ns/dB was obtained [4].

Supercontinuum generation

We have fabricated microstructure tellurite fibers for supercontinuum generation. The microstructure tellurite fiber has a microstructure of "wagon wheel' sructure

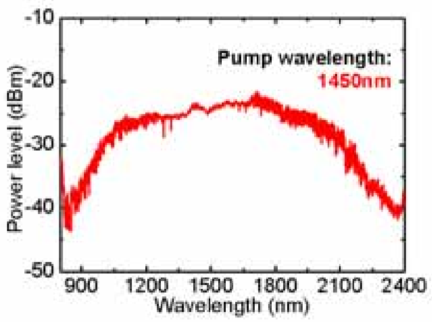

Fig. 3 The measured SC spectra from 57.4 cm long microstructure tellurite fiber.

and consists of a ~1.55 μm diameter tellurite core surrounded by six air holes with diameter of 1.28~2.0μm. The background loss of the fiber was 5dB/m at 1.064 μm. The mode area of the fiber mode is 1.16 μm^2, which gives a nonlinear waveguide coefficient of ~880km^{-1}W^{-1} calculated by using a nonlinear index of 2.5×10^{19} m^{2}W^{-1} . The microstructure tellurite fiber has a zero dispersion wavelength of ~1.275 μm, and a flattened dispersion profile in the wavelength range of 1275~1500 nm. This result shows that the "wagon wheel" microstructure fibers with small size air holes have a potential to generate flattened SC spectrum. The calculated results on mode intensity profile show that even though this fiber supports several modes (not just the fundamental mode), light is well confined inside the fiber core.

Figure 3 shows the measured SC spectra from 57.4 cm long microstructure tellurite fiber. We launched the tunable femtosecond laser with a pulse width of ~180 fs and repetition rate of ~1 kHz from a TOPAS laser system pumped by 800 nm Ti:sapphire femtosecond laser. The average power was ~35 mW.

We obtained very flattened SC spectra expanding from 1000 to 2100 nm. When the pumping wavelength was 1450 nm, the zero dispersion wavelength of the microstructure tellurite fiber, the bandwidth of SC spectrum is much narrower than that achieved by tuning the pumping wavelength to the range of 1400~1600 nm. To clarify the effects of the dispersion on the SC generation in our microstructure tellurite fiber, we simulated the SC generation in microstructure tellurite fiber by solving the generalized nonlinear Schrödinger equation[5]. Our simulation results clearly show that the microstructure "wagon wheel" tellurite fiber with small size air holes could generate flattened SC spectrum.

Conclusions

The effects of Raman spectrum on the relative gain flatness and the effective bandwidth were investigated using the TBSNWP glass with one broad main Raman shift peak. Our results suggested that the TBSNWP tellurite fibers can realize a broad band Raman gain spectra covering the S+C+L band. Highly efficient Brillouin slow light generation was demonstrated in a tellurite fiber. Tellurite fiber gave the highest value (~3.76 ns/mW) of the time delay per unit power ever reported, to our best knowledge.

We demonstrated flattened supercontinuum generation from a microstructure tellurite fiber pumped by a ultrafast laser source with a pulse width of 180 fs. When the pump light is launched into 57.4 cm long microstructure tellurite fiber, we obtain flattened SC spectra expanding from 1000 to 2100 nm. Our experimental and simulated results showed that the microstructure tellurite fiber with small size air holes could generate a flattened supercontinuum spectrum.

We have shown that tellurite fibers have high potential as lightwave signal processing media.

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