Experimental investigation of Brillouin and Raman scattering in a $Ge_{15}Sb_{20}S_{65}$ microstructured chalcogenide fiber

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Abstract
We investigate the Brillouin and Raman properties of a $Ge_{15}Sb_{20}S_{65}$ chalcogenide microstructured fiber around 1550nm. We have found Brillouin and Raman gain coefficients 100 and 180 larger than fused silica.

Introduction

Brillouin and Raman scattering effects are famous phenomena of both fundamental and applicative interests [1-3]. For almost a century, they have been studied in a large number of media, leading to numerous applications in the field of optical physics. For most of their applications, it may be desirable to found a medium with a large nonlinear efficiency in order to decrease the required input power as well as to compact the set-up for efficient implementation and stability. Chalcogenide glass fiber was found to be an excellent candidate for nonlinear applications [1] thanks to a nonlinear index over two to three orders of magnitude stronger than in standard fused silica fiber. In this work, we investigate for the first time to our knowledge the Brillouin and Raman scattering properties of a microstructured strong nonlinear $Ge_{15}Sb_{20}S_{65}$ chalcogenide fiber. We have found that the Brillouin and Raman gain coefficients in the microstructured chalcogenide fiber are about ~100 and ~180 times larger than standard fused silica fiber.

Microstructured Chalcogenide Fiber

The microstructured chalcogenide fiber was designed and drawn at the University of Rennes 1 following the technique of stack and draw (Fig.1). Its composition is $Ge_{15}Sb_{20}S_{65}$ and the losses, measured by the cut back technique, are found to be 5.5dB/m at 1.55µm.

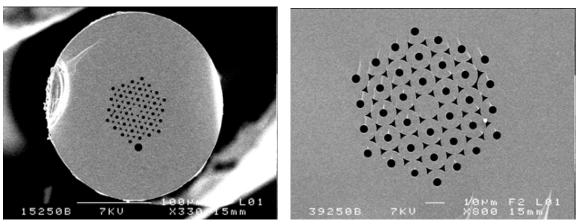

Figure 1: Pictures of the section of the $Ge_{15}Sb_{20}S_{65}$ chalcogenide microstructured optical fiber.

The pitch Λ is 13.3µm and the d/Λ ratio is 0.3 at 1.55µm corresponding to a single mode behaviour. The mode field diameter is around 8 µm at 1.55µm and the effective area of the waveguide is 50µm².

Brillouin characterization

Figure 2 illustrates the experimental set-up used to characterize the Brillouin properties of the $Ge_{15}Sb_{20}S_{65}$ microstructured chalcogenide fiber. A continuous wave (cw) is first generated at 1551.9nm by means of a distributed feedback (DFB) laser diode having a spectral linewidth given by the manufacturer of 150kHz. Thanks to an acousto-optical switch (AO), we then convert this cw into a 140-ns quasi Gaussian pulse train at a repetition rate of 500kHz. The pulse train is then amplified by means of an erbium doped fiber amplifier (EDFA) at an average power of 30dBm. A variable attenuator (VA), associated with a 90:10 coupler and a power meter (P_wM) are then inserted to adjust the injected power. The resulting signal is launched into a circulator whose port #2 is used to inject the incident light into the 2-m long microstructured chalcogenide fiber and port #3 to collect the backscattered light. The intensity of the Brillouin Stokes component is then measured at port #3 thanks to an optical spectrum analyzer (OSA) having a spectral resolution of 0.02nm.

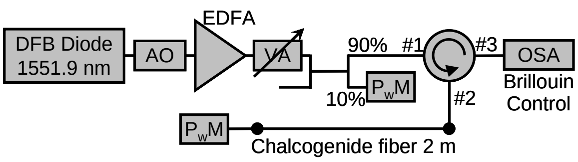

Figure 2: Experimental set-up for Brillouin characterization.

As shown in Fig.3 (inset), the Brillouin component is generated with a smaller frequency shift (8.2GHz) than in fused silica (11GHz). The threshold and Brillouin gain were determined by recording the backscattered (circles) and transmitted powers (triangles) as a function of the injected power (Fig.3). The Brillouin threshold defined as the power leading to an amount of backscattered energy equal to the

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transmitted one was found to be 1.95W, corresponding to a Brillouin gain of g_B=8.10^{-10}m/W that is to say 100 more than in standard fused silica fiber. The Brillouin gain spectrum was also measured by means of an auto-heterodyne set-up and was found to be a 9.5-MHz Lorentzian function.

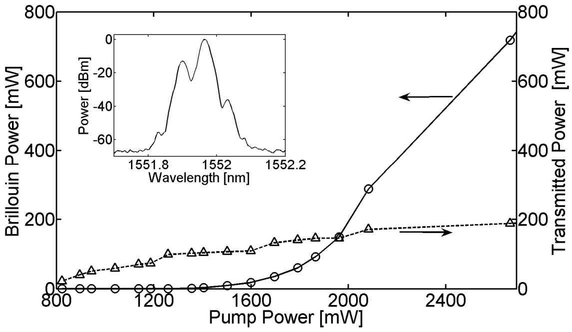

Figure 3: Backscattered and transmitted powers as a function of the 2-m long chalcogenide fiber input power. Inset: Typical Brillouin spectrum.

Raman characterization

Then, we have focused our attention on the Raman scattering effect occuring in 1.5m of the same microstructured chalcogenide fiber. Figure 4 shows the experimental set-up. A 1-kHz 10-ns square pulse laser emitting around 1553nm is used as Raman pump. In order to determine the Raman gain, we have measured the amplification undergone by a seed-signal injected in co-propagation configuration and shifted by 83nm from the Raman pump (see spontaneous response Fig.5, inset1). The 1636nm seed component was obtained through the generation of a frequency-comb by a multiple four-wave mixing (MFWM) process taking place into a 500-m long highly non-linear fiber and initiated by a 30dBm average-power beat-signal centred around 1560nm [4]. The inset2 of Fig.5 shows the resulting MFWM spectrum as well as the 1636nm Raman seed signal used in this experiment. At the output of the fiber under-test, only the part of the signal wave which has been amplified was injected into the optical spectrum analyzer thanks to an acousto-optic synchronised on the Raman pump.

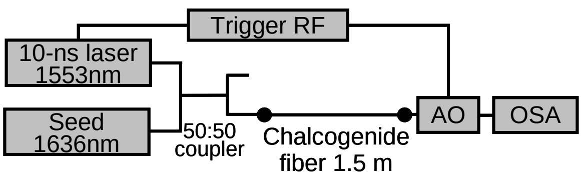

Figure 4: Experimental set-up for Raman characterization.

The Raman properties of the chalcogenide fiber were first characterized in spontaneous regime (without seeding) thanks to the 1553-nm 10-ns laser. Inset1 in Fig.5 illustrates the spontaneous Raman response of the chalcogenide fiber for an input pump peak power of 80W. The Raman detuning was measured at 83nm around 1636nm (9.7THz) vs 100nm for standard fused silica fiber. In stimulated regime, we have measured the amplification gain of the 1636-nm seed signal as a function of the input 1553-nm Raman pump power. As can be seen in Fig.5, a strong amplification of the input signal was observed, with a maximum gain of more than 37dB for an input pump power of 35W. This value corresponds to a gain per unit length of 24.7dB/m and a Raman gain of g_R=1.8.10^{-11}m/W, that is to say 180 times larger than in a classical fused silica fiber and three-fold higher than the previous result of ref. [3].

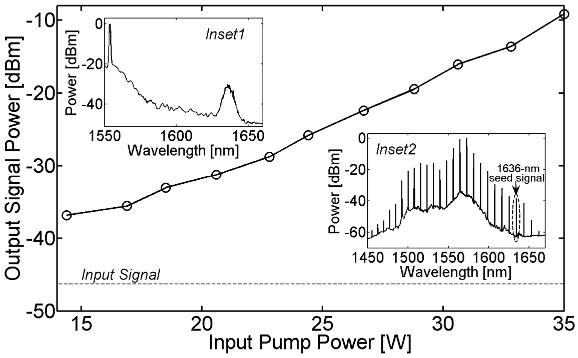

Figure 5: Output 1636-nm seed signal power as a function of input 1553-nm pump power. Inset1: Spontaneous Raman scattering for an input pump power of 80W. Inset2: Frequency-comb used to generate the 1636-nm seed signal.

Conclusions

In this work, we have investigated the Brillouin and Raman properties of a microstructured $Ge_{15}Sb_{20}S_{65}$ chalcogenide single mode fiber around 1.55µm. We have found a Brillouin and Raman gain coefficients of g_B=8.10^{-10}m/W and g_R=1.8.10^{-11}m/W corresponding to 100 and 180 times larger than those of fused silica for a frequency shift of 8.2GHz and 9.7THz, respectively. We believe that this kind of fiber which presents nonlinearity properties two orders of magnitude larger than fused silica and which could be over enhanced by increasing the field confinement by means of a microstructure reduction could find many applications in the field of nonlinear optical physics and in particular for the implementation of optical processing functions into a compact form.

References

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