Stimulated Brillouin scattering in chalcogenide-PMMA hybrid microwires

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Abstract: We investigate the onset of nonlinear effects in hybrid As_2Se_3–PMMA microwires and demonstrate that they provide an enhanced Kerr nonlinearity while mitigating stimulated Brillouin scattering when compared to chalcogenide and silica optical fibers.
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Stimulated Brillouin scattering (SBS) is detrimental to all-optical signal processing using continuous-wave and narrow-linewidth pump lasers. In the last few years, numerous efforts were made to improve the nonlinear (Kerr) figure of merit (FOM) of optical fibers while mitigating the SBS Chalcogenide optical fibers are promising candidates in this regard as they exhibit an ultra-high Kerr nonlinearity and a comparatively lower Brillouin gain increase at 1.55 µm [1-6]. In comparison with silica glass, the nonlinear refractive index of As_2Se_3 is enhanced ~930 times while the Brillouin gain coefficient is limited to an enhancement of ~220 times [4]. In the context of exploiting the Kerr effect without limitation from the Brillouin effect and without axially varying structural characteristics, the overall enhancement in FOM when replacing silica by As_2Se_3 can be quantified with the Kerr-to-Brillouin FOM is 930/220 = 4,3. In this paper, we investigate the SBS in hybrid As_2Se_3-PMMA microwires and report a Kerr-to-Brillouin FOM of 110 when replacing the silica fiber by a hybrid microwire, and 27 when replacing an As_2Se_3 fiber by a hybrid microwire. We also show that the high nonlinear figure of merit of hybrid microwires relies on the strong Brillouin linewidth broadening due an acoustic wave damping effect of the PMMA coating.

To estimate the SBS limitation, we use the Kerr-to-Brillouin FOM for optical fiber that has recently been introduced by Lee *et al.* [8]. This nonlinear figure of merit is written as B-FOM = $\gamma\, L_{eff}\, P_{th}$, where γ is the Kerr coefficient, L_{eff} is the effective length and P_{th} is the SBS power threshold. The As_2Se_3 microwires used in the experiments are coated with PMMA, following the procedure detailed in Ref. [1]. The polymer coating adds strength to the otherwise fragile microwire and prevents optical interaction and damage from the outside environment. The microwires are butt-coupled to single-mode fibers (SMF-28) and permanently bonded with UV-epoxy. The microwires have a 13 cm long uniform section and have a total insertion loss between 4 dB to 6 dB for 0.7 µm to 1 µm core diameter, with ~1 dB from the Fresnel reflections at the two As_2Se_3 to silica interfaces, ~1 dB propagation loss, and ~1-2 dB from the mode-mismatch at the input and output ends.

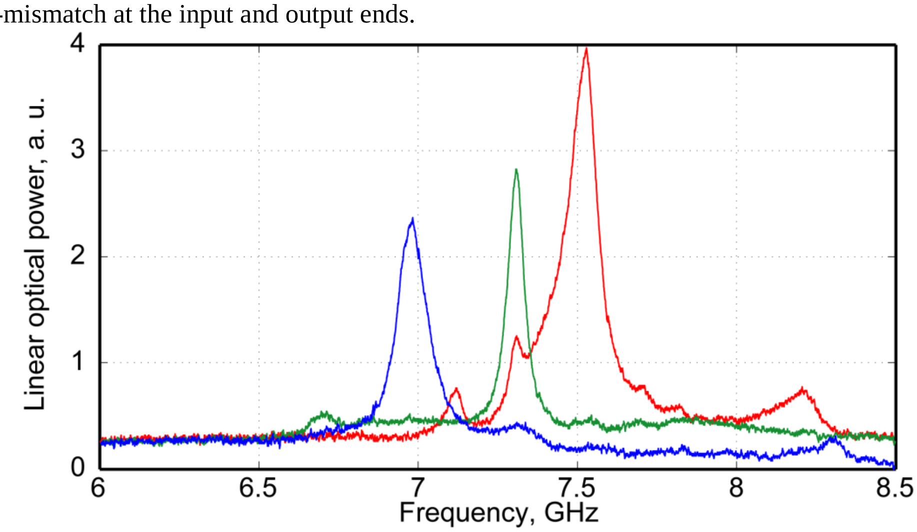

Figure 1: Brillouin spectra measured at a wavelength of 1.55 µm in three 13-cm long chalcogenide microwires with a diameter of 1 µm (red), 0.9 µm (green) and 0.7 µm (blue). The pump power is 1 mW at the chalcogenide fiber input. On the vertical axis, the total amplitude has been normalized to arbitrary unit but the relative amplitudes between fiber diameters have been conserved.

SBS measurements were performed with a pump wavelength of 1.55 µm and using a standard heterodyne detection [9]. Fig. 1 shows the SBS spectra of three microwires with diameters of 1 um, 0.9 um and 0.7 um. A comparison of the spectra shows that the main SBS frequency peak decreases with the diameter as should be expected from the phase-matching condition and the effective index of the fundamental guided mode. Note also the local peak at a frequency ~8.2 GHz comes from SBS in the 3 cm long untapered sections of As_2Se_3 fiber. For the strongest SBS peaks generated in the wire section of the microwires, the SBS linewidth is ~100 MHz, a significantly increased value with respect to the 16 MHz linewidth measured in bulk As_2Se_3 [5]. The PMMA cladding surrounding the microwire, with an SBS linewidth of 120 MHz, is expected to be responsible of this spectral broadening [2]. This is explained from the larger elastic losses and stronger viscosity of PMMA relative to As_2Se_3.

Table 1 compares the linear and nonlinear parameters of standard silica SMF-28, As_2Se_3 fibers [5], and the As_2Se_3 microwires under test. The 0.7 µm microwire exhibits the highest B-FOM, which is 27 times higher than As_2Se_3 fibers.

	Unit	SMF-28	As_2Se_3 fiber*	Wire1	Wire2	Wire3
Core diameter	**µm**	**10**	**6**	**1**	**0,9**	**0,7**
Effective area (@1550nm)	**µm²**	85	39	0,483	0,404	0,273
Loss (@1550nm)	**$dB.m^{-1}$**	**0,0002**	**0,84**	**10**	**10**	**10**
Length	**m**	**1000**	**4,92**	**0,13**	**0,13**	**0,13**
Effective length, L_{eff}	**m**	977,32	3,17	0,11	0,11	0,11
Nonlinearity, γ	**$W^{-1}.m^{-1}$**	0,001	2	201	241	356
Nonlinear coefficient, n_2	**$m^2.W^{-1}$**	2,5E-20	2,4E-17	2,4E-17	2,4E-17	2,4E-17
Effective index		1,44	2,81	2,59	2,54	2,37
Brillouin frequency shift	**GHz**	**11,10**	**7,95**	**7,53**	**7,37**	**6,87**
Brillouin linewidth	**MHz**	**27**	**13,2**	**125**	**65**	**110**
Brillouin gain	**$m.W^{-1}$**	2,71E-11	**6,00E-09**	3,72E-10	6,20E-10	2,24E-10
Brillouin threshold, P_{th}	**dBm**	20,0	**18,1**	25,6	22,6	25,3
K-FOM ($\gamma.L_{eff}$)	**W^{-1}**	1,17	7,92	22,63	27,05	40,04
B-FOM ($\gamma.L_{eff}.P_{th}$)		0,08	0,34	5,50	3,29	9,13

Table 1. : Comparison of linear and nonlinear parameters of single-mode fibers, As_2Se_3 fibers, and our subwavelength-diameter As_2Se_3 microwires with PMMA coating. The measured values are in bold. * ref [5].

To summarize, we have investigated the relative magnitude of nonlinear effects in subwavelength-diameter As_2Se_3 microwires and demonstrated a strong increase in the Brillouin threshold compared to As_2Se_3 fiber owing to the PMMA coating. This work contributes to the design of a new class of Brillouin-less optical signal processing devices based on the Kerr effect.

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