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On-chip stimulated Brillouin scattering

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Abstract: We report the first demonstration of on-chip stimulated Brillouin scattering (SBS). The measured Brillouin shift and line width are ~7.7 GHz and 6 MHz in a 7 cm long chalcogenide waveguide.

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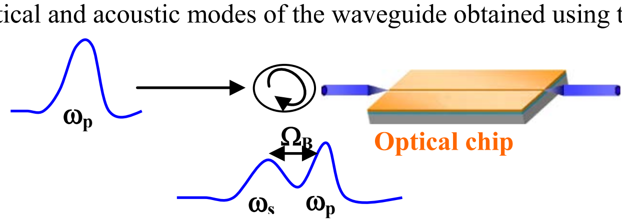
Stimulated Brillouin scattering (SBS) is a nonlinear process resulting from the interaction between light and acoustic modes in an optically transparent structure [1]. SBS has been exploited in a number of applications ranging from slow-light to Brillouin lasers using long length (~km) optical fibers [2, 3]. However, the investigation of on-chip SBS, in which the effect is induced in an integrated optical structure, has been limited because most platforms commonly used in nonlinear optics either have very small SBS gain coefficient (as is the case for Silica) or have no SBS even though they have very high Kerr nonlinearity (e.g. for Silicon). Chalcogenide glass, on the other hand, has both large SBS gain coefficient and Kerr nonlinearity [4]. SBS has been measured in chalcogenide fibers and the measured Brillouin shift and linewidth are 7.985 GHz and 13 MHz respectively [4]. We present the first demonstration of on-chip SBS in a 7 cm long, silica-clad chalcogenide (As_2S_3) rib waveguide. The measured Brillouin shift and linewidth are ~7.72 GHz and ~6 MHz respectively, consistent with previous results in chalcogenide fibers.

Figure 1 shows a schematic of on-chip SBS process where a pump beam at frequency (ω_p) is launched into the As_2S_3 optical-chip and is backscattered by the acoustic wave of frequency (Ω_B). The scattered light, known as the Stokes wave, appears at a frequency $\omega_s = \omega_p - \Omega_B$. Figure 1 shows the cross-section of the As_2S_3 waveguide and the optical and acoustic modes of the waveguide obtained using the finite element method.



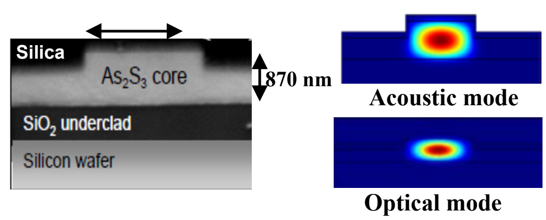


Figure1. Principal of on-chip stimulated Brillouin scattering

The large Brillouin gain coefficient (g_B) for As_2S_3 has its origin in its large refractive index (n=2.44). The gain coefficient g_B depends on *n* according to [1, 4]

$$g_B = I\, 2\pi n^7 P_{12}^2 / (c \rho v_a \Delta\nu_B \lambda_p^2), \qquad (1)$$

where I is the overlap integral between the acoustic and optical mode, P_{12} is the longitudinal elasto-optic coefficient, c is the speed of light in vacuum, ρ is the material density, v_a is the acoustic speed, $\Delta\nu_B$ is the Brillouin linewidth. The value of g_B is obtained by solving the acoustic and optical modes for the waveguide and calculating the overlap integral and has a value of $g_B \sim 2 \times 10^{-9}$ m/W.

Figure 2 shows the experimental set-up for investigating SBS in As_2S_3 chip. Light from a DFB laser at a pump wavelength (λ_p) of 1550.025 nm is modulated, after propagating it through a fiber polarization controller (FPC), using a 25 kHz pulse train with a duty cycle of 1% to generate 400 ns pump pulses. Pump pulses are amplified using an EDFA and coupled to the circulator. A lensed fiber at port 2 of the circulator is used to couple light to the waveguide. Back scattered light is collected at port 3 of the circulator and sent to an RF spectrum analyzer and an optical spectrum analyzer (OSA) using a 90/10 splitter. The waveguide is 7 cm long and has a cross-sectional area of 4μm x 870 nm with a top silica cladding of 140 nm.

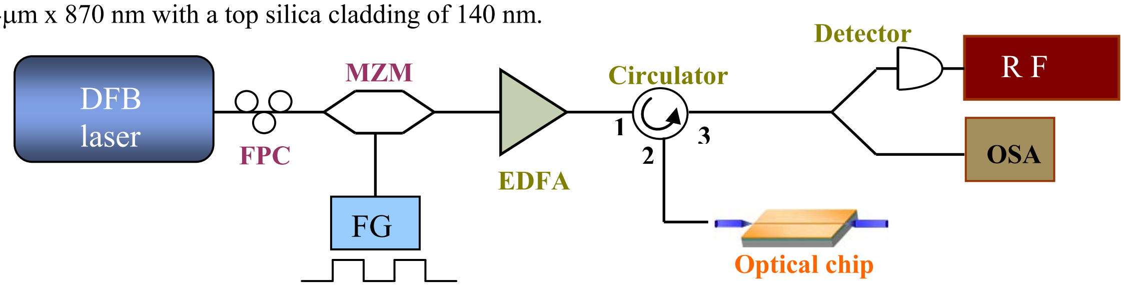


Figure 2 Experimental set-up for investigating on-chip SBS.

Figure 3 shows the back-scattered optical spectra for the As_2S_3 waveguides for different input average powers before coupling to the waveguide. From Fig. 3 it is evident that the Stokes signal starts to appear as the pump power is increased. Figure 4 shows the RF spectra corresponding to the minimum and maximum input powers. From Fig. 4, we note that both the Brillouin shift and line width are slightly different for these two powers. The Brillouin shift for the minimum and maximum input powers, as inferred from the RF spectra, are 7.72 GHz and 7.73 GHz respectively and the corresponding 3 dB linewidths of the RF spectra are ~ 6 and ~ 8 MHz respectively. We attribute the broad line width and different shift at larger power to chip heating due to higher power dissipation in the waveguide. The measured Brillouin shift and linewidth are consistent with the measured values in chalcogenide fiber by Abedin *et al.* [4].

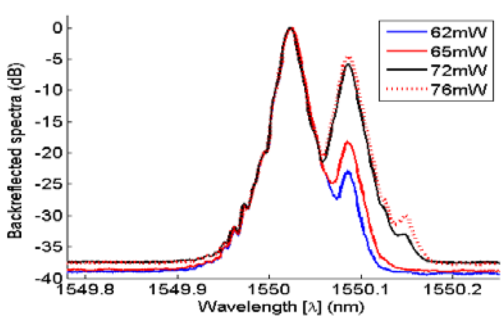


Figure 3 Backreflected spectra at different input powers for a 7 cm long As_2S_3 waveguide showing the increase of the Stokes signal with power.

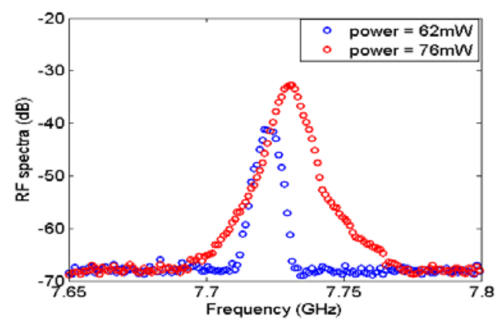


Figure 4 RF spectra at the minimum and maximum input power for a 7 cm long As_2S_3 waveguide.

Finally, we calculate the Brillouin threshold for our As_2S_3 waveguide using the expression [4]

$$K g_B (P_{th}/A_{eff}) L_{eff} \approx 21, \qquad (2)$$

where P_{th} is the threshold pump power, A_{eff} is the effective mode area, K is a factor for taking into account the polarization effects and L_{eff} is $(1 - \exp(-\alpha L))/\alpha$ with α and L being the propagation loss and device length respectively. Table 1 compares the Brillouin threshold for our optical chip and the same length of single-mode fiber (SMF) using K = 1. Note that the Brillouin threshold for the optical chip is three orders of magnitude smaller than that for the same length of SMF owing to its 100 times larger g_B and smaller mode area.

Table 1 Comparison of the Brillouin threshold for optical chip and same effective length of SMF.

Device	g_B (m/W)	L_{eff} (cm)	A_{eff} (m^2)	P_{th} (W)
SMF	2.0×10^{-11}	3	80×10^{-12}	2800
Optical chip	2.0×10^{-9}	3	3×10^{-12}	1.0

In conclusion, we have presented the first demonstration of on-chip SBS with low Brillouin threshold. On-chip SBS will enable chip-based devices for applications such as slow-light, signal processing.

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