On-chip stimulated Brillouin scattering

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

Keywords-Brillouin scattering; slow-light; nonlinear waveguide

I. INTRODUCTION

Stimulated Brillouin Scattering (SBS) is a nonlinear process, which results from the interaction of light with acoustic modes in an optically transparent medium [1]. This acousto-optical interaction allows the properties of light to be controlled by tailoring the properties of the acoustic modes and leads to light-light interactions via the sound waves in the medium. However, light-sound and light-light interactions via Brillouin scattering have only been realized using long (~km) optical fibers because most planar platforms commonly used in nonlinear optics either have very small SBS gain coefficient (as is the case for Silica) or have no SBS (e.g. for Silicon). Chalcogenide glass, on the other hand, has very large SBS gain coefficient [2], which has been characterized in chalcogenide fibers with a measured Brillouin shift and linewidth are 7.985 GHz and 13 MHz, respectively, at relatively moderate power levels [2].

In this paper, we present the first demonstration of on-chip SBS. We report detailed measurements of 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 optical fibers. Exploiting the SBS on chip scale will improve fundamental understanding of light-sound interaction for opto-mechanical oscillators [3], nonlinear devices and slow-light applications [4, 5].

II. CONCEPT

Figure 1(a) shows a schematic of an on-chip SBS process where a pump beam at frequency (ω_p) is launched into an As_2S_3 optical waveguide and undergoes backscattering by the acoustic wave of frequency (Ω_B). The backscattered light, known as the Stokes wave, appears at a frequency $\omega_s = \omega_p - \Omega_B$. Figure 1(b) shows the cross-section of the As_2S_3 waveguide and the calculated optical and acoustic modes of the waveguide calculated using the finite element method. These profiles were used to determine the overlap integral (I) between the optical mode and density change induced by the acoustic mode, which is then used to determine the Brillouin gain coefficient for the optical chip. The gain coefficient g_B is given by [1, 2]

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

where 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 calculated g_B for our chip ~ 2 x 10^{-9} m/W.

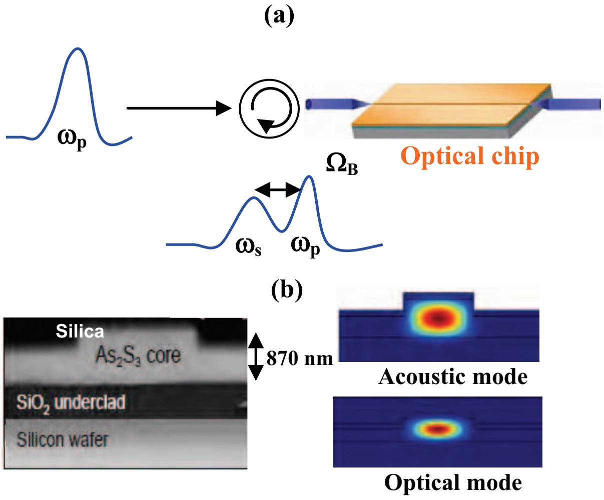

Figure1 (a) Principal of on-chip stimulated Brillouin scattering (b) Cross-section of As_2S_3 chip and calculated optical and acoustic modes

III. EXPERIMENT AND RESULTS

Figure 2 shows the experimental set-up for investigating SBS. Light from a DFB laser at a pump wavelength (λ_p) of 1550.025 nm passed through a fiber polarization controller (FPC) and was modulated using a 25 kHz pulse train with a duty cycle of 1% to generate 400 ns pump pulses. These were amplified using an EDFA and passed to a circulator. A lensed fiber at port 2 of the circulator was used to couple the light into the waveguide. Back scattered light was collected at port 3 of the circulator and sent to both an RF spectrum analyzer and an optical spectrum analyzer (OSA) using a 90/10 splitter.

The waveguide was 7 cm long and has a cross-sectional area of 4μm x 870 nm and was overclad with a 140nm silica layer.

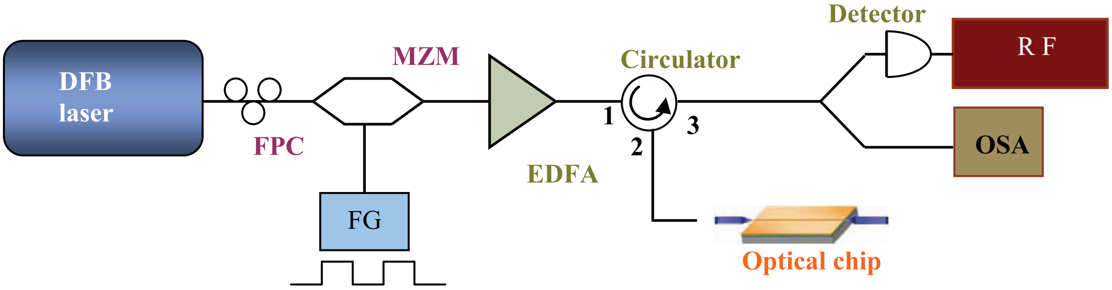

Figure 2 Experimental set-up for investigating on-chip SBS.

Figure 3 shows the measured back-scattered optical spectra for the As_2S_3 waveguides for different input average powers measured in the input fiber before coupling into the waveguide. From Fig. 3 it is evident that the Stokes signal start appeared above an average pump power of ≈60mW.

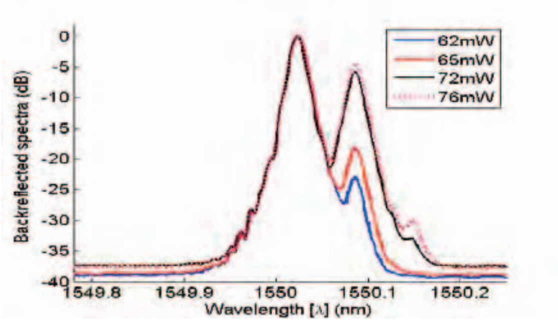

Figure 3 Backscattered spectra at different input powers for a 7 cm long As_2S_3 waveguide showing the increase of the Stokes signal with power.

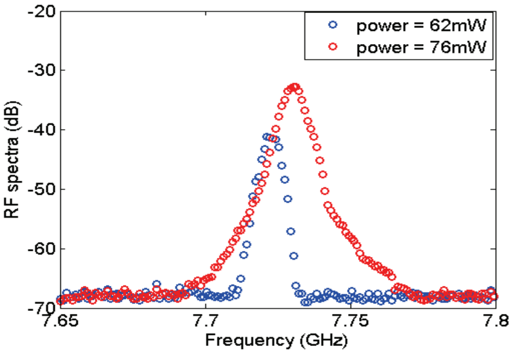

Figure 4. RF spectra at the minimum and maximum input power for a 7 cm long As_2S_3 waveguide.

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 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.* [2].

Finally, we calculated the Brillouin threshold for our As_2S_3 waveguide using the expression [2]

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

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, calculated using the parameters in the table, 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 threshold powers. On-chip SBS will enable chip-based devices for applications such as slow-light, and advanced optical signal processing.

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