Stimulated Brillouin Scattering in AlGaAs on insulator waveguides

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Abstract: We observe stimulated Brillouin scattering (SBS) in AlGaAs-on-insulator integrated waveguides. A guided transverse acoustic mode has a 12.3 GHz Brillouin shift, and a full-width half-maximum of 25 MHz. © 2020 The Author(s)
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Recent advances in on-chip stimulated Brillouin scattering (SBS) have shown the great potential of combining integrated photonics with acoustics, with applications including high performance microwave photonic filters [1] and ultra-narrow linewidth lasers [2]. Unfortunately, SBS has two demanding requirements for the effect to be useful: the optical and acoustic waves must co-propagate (or counter-propagate), and the optical loss must be low. To achieve the former requirement in many material systems, including Si, SiO2, and AlN, the only solution is to suspend the waveguide and leave it unclad. Here, we consider the (Al)GaAs on insulator waveguide – a promising new platform for nonlinear integrated photonics – as a solution to this problem. Recent works have demonstrated record high second-harmonic generation efficiency [3], as well as record-low threshold for Kerr comb generation [4] due to the combined advantages of high modal confinement, low propagation loss, and the orders-of-magnitude higher second and third order nonlinear coefficients in (Al)GaAs as compared to typical nonlinear dielectric materials (including $LiNbO_3$, Si_3N_4, SiO_2). We add stimulated Brillouin scattering (SBS) to the suite of nonlinearities available in this platform by taking advantage of the unique acoustic properties of the $AlGaAs/SiO_2$ material system. This is the first demonstration of SBS in an un-suspended semiconductor waveguide.

To achieve SBS in this platform, we use the low shear (transverse) acoustic velocity in AlGaAs. Since the AlGaAs core has a lower shear acoustic velocity (3.1e5 cm/s) than the SiO2 cladding (3.7e5 cm/s), it is possible for a guided acoustic mode to exist simultaneously with the optical mode within the waveguide core. To confirm this, both optical and acoustic modes were simulated in COMSOL Multiphysics for a 400 nm thick AlGaAs layer, partially etched to form a rib waveguide. The optical mode profile is shown in Fig. 1(a), while guided acoustic mode profile is shown in Fig. 1(b). The acoustic mode is antisymmetric in the vertical direction, and the primary components of displacement are in the transverse vertical and longitudinal (not shown) directions. The acoustic phase velocity of this mode is 3.2e5 cm/s, consistent with the acoustic velocity of shear acoustic waves in bulk AlGaAs. Based on the phase matching condition between acoustic and optical modes, we estimate a Brillouin shift of 12.2 GHz.

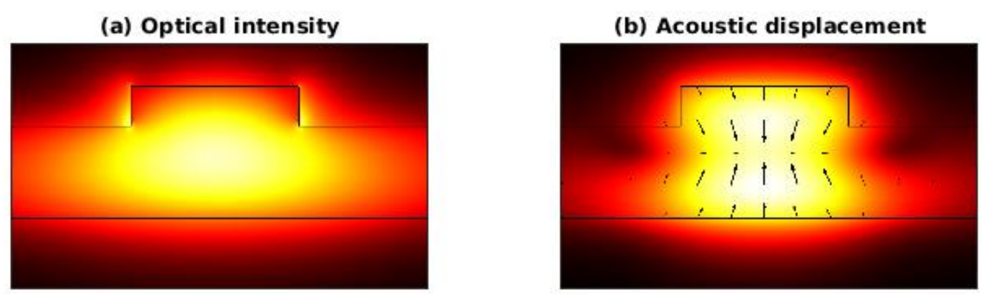

Fig. 1. (a) Optical intensity of the fundamental TE mode in the SBS waveguide at 1550 nm. (b) Physical displacement of the acoustic mode at 12.2 GHz, superimposed with arrows indicating the transverse components of displacement

The fabrication process for the $Al_{0.2}Ga_{0.8}As$ device follows the same process as the GaAs on insulator platform [3, 4]. The aluminum fraction (0.2) is chosen to yield a bandgap of 743 nm in order to avoid two photon absorption within the telecommunications C band. The waveguide is 500 nm wide and is formed by etching 120 nm of the 400 nm thick AlGaAs. The device consists of a 10 cm long waveguide and has propagation loss around 0.5 dB/cm.

Lensed fibers are used to couple light onto the chip, with an estimated coupling loss of 4 dB to 5 dB per facet. The gain spectrum is measured using the pump-probe measurement technique [5]. The pump laser is fixed at 1550.1 nm and is amplified using an erbium-doped fiber amplifier before being coupled on-chip. The probe is generated by a tunable laser and coupled on-chip in the reverse direction. To obtain the gain spectrum, the transmitted probe power is monitored as the probe laser is tuned across the wavelength of the pump. The resultant spectrum is shown in Fig. 2(a). The feature at 0 GHz offset is due to reflection of the pump light by self-phase modulation from the standing wave formed by pump and probe and is not associated with SBS. The features at +10.8 GHz and -10.8 GHz represent the respective anti-Stokes and Stokes SBS interactions within the fiber used to couple to the chip. At +12.34 GHz and -12.34 GHz, we observe anti-Stokes loss and Stokes gain associated with the AlGaAs waveguide itself, in good agreement with the simulated 12.2 GHz Brillouin shift. A high-resolution scan of the Brillouin peak, shown in Fig. 2(b) reveals a full-width half maximum (FWHM) of approximately 25 MHz. At 25 dBm power injected into fiber, for which we estimate the on-chip power to be approximately 100 mW, we observe a peak gain of 0.8 dB.

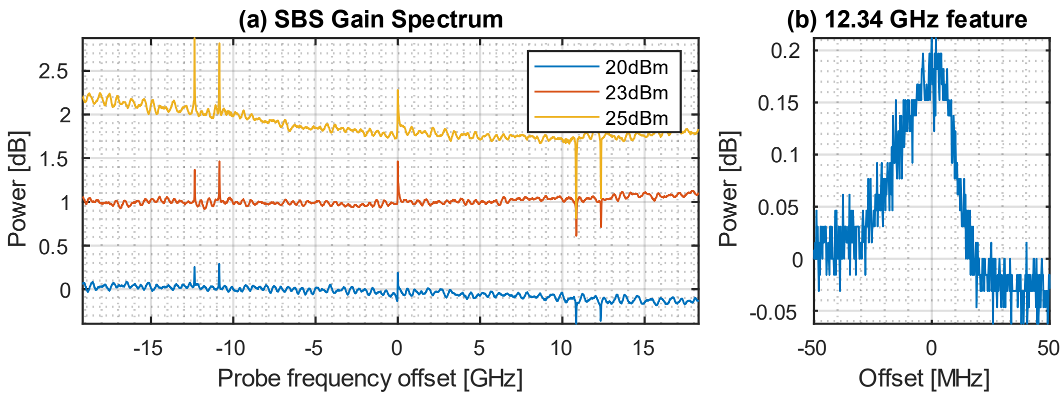

Fig. 2. (a) SBS gain spectrum of the probe with respect to a pump wavelength at 1550.1 nm, with pump power (into fiber) between 20 dBm and 25 dBm. (b) High resolution scan of the 12.34 GHz Brillouin peak with 25 MHz FWHM for 20 dBm power launched into fiber.

With this report, AlGaAs on insulator becomes the first semiconductor waveguide capable of supporting guided acoustic and optical modes without suspended structures. This presents a unique possibility for heterogeneous integration with active gain materials that would be difficult to achieve in other Brillouin active platforms. Integration of electrically pumped gain media requires depositing metals and dielectrics in order to route electrical signals, which would be complicated if the waveguide core must remain suspended and unclad, as is required for observing SBS in integrated silicon, silicon dioxide, and AlN waveguides [6]. Furthermore, compared with thin silicon nitride [2] and chalcogenide glass [1,5], the only other un-suspended Brillouin platforms, the higher refractive index and material compatibility with other III-V gain materials of AlGaAs would simplify coupling light between active and passive waveguides. With a reduction in waveguide loss, net Brillouin amplification may be achievable in this platform, paving the way towards cointegration of Brillouin lasers with electrically driven pump lasers.

In conclusion, we make the first ever report of stimulated Brillouin scattering in un-suspended semiconductor waveguides. We observe a Brillouin shift of 12.34 GHz, with a FWHM of 25MHz, and gain of 0.8 dB for an on-chip pump power around 100 mW. This result opens the door to integration of Brillouin active waveguides with a host of other nonlinear devices including frequency combs [4] and electrically pumped gain media.

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