Silicon nitride based guided-acoustic stimulated Brillouin scattering for microwave photonic signal processing

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In this work we present a microwave photonic notch filter created with our on-chip SBS gain. By combining the gain with a microring resonator in the same platform, we create a notch filter with a rejection of more than 60 dB. The filter can be tuned by tuning the ring resonator and pump laser. The filter has a link gain of -10 dB, an SFDR of 100.5 dB/Hz$^{2/3}$*, and a noise figure of 43.7 dB.*

Stimulated Brillouin scattering in silicon nitride waveguides

Stimulated Brillouin scattering (SBS) is a third order nonlinear optical process, based on interacting acoustic and optical waves [1]. The interest in SBS induced in integrated photonic circuits has been grown in the past few years, as it has shown promising uses in signal processing [2], high-precision sensors [3], non-reciprocal control of light propagation [4], and ultra-narrow linewidth laser sources [5]

Silicon nitride has emerged as a leading platform for microwave photonic signal processing [6]. Adding SBS to the existing toolbox in this platform would open up new ways of improving the performance of the processing, and open up new possibilities. SBS in silicon nitride waveguides is weak however, because acoustic waves are not guided in a silicon oxide cladded silicon nitride waveguide [7].

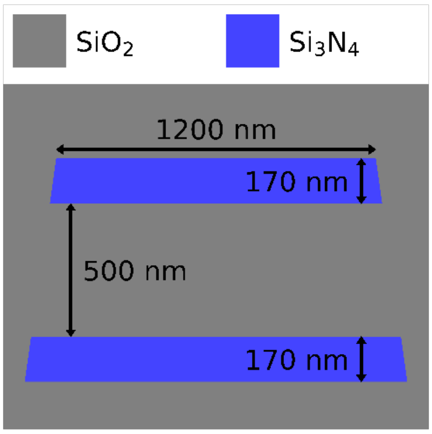

Figure 1: The geometry of our symmetric double-stripe waveguide.

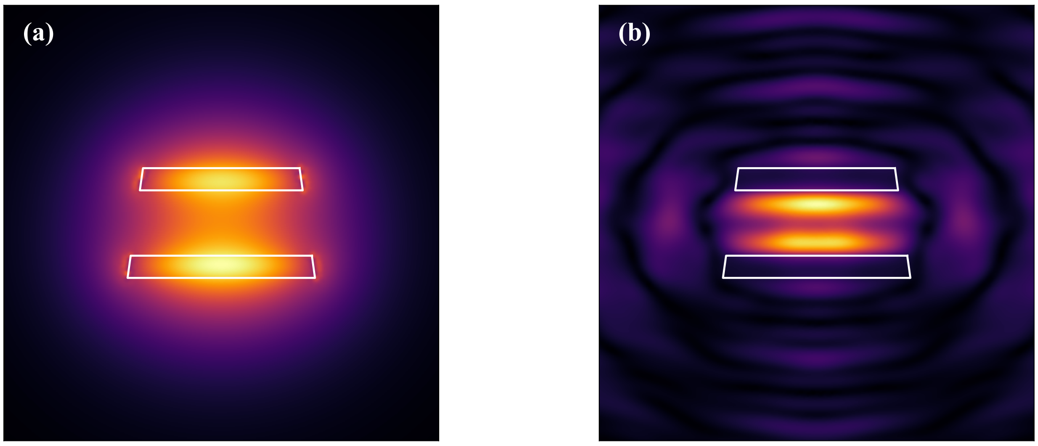

Figure 2: **(a)** the optical mode of our waveguide. **(b)** the acoustic response of the waveguide.

We have recently shown the first example of guided-acoustic SBS in silicon nitride waveguides [8]. The geometry of our waveguide, the symmetric double stripe (SDS) can be seen in Figure 1. By using two layers of silicon nitride, we are able to prevent the acoustic wave from leaking, creating acoustic guidance. Figure 2 **(a)** shows the optical mode of (SDS) waveguide. The corresponding acoustic response is depicted in Figure 2 **(a)**. Note how the acoustic wave is trapped in between the two silicon nitride layers.

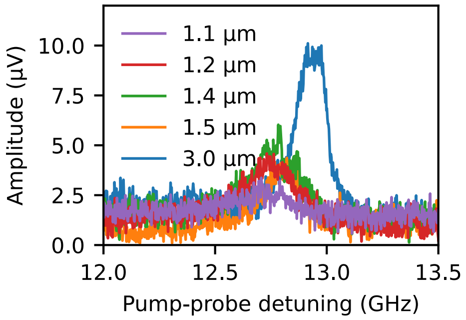

Figure 3: The measured SBS response of waveguides with different widths.

Using this geometry, we are able to achieve a Brillouin gain coefficient of 0.24 $m^{-1}W^{-1}$. Further enhancement of the acoustic guiding, and therefor of the Brillouin gain can be achieved by making the waveguide wider than the 1.2 µm depicted in Figure 1. Increasing the width to 3.0 µm leads to the highest measured Brillouin gain, as depicted in Figure 3. The Brillouin gain coefficient of this waveguide is 0.40 $m^{-1}W^{-1}$, which is a record for silicon nitride based waveguides, and 4 times higher than previous results [7].

Microwave photonic notch filter with SBS

The linewidth of the Brillouin response in our waveguide is 130 MHz, making it very promising for signal processing. To demonstrate the potential of our waveguides we combined it with a ring resonator in the same platform to create a microwave photonic notch filter [9]. Figure 4 shows the working principle of the filter. The ring resonator is used to impart a π phase shift into one of the sidebands. The SBS process, with its narrow linewidth, is uniquely able to counteract the ring losses. This leads to destructive interference at the desired frequency.

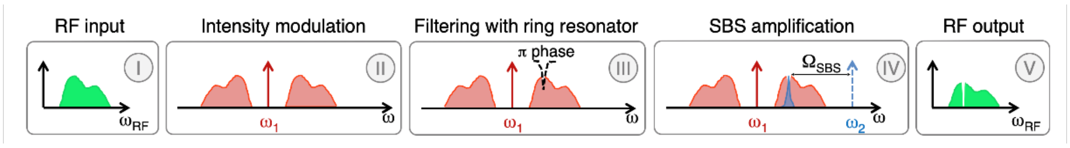

Figure 4: Working principle of the filter. The RF signal (I) is modulated using intensity modulation (II). Then, an over-coupled ring resonator processes the upper sideband, creating a notch with π phase shift (III). The SBS amplification is then used to compensate for the ring losses (IV). When the signal beats at the photodiode, the π phase shift results in a notch in the RF spectrum (V)

Figure 5 shows the setup we used to implement the filter. The ring resonator is made from the same SDS waveguide geometry, showing that these elements can readily be integrated.

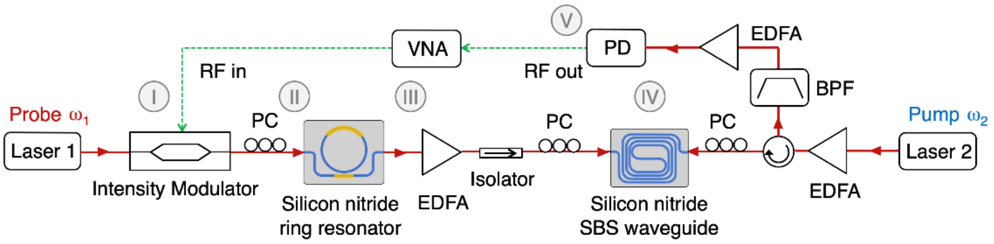

Figure 5: Schematic overview of our setup. BPF: band-pass filter, EDFA: erbium doped fiber amplifier, PC: polarization controller, PD: photodiode, VNA: vector network analyzer.

Figure 6 shows the resulting notch filter. The rejection is more than 60 dB. Tuning of the center wavelength of the filter can be achieved by simultaneously tuning the ring resonator and the pump laser. The filter has a 3 dB-bandwidth of 2.4 GHz, a link gain of -10 dB, an SFDR of 100.5 dB/Hz$^{2/3}$, and a noise figure of 43.7 dB. These numbers are comparable to previously reported numbers of similar SBS notch filters in suspended silicon waveguides [10].

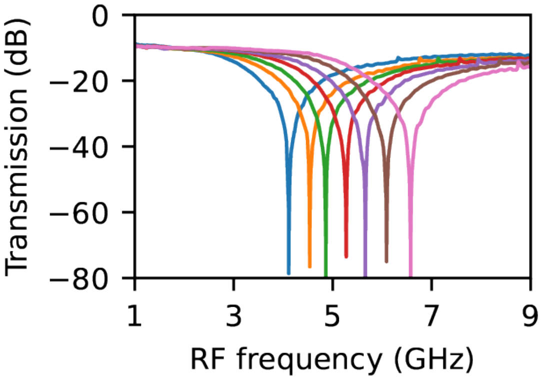

Figure 6: The notch filter created with our SBS setup. The center wavelength is tunable.

Conclusion and outlook

We have shown the first guided-acoustic stimulated Brillouin scattering in silicon nitride waveguides, which we further enhanced by increasing the waveguide width. Using this Brillouin gain, we were able to demonstrate the first microwave photonic notch filter using SBS in the platform. This filter is on par with similar filters in other platforms.

From here we will work on further enhancing the Brillouin gain. An increased gain will lead to more use cases, such as for high precision sensing, and narrow linewidth lasers.

Acknowledgements

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