Higher Order Cascaded SBS Suppression Using Gratings in a Photonic Integrated Ring Resonator Laser

Matthew Puckett,[1] Debapam Bose,[2*] Karl Nelson,[1] and Daniel J. Blumenthal[2]
[1]Honeywell International, USA
[2]Department of Electrical and Computer Engineering, University of California, Santa Barbara (UCSB), CA 93106, USA
**dbose@ucsb.edu*

Abstract: An integrated Brillouin laser that maintains lasing in only the first Stokes order with up to 1W input pump power is demonstrated by incorporating Bragg gratings in the resonator waveguide.

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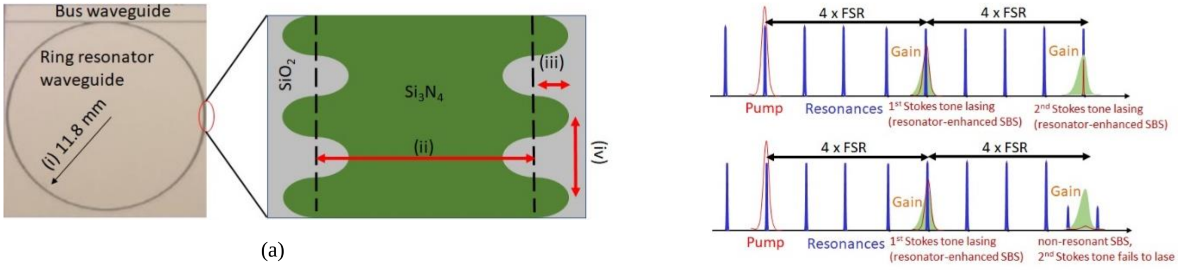
1. Introduction:- Brillouin lasers are of great interest for a wide range of applications including microwave photonics, optical gyroscopes, and coherent communications due to their exceptionally low linewidths. [1] They have been demonstrated on the chip scale on platforms such as arsenic trisulfide [2], silicon [3], and silicon nitride [4]. Previously, we have demonstrated a chip scale ring resonator-based Brillouin laser with a loaded quality factor of 28 million and an fundamental linewidth of 0.7Hz [4]. Even narrower linewidths may be generated by this type of laser by suppressing the lasing of cascaded higher order tones. In addition to increasing the power in the fundamental Stokes tone resulting in a lower Schawlow-Townes linewidth, this also reduce the noise contributed to the laser by anti-Stokes generation [5]. In this work, we demonstrate an integrated Brillouin laser that generates only the first stokes tone by incorporating Bragg gratings into the resonator architecture leading to a new class of ultra-low noise SBS lasers.

2. Grating Resonator Design:- In the previously demonstrated photonic integrated Brillouin resonator design [4,6], the ring radius defined longitudinal mode, corresponding to the first Stokes order, is separated from the pump frequency by four times the free spectral range (FSR). Here we incorporate a Bragg grating into the resonator design as in Fig. 1(a) in order to split the resonant modes by an amount by an amount as large as one half of the FSR. This effect can be utilized to prevent higher order Stokes tones from lasing by aligning the stopband of the grating to the Stokes order to be suppressed allowing only a small amount of spontaneous Brillouin scattering to be generated, as illustrated in Fig. 1(b), and additionally reduces the field enhancement factor of the split resonances. These two effects work in combination to increase the threshold powers for higher Stokes orders. In our design, the second Stokes order is aligned to the center of a pair of split resonances generated by the grating function, whereas the first Stokes order is aligned to a resonance that is not split. Spatially, the grating function is a sum of four sinusoids, each with a periodicity corresponding to the wavelengths at which the ring resonances are to be split. The modulation function was additionally designed to have an amplitude of 75nm.



(a)

(b)

Fig. 1. (a)On the left is our fabricated ring resonator with (i)radius of 11.8mm; To the right – grating ring resonator waveguide's top view with its (ii)Width, (iii)Amplitude, and (iv) Period. (b) Cascaded lasing action in ring Resonator without a grating(top), no cascaded lasing if a grating is present(bottom)

3. Experimental Results:- The grating resonators were fabricated as in [4] and consist of the same geometries. Scanning electron microscope (SEM) images of a portion of the grating resonator waveguide can be seen in Fig. 2(a). The measured periods of the gratings were around 530nm with amplitudes of approximately 32nm. There were five grating resonator die on one 4 inch wafer, and one grating resonator die occupied a surface area of 25mm x 26.5mm. Passive measurements of the transmission of the grating resonators yielded loaded quality factors of 20 million, measured using a swept 1550nm laser source. The mode splitting due to the gratings in the resonator was measured directly from the passive transmission spectrum and can be seen in Fig. 2(b). Each point on the plot corresponds to the splitting of a single longitudinal mode order, and as can be clearly seen, there are four unique splitting maxima, each of which corresponds to a separate subgrating. The measured stopband positions correspond to respective grating periods of 535.22 nm, 535.25 nm, 535.39 nm, and 535.42 nm, and a modal effective index of 1.4482.

(i) (ii)

(a)

(b)

Fig. 2. (a) SEM Images of (i) fabricated grating resonator waveguide (ii) a close-up of the grating part. (b) Measured resonance splitting in fabricated grating resonator

The grating resonator operated successfully as a Brillouin laser. An external laser was locked to the pump resonance at 1550.02 nm, using the PDH technique as described in [4]. Choosing this pump wavelength allowed us to position the second order Stokes wave at approximately 1550.2 nm, which we know to correspond to strongly split resonances in the device. Compared to previous resonators lacking Bragg gratings, we found that increasing the pump power to values approaching 1 W did not generate a second order Stokes wave, and the absence of this lasing order can be directly observed in Fig. 3, which shows the optical spectrum obtained by combining both of the resonator die's output ports. Furthermore, plotting the power in the Stokes tones as a function of pump power in Fig. 4 reveals that power clamping of the first Stokes tone does not occur at any level, confirming that higher order Stokes modes are truly suppressed. This technique allows for the generation of narrow linewidth sources with linewidths approaching the mHz level, making it critical to several applications in sensing and precision timing and navigation.

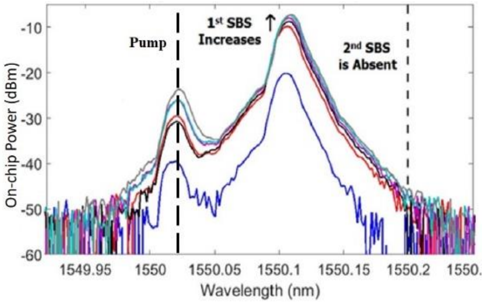


Fig. 3. Optical Spectrum of total power in grating resonator chip when lasing from pump powers of 18.8dBm to 30dBm.

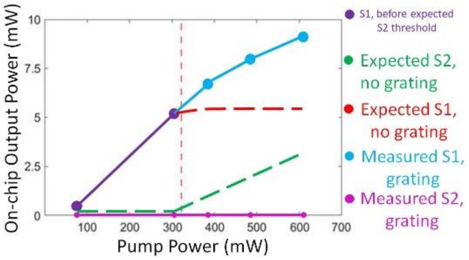


Fig. 4. Output Power in Stokes tones vs Pump Power where S1 – 1st Stokes tone, S2 – 2nd Stokes tone, showing that fundamental SBS tone is not clamped in the grating resonator as 2nd order SBS is absent, wherein without any grating on the resonator it would have been clamped. Vertical dashed line is pump power at which the 1st stokes tone would normally have clamped.

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5. References

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