Integrated Ultra-Narrow Linewidth Lasers and Their Applications

(Invited Paper)

Daniel J. Blumenthal
University of California at Santa Barbara, Department of ECE, Santa Barbara, CA 93016 USA; Email: danb@ucsb.edu

Abstract: Ultra-narrow linewidth, ultra-stable lasers, the heart of precision high-end scientific systems, are making the leap from the laboratory to compact photonic integrated circuits. A new class of integrated stimulated Brillouin scattering laser will be described and application to chip-scale systems including data center communications, atomic clocks, optical gyros and microwave synthesis. © 2019 The Author(s).

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1. Introduction

Photonic integrated ultra-low linewidth lasers will enable systems-on-chip solutions for a wide range of high-end and commercial applications enabled by spectrally-pure lasers including coherent communications [1], next-generation data center networks [2], atomic timekeeping [3], optical position and navigation [4] and microwave synthesis [5]. Translating the performance of stable, spectrally-pure lasers to wafer-scale integrated devices will bring lower cost, size, weight and power with increased environmental robustness to applications that today, are relegated to the laboratory scale.

In this talk, a new class of photonic integrated ultra-low linewidth stimulated Brillouin scattering (SBS) laser [6] and applications will be described. The laser is fabricated in an ultra-low loss silicon nitride (Si_3N_4) waveguide platform and achieves sub-Hz fundamental linewidth emission. The underlying physics, design, fabrication and performance will be covered as well as inherent phase noise mechanisms [7] and techniques to achieve low integral linewidths and highly stable long term frequency drift.

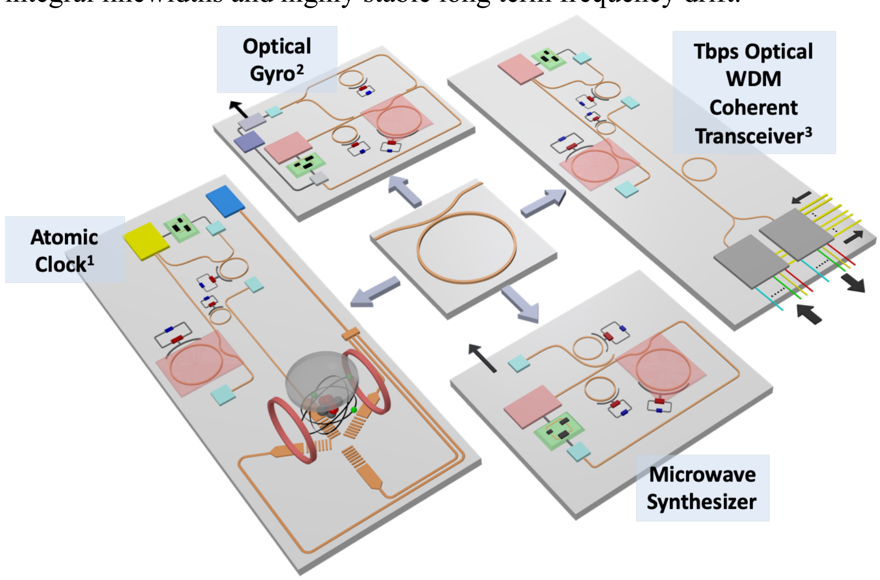

Figure 1. Applications of ultra-low linewidth integrated waveguide SBS laser: (1) Chip-scale atomic clock – DARPA ACES program, (2) Optical Gyroscope – DARPA PRIGM/AIMS program and (3) ARPA-e OPEN 2018 FRESCO project.

The silicon-foundry compatible Si_3N_4 design supports low-loss from 405 nm to 2350 nm and can be integrated with other components to support a wide range of applications from the visible to IR [8]. Figure 1 illustrates applications and research projects at UCSB including the DARPA funded PRIGM/AIMS funded integrated optical gyroscope, DARPA ACES funded chip-scale atomic clocks and the ARPA-e OPEN-2018 funded frequency stable coherent optical transmission link for low-energy scalable data center interconnects (FRESCO) project [9]. The stimulated Brillouin scattering (SBS) laser produces highly coherent, spectrally-pure emission [10] and can be designed to operate from the visible to the infrared. Brillouin lasers have the unique property in that they can narrow the pump laser linewidth by many orders of magnitude [11] producing a low white-frequency-noise-floor, low close-to-carrier frequency noise and low relative intensity noise (RIN). The laser is fabricated in a monolithic ultra-low loss Si_3N_4 platform [8] involving a single Si_3N_4 etch followed by plasma enhanced chemical vapor deposited (PECVD) silicon dioxide upper cladding. This process is fully compatible with a wide range of already demonstrated active and passive devices [8]. The laser a bus-ring waveguide resonator design with ~30 Million loaded Q (Fig. 1 (a)). The Brillouin gain is derived from long lifetime photons that continually generate short-lived phonons along the optical waveguide path (Fig. 1 (b)). Brillouin lasing is shown with a clear threshold as a function of pump power, linewidth narrowing at the lasing transition, and spectral narrowing as the laser power is increased from below to above threshold (Fig. 1 (c) and (d).

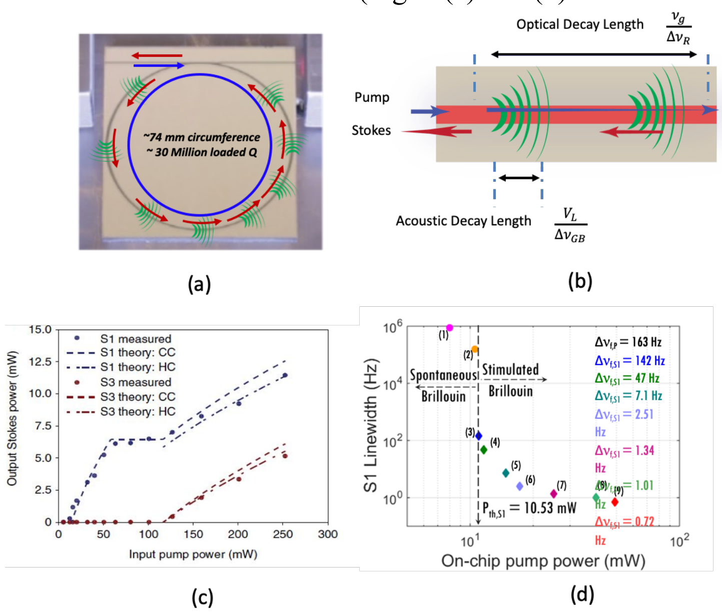

Figure 2. (a) Ring-bus waveguide laser with pump (blue) and S1 (red). (b) Long photon lifetime (blue) and unguided short lived phonons (green) continually generating S1 (red). (c) Steady state S1 and S3 threshold and power curves. (d) S1 spontaneous emission width below threshold and fundamental linewidth above threshold demonstrating emission linewidth narrowing as a function of increased on-chip power.

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3. References

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