# Integrated Low Linewidth Brillouin Lasers in Ultra Low Loss $Si_3N_4$ Waveguide Platform

**Daniel J. Blumenthal[1], Sarat Gundavarapu[1], Debapam Bose[1], Grant Brodnik[1], Taran Huffman[1,2], Ryan Behunin[3], Peter Rakich[4]**

[1]*Department of Electrical and Computer Engineering, University of California Santa Barbara, Santa Barbara, CA 93106 USA*
[2]*GenXComm, Inc. 1604 San Antonio St, Austin, TX 78701*
[3]*Department of Physics and Astronomy, Northern Arizona University, Flagstaff, Arizona 86011 USA*
[4] *Department of Applied Physics, Yale University, New Haven, CT 06520 USA)*
*Author e-mail address: danb@ucsb.edu*

**Abstract:** We describe a new class of integrated, ultra-low phase noise Brillouin laser. Leveraging novel laser dynamics in a very-high Q $Si_3N_4$ waveguide resonator, record low linewidths and noise in cascaded-order operation, with potential operation across the visible to infrared, can be achieved. Potential applications that span the visible to the infrared are described. 

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## 1. Introduction

Highly coherent ultra-low linewidth photonic integrated lasers are poised to make the leap from the laboratory to the chip. Applications pushing for this transition include ultra-high capacity coherent communications [1,2], atomic clocks [3], metrology [4,5], microwave photonics [7], spectroscopy [8], optical gyroscopes [9], optical combs [10,11] and frequency synthesizers [12]. Scaling this level of performance to the chip-scale presents significant challenges in device physics, materials, design, and integration technology. Additionally, these applications require operation from the visible to the infrared posing further material and integration challenges. Stimulated Brillouin scattering (SBS) lasers are capable of extremely low linewidths, yet photonic integration of SBS lasers, and integration using a wafer-scale platform that enables higher functionality photonic circuits, has remained elusive. In this talk we describe a monolithically integrated ultra-low fundamental linewidth [13] photonic-integrated Brillouin waveguide laser.

We describe a unique type of integrated Brillouin laser [14] based on a novel waveguide physics in an ultra-low loss, large volume, high Q silicon nitride bus-coupled waveguide resonator [15]. This laser addresses the stability, size and cost limitations of discrete optical component Brillouin lasers [16,17] and coherence limitations of previously demonstrated chip-scale Brillouin lasers [18,19]. Additionally, the combination of novel Brillouin waveguide physics and extended low loss wavelength range achievable in silicon nitride waveguides shows promise for ultra-narrow linewidth photonic-integrated SBS lasers capable of operation across the wide range from 405 nm to 2350 nm [20,21].

## 2. Laser Overview

The Brillouin laser operates via nonlinear photon-phonon coupling within a monolithic integrated waveguide bus-coupled ring resonator fabricated using simple CMOS foundry compatible process steps. Low-loss $Si_3N_4/SiO_2$ waveguides [22] form the foundation of our laser design. These waveguides support ultra-low loss TE only modes and can produce optical amplification through Brillouin scattering. By harnessing this resonant scattering process, a weak Stokes beam is amplified as it propagates along the waveguide by energy transfer from a strong pump beam. Unique to this design is the harnessing of unguided phonons leading to a Brillouin gain phonon decay rate 3-4 times larger than comparable integrated SBS lasers [16,19], in contrast to other integrated designs that utilize acoustic guiding. The large mode-volume bus coupled resonator has a loaded Q on the order of 28 Million. The combination of fast phonon decay and long photon lifetime, suppresses the transfer of pump phase noise to the Brillouin laser emission [23,24], and the large on-chip optical cavity enables extremely low fundamental linewidths of the laser. This broadened gain bandwidth also relaxes the phase matching conditions and improves resonator fabrication tolerances.

In this talk we will describe the theoretical basis for this integrated cascaded-order Brillouin laser [25] and an overview of the laser design, fabrication and properties that lead to narrow linewidth emission. We will also describe laser phase, frequency and linewidth measurements [26], potential applications, and future directions for this technology.

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