Suspended Multimode SiN Platform for Strong Intermodal Brillouin Scattering

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Primary CNF Tools Used: ASML stepper, Oxford 100 Inductively coupled plasma reactive ion etching (ICP-RIE), YES EcoClean Asher, Oxford PECVD, Furnace, JEOL-9500, Heidelberg Mask Writer-DWL2000, ABM Contact Aligner, Woollan RC2 Spectroscopic Ellipsometer, YES Ecoclean asher, Critical pointer dryer-Leica

Abstract:

We demonstrate forward intermodal Brillouin interactions with fundamental acoustic modes (FIM-FAM) in a suspended triple-core Si_3N_4 waveguide, achieving sub-50 kHz linewidths and a gain coefficient over 1100 $W^{-1}\cdot m^{-1}$. This platform enables narrowband RF filtering in a CMOS-compatible photonic circuit.

Summary of Research:

Microwave filters based on stimulated Brillouin scattering (SBS) in integrated photonic platforms offer the potential for ultra-narrowband, reconfigurable RF filtering with high spectral resolution and compact form factors[1–4]. While Brillouin interactions in silicon nitride (Si_3N_4) waveguides are attractive due to the material's low optical loss and CMOS compatibility, achieving high SBS gain has been hindered by low photoelasticity and weak acoustic confinement[5–7]. To overcome these challenges, we demonstrate an on-chip forward intermodal SBS platform based on a suspended triple-core Si_3N_4 waveguide structure. This design supports SBS interactions between the TE_1 and TM_0 optical modes, which collectively drive low-frequency fundamental acoustic modes, including both flexural-y and torsional modes, via radiation pressure.

The waveguide geometry is carefully optimized to support strong acoustic mode confinement through large impedance mismatch at air-Si_3N_4 interface and to ensure momentum matching by engineering the effective index difference between the interacting optical modes. Importantly, the suspended waveguide is fabricated with a central core and two symmetric outer cores, creating a spatially distributed radiation pressure profile that avoids destructive cancellation and enhances net optical force coupling.

Using phonon-mediated four-wave mixing spectroscopy, we measure a Brillouin gain coefficient exceeding 1100 $W^{-1}\cdot m^{-1}$ and linewidths as low as 45 kHz, representing a record performance for SBS in Si_3N_4 waveguides. The suspended region is defined using a combination of dry etching and buffered oxide undercut, followed by critical point drying to preserve mechanical integrity. The triple-core waveguide supports large acoustic impedance mismatch with the surrounding air, suppressing phonon leakage and maintaining long phonon lifetimes. The structure also enables the formation of an acoustic cavity, where coherent reflections at the suspended region boundaries discretize the phonon spectrum, contributing to reduced acoustic linewidth.

This platform provides efficient access to fundamental acoustic modes with long coherence times and enables RF filtering capabilities that are fully compatible with planar photonic integration. Compared to SBS in

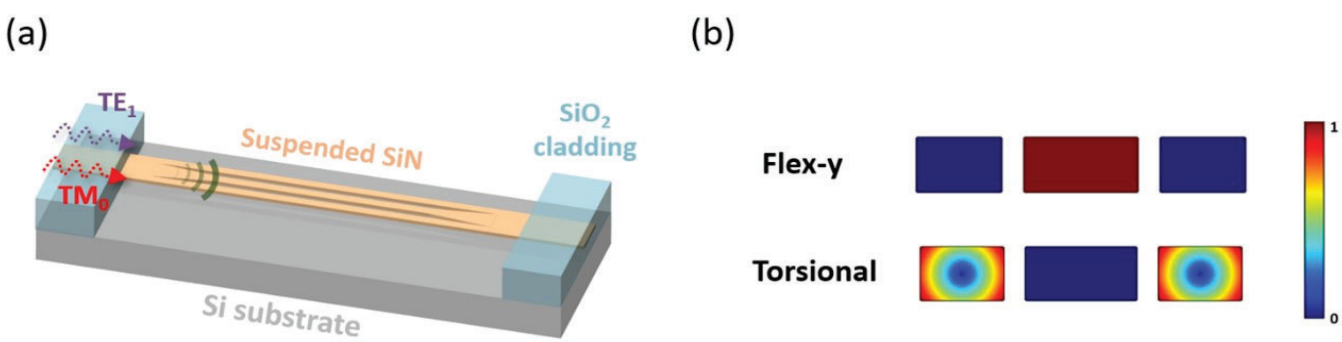

Figure 1: (a) Schematic of the suspended triple waveguide design (b) Simulated results for flexural-y and torsional acoustic modes.

optical fibers or hybrid materials, the demonstrated approach offers significant size reduction and process scalability, laying the foundation for on-chip microwave photonic filters with kHz-level resolution, high spectral selectivity, and low power operation.

Schematic plot of the suspended triple waveguide design and two fundamental acoustic modes confined in triple-core waveguide are shown in Fig. 1. The main fabrication steps for our design are illustrated in Fig. 2. The fabrication process begins with the deposition of a 4 µm thermal oxide bottom cladding layer, followed by a low-loss silicon nitride (Si_3N_4) core layer using low-pressure chemical vapor deposition (LPCVD). A PECVD oxide layer is then deposited to serve as an etch mask. Waveguides are defined using electron-beam lithography with a JEOL-9500 system and a negative-tone MaN resist. The pattern is transferred into the Si_3N_4 layer via inductively coupled plasma reactive ion etching (ICP-RIE) using an Oxford 100 system. Post-etching, the resist is stripped with a YES EcoClean plasma asher, and a top oxide cladding is deposited using PECVD.

To define the suspended region, a protective GKR resist layer is spun onto the chip, and an ASML stepper is used to expose the undercut windows. The top oxide thickness in the suspended area is partially reduced by another ICP etching step using the Oxford 100. The chip is then immersed in buffered oxide etchant (BOE) to selectively undercut the oxide beneath the waveguides, thereby achieving full suspension of the Si_3N_4 core. Finally, a critical point dryer (Leica CPD) is used to ensure structural integrity during the drying process. Fig. 3 shows the SEM image of the suspended Si_3N_4 waveguide, drying with the nitrogen gun and the critical point dryer.

Conclusions and Future Steps:

In conclusion, we demonstrate efficient on-chip forward intermodal stimulated Brillouin scattering (SBS) in a suspended triple-core silicon nitride waveguide, enabling strong interaction with low-frequency fundamental acoustic modes. Through careful mode engineering and acoustic confinement, we achieve a record Brillouin gain coefficient exceeding 1100 $W^{-1} \cdot m^{-1}$ with sub-50 kHz linewidths. This platform offers a compact, CMOS-compatible solution for narrowband microwave photonic filtering and establishes a scalable foundation for future low-power, high-resolution RF signal processing on chip.

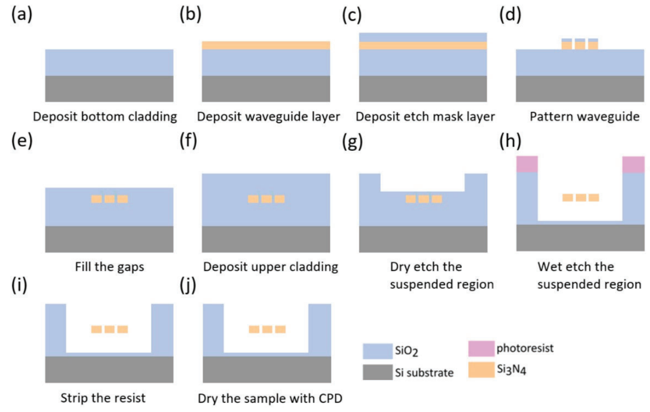

Figure 2: The main fabrication steps.

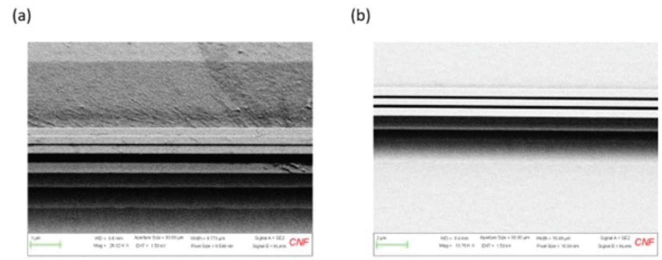

Figure 3: The SEM pictures of suspended Si3N4 waveguide. (a) Drying with the nitrogen gun (b) Drying with the critical point dryer.

References:

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