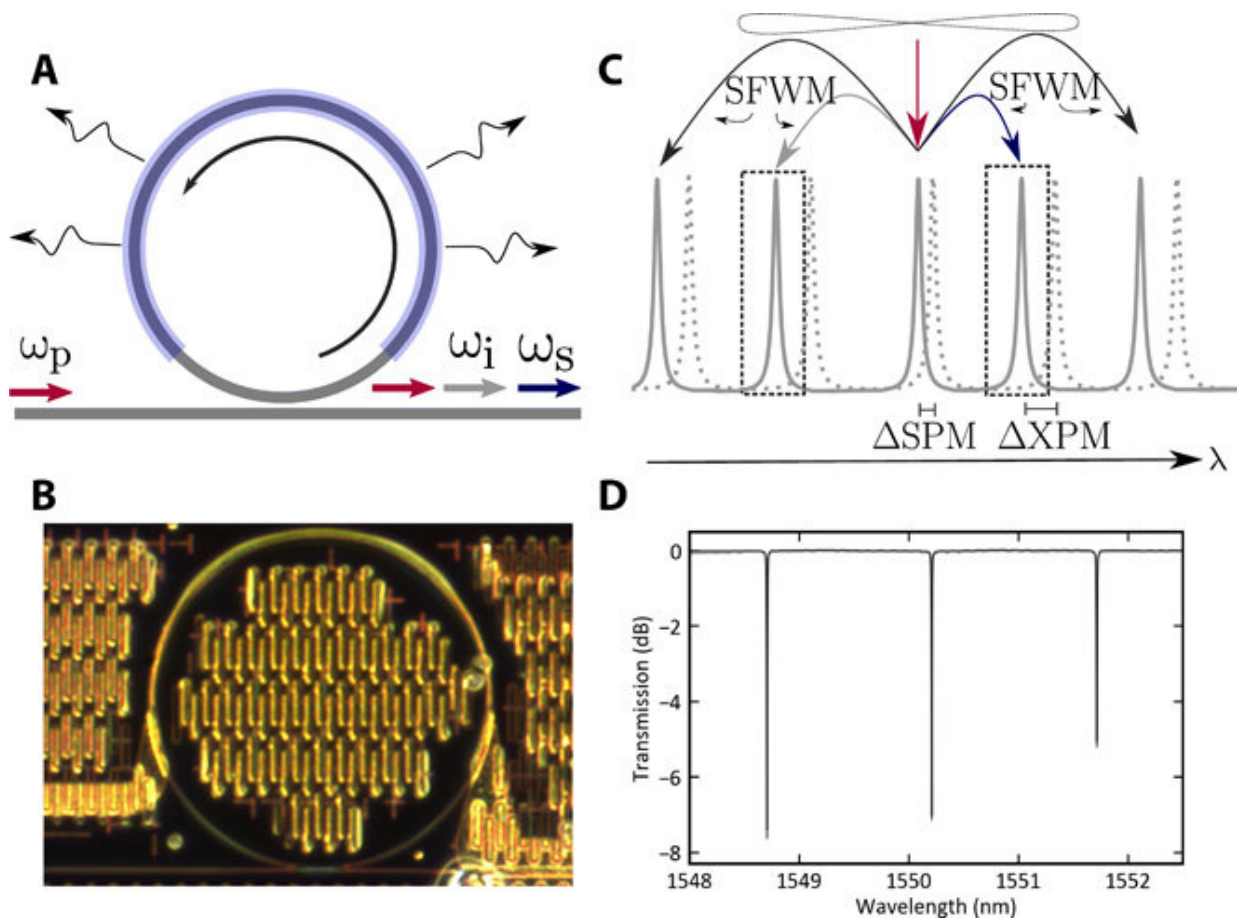


Squeezing light: Developing an integrated nanophotonic device to generate squeezed light

October 5 2020, by Thamarasee Jeewandara



Overview of device. (A) Schematic of microring device showing resonator, side channel, microheater (blue), and scattering modes. (B) Optical microscope image of device. (C) Illustration of intracavity SFWM process, showing frequency shifts ΔSPM and ΔXPM associated with self- and cross-phase modulation (SPM and XPM, respectively). (D) Representative transmission spectrum of microring

device, showing three overcoupled resonances near 1550 nm. Credit: Science Advances, doi: 10.1126/sciadv.aba9186

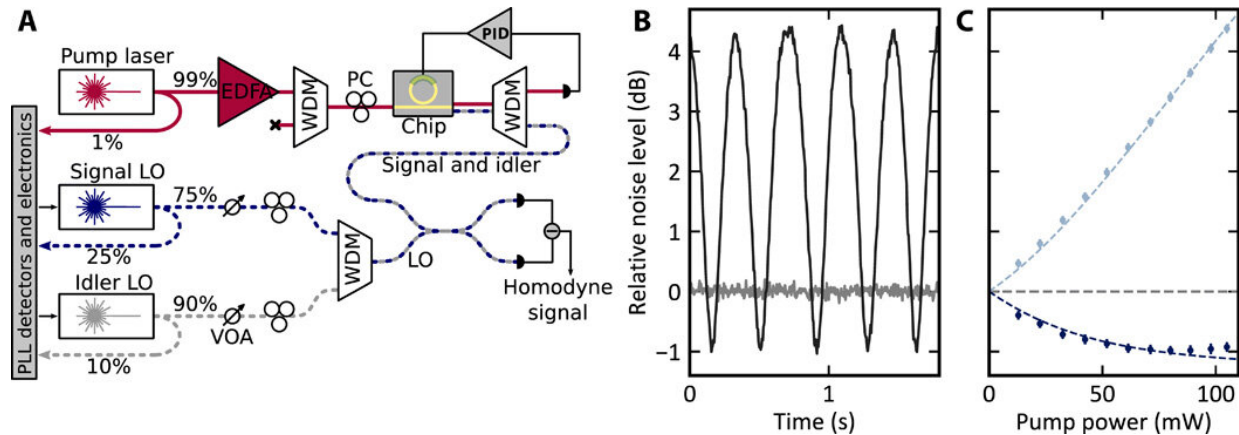
Scientists can generate squeezed light via strongly driven spontaneous four-wave mixing below threshold in silicon nitride [microring resonators](#). The generated light can be characterized with [homodyne detection](#) (to extract phase- or frequency-encoded information) and through direct measurements of photon statistics. In a new report now published on *Science Advances*, V.D. Vaidya, and a team of scientists in Canada and the U.S. measured the quadrature-squeezed vacuum and photon number difference generated within an integrated nanophotonic device. The results will impact applications in quantum technology.

The concept of squeezed [light](#) is relevant in quantum optical processing, where the associated architectures of continuous variable photonics demand high-quality, scalable devices to generate squeezed light for many fundamental photonic [quantum information processing](#) applications. Examples include [continuous variable \(CV\) quantum computation](#) and [Gaussian boson sampling](#), which is a promising avenue to achieve near-thermal quantum advantage and accommodate a range of intriguing concepts, including molecular [vibronic spectrum](#) simulations, [graph isomorphism](#), [perfect matchings](#) and [graph similarity](#).

Squeezed light for quantum optical processing

Most of these quantum applications require a scalable source of squeezed light to implement and enhance optical sensing [near the quantum limit](#). Integrated photonics is a natural platform to explore these scalable squeezed light sources, where the stability and high-throughput manufacturability offered by modern [lithographic \(patterning\) methods](#) present promising pathways to realize useful quantum technologies at

scale. However, [progress to date](#) on chip-integrated squeezing is limited. In the present study, therefore, Vaidya et al. used [spontaneous four-wave mixing](#) (SWFM) in silicon nitride microring resonators to provide a readily accessible and mature technology on commercial fabrication platforms.

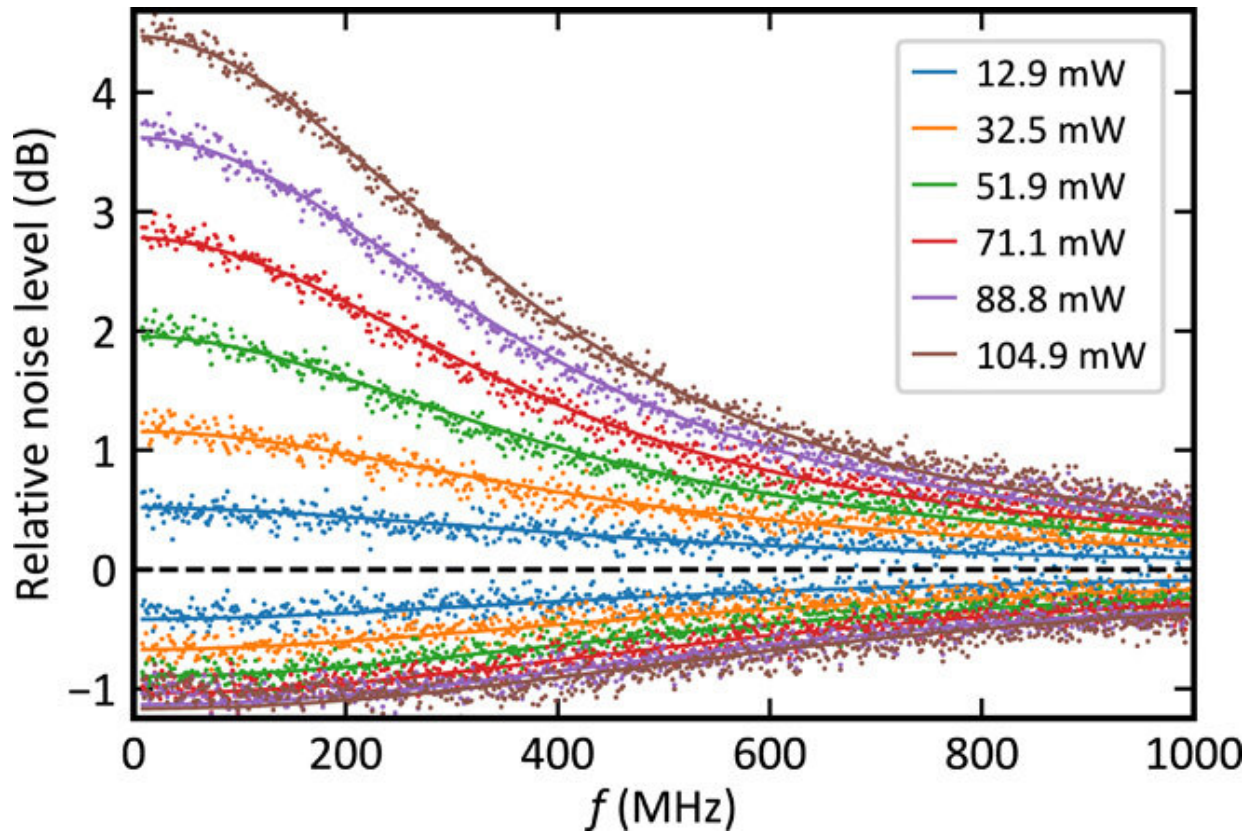


Quadrature squeezing. (A) Overview of experimental setup. Details in the main text and the Supplementary Materials. WDMs, wavelength division multiplexing components. LO, local oscillator; EDFA, erbium-doped fiber amplifier; PLL, phase-locked loop; VOA, variable optical attenuator; PC, polarization controller; PID, proportional-integral-derivative. (B) Quadrature variance (black line) relative to shot noise (gray line) as a function of time, while the local oscillator phase is ramped, exhibiting 1.0(1) dB of squeezing. Traces are obtained from the homodyne detector photocurrent fluctuations monitored on an electrical spectrum analyzer in zero-span mode at 20-MHz sideband frequency, with a resolution bandwidth of 1 MHz and a video bandwidth of 300 Hz. (C) Maximum and minimum quadrature variances as a function of pump power for the 20-MHz sideband, showing the power scaling of the squeezed and antisqueezed quadratures. The top and bottom dashed lines are obtained by fitting to equation derived in the study; the shot noise level is shown (dashed line at 0 db). Credit: Science Advances, doi: 10.1126/sciadv.aba9186

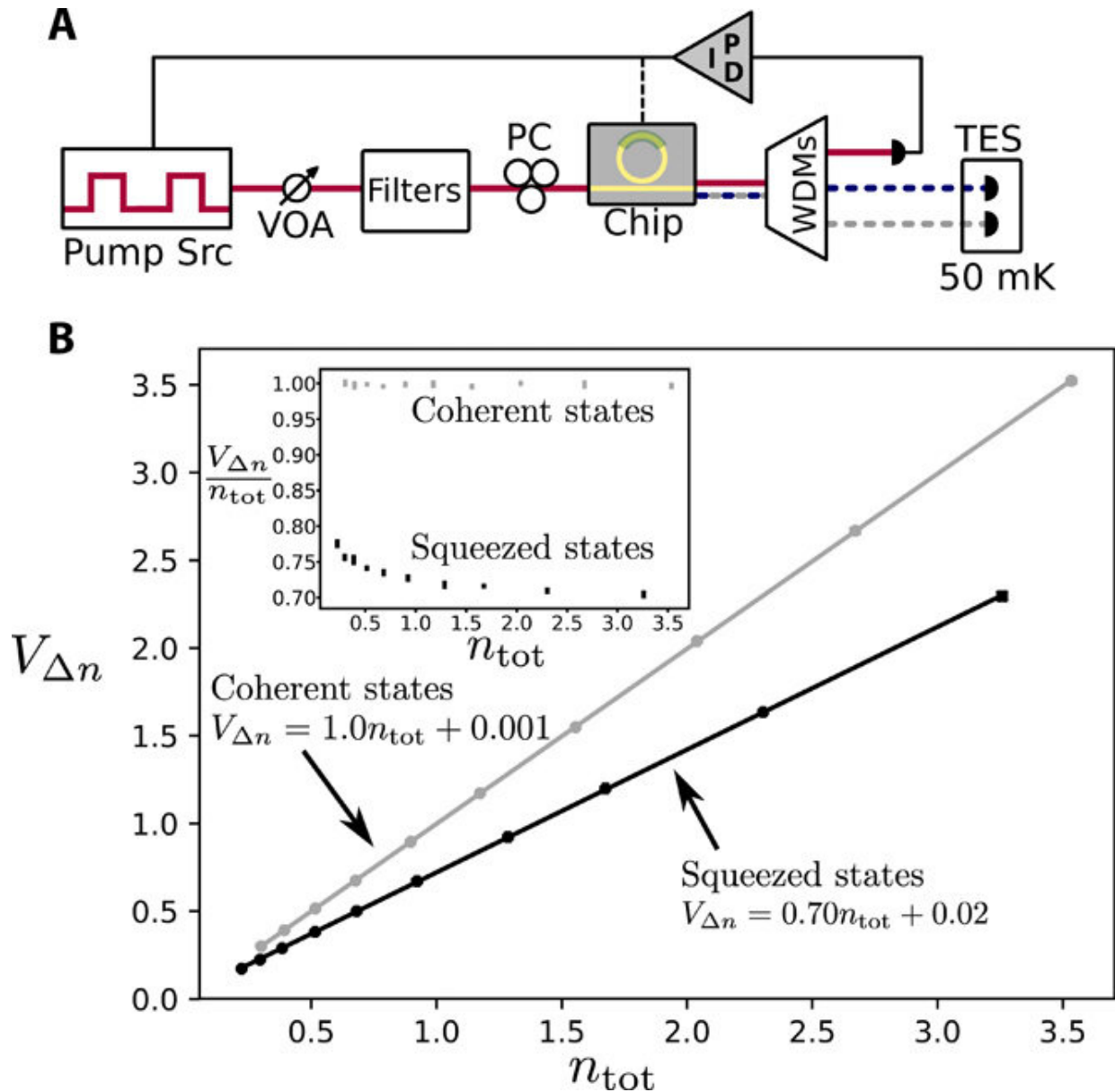
The experimental device itself had simple dimensions, where both quadrature and [photon](#) number difference squeezing could be generated in silicon nitride (Si_3N_4) microring resonators, point coupled to [channel waveguides](#). The setup also included microheaters overlaid for resonance wavelength tuning and stabilization. The scientists used a commercial foundry for fabrication where the waveguide contained silicon nitride fully clad in silicon dioxide (SiO_2). The team used SWFM to generate squeezing and form a pair of signal and idler photons. The experimental setup allowed significant quadrature squeezing at modest input power levels. The team measured the quadrature and photon number statistics from the device and compared the results with [theoretical predictions](#).

Quadrature squeezing - the experiment

The team characterized the quantum state of the resonator output as a two-mode squeezed vacuum state subjected to loss, where the loss arose from the imperfect escape efficiency of the cavity and downstream losses at the coupling point of the chip. The scientists understood this state as a product of two single mode squeezed states: each having a frequency support at both the signal and idler resonances. Vaidya et al. measured the quadrature variances of the modes of interest using [balanced homodyne detection](#), a method that allowed the extraction of information encoded as the phase or frequency of an oscillating signal.



Squeezing and antisqueezing frequency spectrum from 20 MHz to 1 GHz at different pump power levels. Powers listed are inferred values on-chip in the input waveguide. Dashed line is shot noise level; solid lines exhibit fits to the theoretical model, showing strong agreement with the measured data. Credit: Science Advances, doi: 10.1126/sciadv.aba9186



Photon number difference squeezing. (A) Overview of experimental setup. Details in the main text and the Supplementary Materials. (B) Measured photon number difference variance $V_{\Delta n}$ as a function of mean photon number n_{tot} , obtained by varying pump power, for coherent states (gray) and squeezed states (black) with linear fits (solid lines). The reduced slope for the squeezed state represents photon number difference squeezing. Inset: Ratio between number difference variance and mean photon number as a function of mean photon number for coherent states (gray) and squeezed states (black). Credit: Science Advances, doi: 10.1126/sciadv.aba9186

During the experiment, the team coupled a continuous wave pump into the chip to extract light via low-loss edge couplers. The pump excited a single resonance of the microring in the chip to generate light across multiple signal and idler pairs. The team selected one such pair of signal and idler modes with off-chip wavelength filters for analysis. They then produced a bi-chromatic local oscillator and combined this with the signal and idler light on a tunable fiber beam splitter. Based on the outcomes, the scientists estimated about 4 dB of squeezing to be available at the monitoring output on-chip, and obtained broadband squeezing, limited by resonance linewidths. However, aside from losses and limitations of pump power the presence of noise too limited light squeezing. To avoid corrupt light squeezing in devices, therefore, the team assessed the presence of excess noise in the system, within the squeezing band and proposed further optimization steps to improve precision and better assess the effect.

Photon number correlations

Although homodyne measurements accurately evaluated quadrature squeezing, the team also verified the compatibility of a squeezed light source with photon counting. The scientists performed number-resolving detection on the output of the device, for this experiment, they used a microring resonator with a wider cross section. Vaidya et al. then separated the signal and idler generated in the setup and filtered them via wavelength division multiplexing components. They then coupled the output to superconducting [photon number-resolving transition edge sensors](#) (TESs) to provide photon number resolution to about 10 photons per channel. The scientists recorded a notable feature in the work, where they detected a high rate of correlated multiphoton events. The results showed the generation of 'many-photon states' in a nanophotonic platform at much higher rates to motivate the development of

applications that demand squeezed light sources.

In this way, V. D. Vaidya and colleagues generated nearly single temporal squeezed states without special engineering effects due to the resonant nature of the setup. Losses were the primary limiting factor of performance, which can be improved to obtain higher resonator quality factors for better light squeezing effects. The team propose improving the signal-to-noise ratio to improve the generation efficiency by reducing the amount of power required to function at the desired level of squeezing. This will also reduce the number of photons generated due to spontaneous [Raman scattering](#) in the fiber components constituting the device. Care must be taken during noise suppression to prevent suppressing the experimental scheme. The team will naturally form the next steps to engineer chip-integrated squeezed light sources.

More information: V. D. Vaidya et al. Broadband quadrature-squeezed vacuum and nonclassical photon number correlations from a nanophotonic device, *Science Advances* (2020). [DOI: 10.1126/sciadv.aba9186](https://doi.org/10.1126/sciadv.aba9186)

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