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SUPPLEMENTARY INFORMATION

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Supplementary Information: Chemically etched ultra-high-Q resonator on a silicon chip

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I. EFFECT OF WEDGE ANGLE ON OPTICAL Q

As noted in the main text, the physical principle at work in the present structures is distinct from the previous work in reference 15. In particular, because the edge roughness has been eliminated the wedge structure no longer plays the role of isolating the optical mode. This behavior can be observed in the data of figure 2 in the main text and is further confirmed in the model of figure 1 of this supplemental section. Here, the optical Q factor is calculated versus resonator diameter with a fixed oxide thickness of 10 microns and for three different angles. As can be seen in the data, the Q factor steadily improves as the wedge angle is increased.

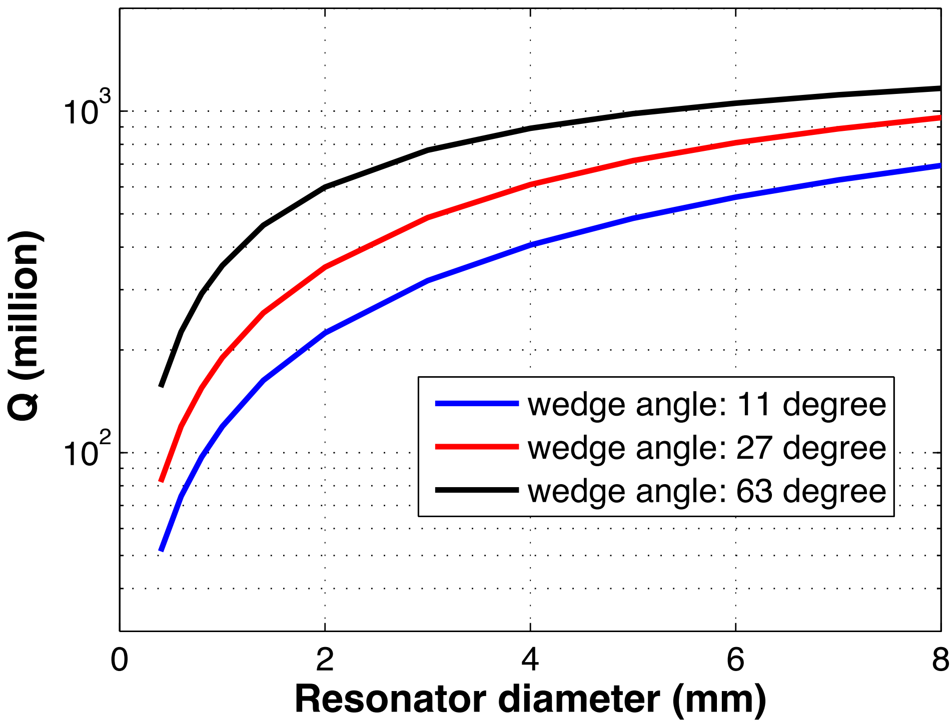

FIG. 1: Optical Q versus diameter for three distinct wedge angles showing the systematic improvement of Q value with increasing wedge angle. The model used is the same as that in figure 2 of the main text.

II. FREQUENCY NOISE OF BRILLOUIN LASER

To characterize the stimulated Brillouin laser (SBL) frequency noise, a Mach-Zehnder interferometer (MZI) having a free spectral range of 6.72 MHz is used as a discriminator and the transmitted optical power is detected and measured using an electrical spectrum analyzer (ESA). To suppress the intensity noise, the complementary outputs of the interferometer were detected using a balanced receiver. This ESA spectrum is related to the frequency-fluctuation spectral density, $S_\nu(f)$, through the following relation:

$$W_{ESA}(f) = \frac{V_{pp}^2 2\pi^2 \tau_d^2 \mathrm{sinc}^2(\tau_d f) S_\nu(f)}{R_L} \tag{1}$$

where τ_d is the Mach-Zehnder delay and V_{pp} is the peak-to-peak voltage of the detected MZI output over one fringe. Using this formula, the frequency-fluctuation spectral density is plotted in Figure 2a. The singularity in the plots at 6.72 MHz is an artifact of the data conversion near the zero of the sinc^2 function. The frequency fluctuation spectra have a relatively flat (white noise) region for carrier offset frequencies above 2 MHz and then a $1/f$-like region at frequencies below 2 MHz. The value of the white noise region is plotted both as a function of SBL power and external cavity Q factor in Figures 2b and 2c, respectively. Also plotted are fits to inverse power and inverse Q^2 curves. These

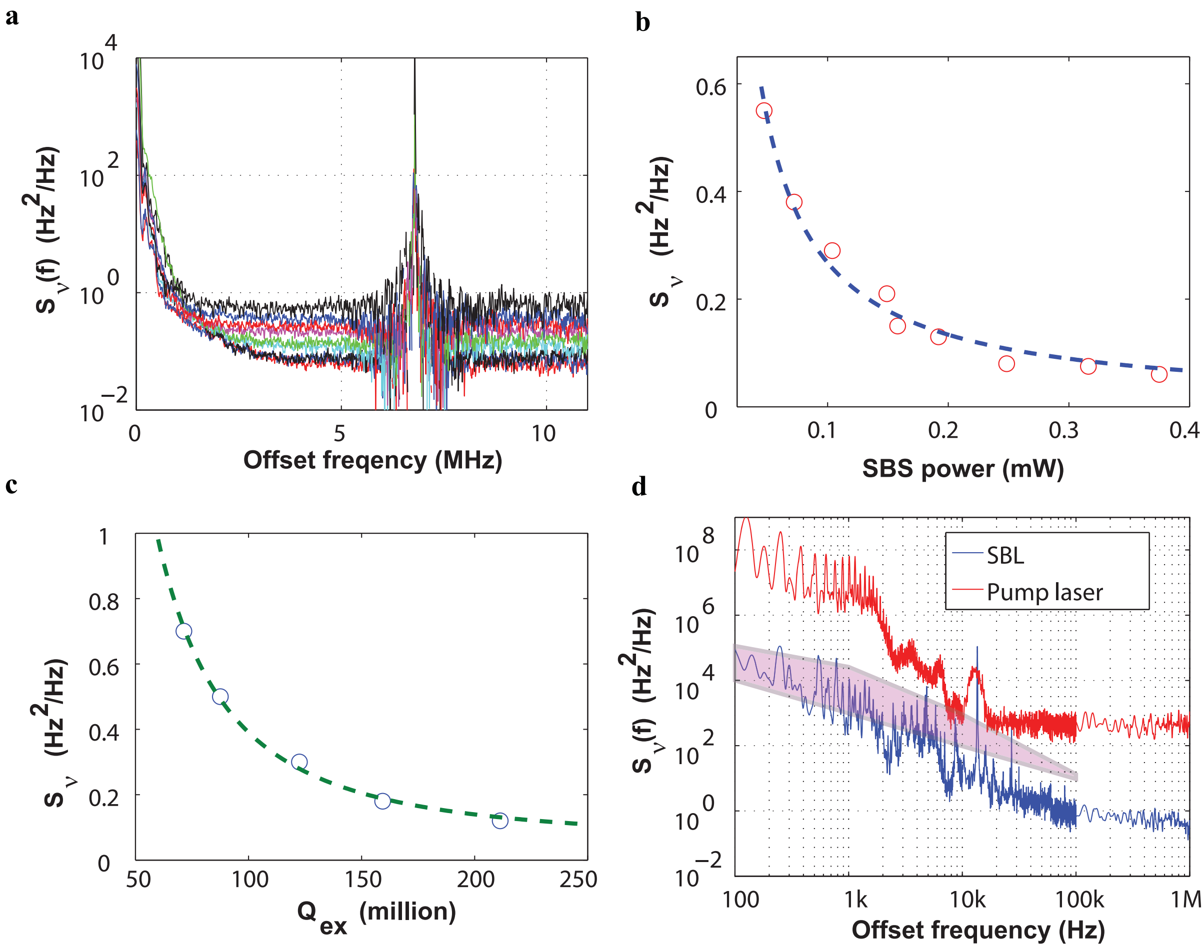

FIG. 2: Measurements of the SBL frequency noise characteristics. **a,** Laser frequency noise spectrum at different output power levels from 0.047 mW to 0.375 mW (indicated by color). **b,** ST noise plotted versus output power. The dashed line is an inverse power fit to the data. **c,** ST noise plotted versus the external cavity quality factor Q_{ex}. The dashed line is a fit using the function $\frac{Q_0+Q_{ex}}{Q_{ex}^2}$. **d,** A typical SBL frequency noise spectrum and the pump laser (external cavity diode laser) frequency noise spectrum at offset frequencies from 100 Hz to 1 MHz. The shaded region is the frequency noise performance of commercial, narrow linewidth fiber lasers.

dependences as well as calculation confirm that the measured frequency noise component is the Schawlow-Townes (ST) quantum noise of the laser. The minimum value of 0.06 Hz^2/Hz is to our knowledge the smallest recorded ST noise for any chip-based laser. It is also interesting to note that, to the authors knowledge, the ST noise dependence on loading has not previously been recorded. This, normally difficult measurement, was possible here on account of the ability to vary the taper loading of the resonator[1].

The $1/f$ noise that appears at lower carrier offset frequencies is given in Figure 2d and approximately tracks a similar-shaped noise spectrum in the laser pump over this frequency range. However, the absolute level of $1/f$ noise of the SBL at a given offset frequency is reduced by about 30 dB relative to the $1/f$ noise in the pump. Indeed, the level of technical noise in this band is comparable to several commercial fiber lasers that were characterized as part of this study. As such, the performance of the SBL, both in the quantum limited ST regime and the technical-noise limited $1/f$ regime, is excellent.

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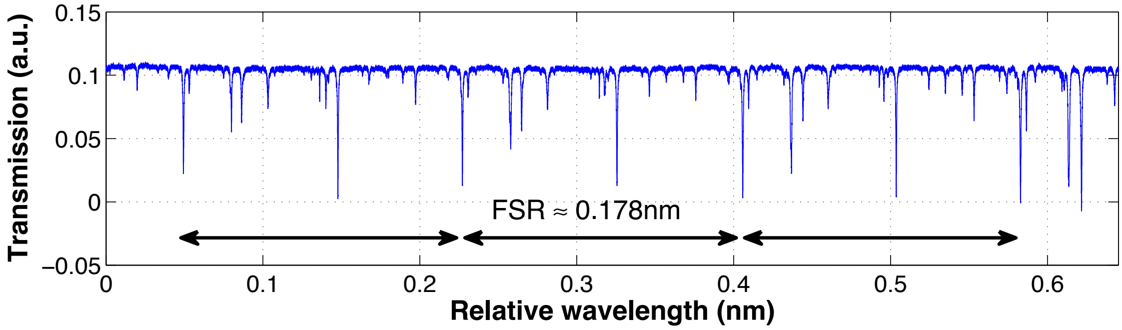

FIG. 3: Broad spectral scan over 3 free spectral ranges (FSR) of a 3 mm diameter resonator.

III. BROAD SPECTRAL SCAN OF THE RESONATOR

Figure 3 provides a wide spectral scan of a resonator with a diameter of 3 mm and a corresponding free spectral range (FSR) of approximately 0.178 nm. The scan includes 3 complete FSRs.

[1] Spillane, S., Kippenberg, T., Painter, O. & Vahala, K. J. Ideality in a fiber-taper-coupled microresonator system for application to cavity quantum electrodynamics. *Phys. Rev. Lett.* **91**, 043902 (2003).