On-chip Q-factor greater than 1 billion

Lue Wu[1,†], Heming Wang[1,†], Qi-Fan Yang[1,†], Maodong Gao[1], Qing-Xin Ji[1,2], Boqiang Shen[1], Chengying Bao[1], and Kerry Vahala[1,*]

[1] *T. J. Watson Laboratory of Applied Physics, California Institute of Technology, Pasadena, CA 91125, USA*
[2] *School of Physics, Peking University, Beijing 100871, China*
[*] *vahala@caltech.edu*

Abstract: A record Q-factor of 1.1 billion is demonstrated in on-chip silica whispering-gallery resonators. Using the devices, sub-milliwatt parametric oscillation threshold is measured in 9 GHz free-spectral-range devices.

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Optical microresonators with ultra-high quality factors (Q-factors) are ideal platforms for study of a wide range of phenomena including nonlinear optics and cavity quantum electrodynamics [1]. They are also powerful tools for applications including spectrometers, ranging systems, ultra-stable microwave sources and gyroscopes. Here, by employing optimized fabrication methods, a record on-chip Q factor of 1.1 billion is demonstrated for wedge resonators [2]. As an additional verification of the Q factor, sub-milliwatt parametric oscillation threshold is demonstrated at the challenging free-spectral-range (FSR) of 9 GHz.

Devices are fabricated using a combination of lithography and wet and dry etching. Intrinsic Q factors are measured by characterizing resonance linewidths (accounting for loading effects) and through cavity ring down measurements. Fig. 1a plots the highest intrinsic Q-factors Q_0 obtained at device diameters ranging from 3 mm to 7.2 mm. The near-linear dependence of Q_0 on diameter (red dashed line) indicates an approximately constant finesse according to $Q/D = n\pi/\lambda_{res} \times F$, where F is finesse, n is refractive index and λ_{res} is resonance wavelength.

Using a device having an FSR of approximately 10 GHz, the full-width-at-half-maximum (FWHM) linewidth is measured (at 1585 nm) to be 220 kHz, corresponding to a loaded Q factor Q_L = 860 M. By measuring the

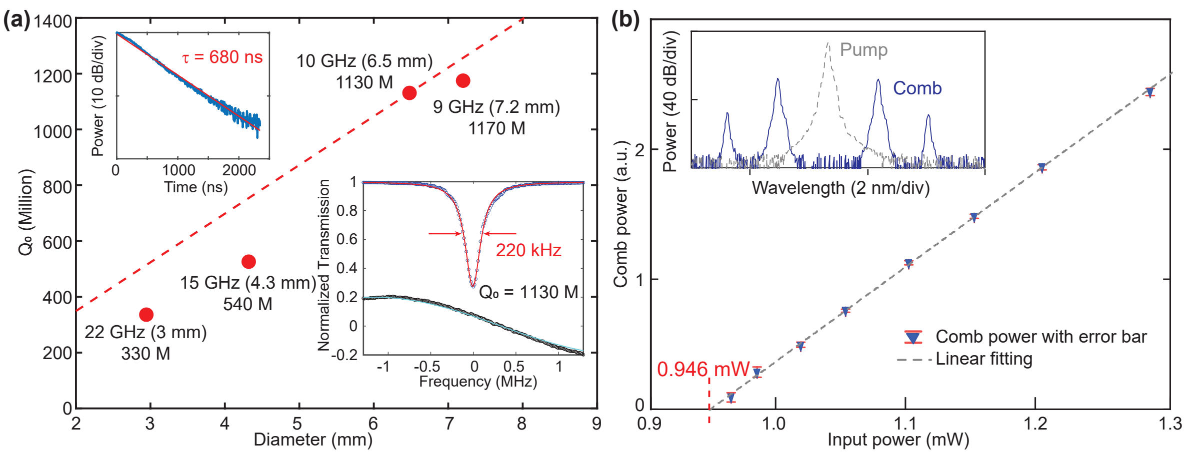

Fig. 1. (a) Q_0 data for microresonators with varying size. Red dashed line corresponds to a finesse of 60,000. Right inset: Resonance linewidth measurement of a 10 GHz device at 1585 nm. Top trace shows measured resonance transmission (blue dots) with Lorentzian lineshape fitting (red curve). Bottom trace shows measured output of a Mach-Zehnder interferometer (black dots) with sinusoidal fitting (cyan curve) to calibrate the frequency (the FSR of the interferometer is 5.979 MHz). The linewidth is fitted to be 220 kHz, corresponding to intrinsic Q_0 =1.1 billion and loaded Q_L = 860 M. Left inset: Ring down measurement of the same device. Measured output power (blue) is fitted with an exponential decay function (red), giving fitted photon lifetime of 680 ns, corresponding to loaded $Q_L \approx$ 810 M. (b) Plot of parametric oscillation power versus input pump power for a 9 GHz device at 1550 nm. Linear fitting gives parametric oscillation threshold of 0.946 mW. Inset: Optical spectrum of pump (dashed gray) and parametric oscillation comb (solid blue) with 1.12 mW input power.

transmission depth, a coupling Q factor of $Q_1 = 3.6$ billion is determined from which an intrinsic $Q_0 = 1.1$ billion is inferred. For the same device, the fitting of ring-down of intracavity power gives a photon lifetime of about 680 ns, which corresponds to a loaded Q factor of approximately 810 million. The linewidth and ring-down data agree well with each other. To the authors' knowledge these are the highest optical Q factors reported for on-chip devices.

To further confirm the Q measurements, parametric oscillation threshold is measured. As shown in Fig. 1b, sub-milliwatt on-chip oscillation threshold (0.946 mW) is achieved using a 9 GHz FSR device at 1550 nm. This is a record low threshold for this low FSR [3]. The comb spectrum just above the threshold (1.12 mW input power) is presented in the inset. For the measurement, the pump was nearly completely filtered to obtain the threshold plot. It has been inserted in the parametric oscillation comb spectrum as the dashed curve in the inset.

In summary, we have demonstrated a record on-chip Q-factor of 1.1 billion in silica optical resonators. The Q values were also verified by measurement of the parametric oscillation threshold, which is also a record low value at the FSR value of 9 GHz. The resulting improvement in Q will benefit low-power applications for soliton microcombs [4,5] and Brillouin lasers [6].

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† These authors contributed equally to this work.

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