Loading short pulses into long lifetime cavities

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Abstract: We demonstrate the loading of very short optical pulses into a high-Q cavity with linewidth much narrower than the pulse frequency envelope. We show that loading into the cavity is significantly enhanced if the pulse is combined with a cw-field, thus altering the pulse frequency profile to better match the cavity profile.

An essential aspect of integrated silicon-nitride micro-resonators is their ability to store optical pulses, which is quantified by their quality factor, narrow frequency linewidth and long cavity lifetime. Recent advances in chip fabrication have dramatically reduced waveguide propagation loss and thus enabled Q factors of more than 10^6. However, the corresponding reduction in the resonance linewidth means that short optical pulses, whose frequency spectrum exceeds the cavity linewidth, interact less efficiently with the cavity, which makes high-Q resonators less suitable for short pulse storage and interaction.

Here we demonstrate enhanced loading of short optical pulses in a high-Q, narrow linewidth resonator by inducing coherent virtual absorption [1] through the addition of a cw-component to the input pulse. We achieve very high-Q for the targeted probe resonance by providing parametric gain through an optical pump that is resonant with a resonance many free spectral ranges away from the probe resonance (Fig1).

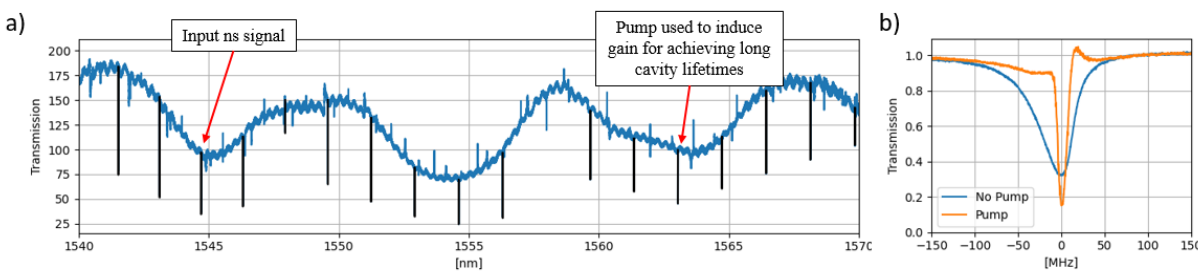

Figure 1: a) Transmission spectrum around the pump and probe resonance b) Transmission spectrum of the cavity in resonance with the signal with and without the gain from the pump

The effect of the cw-pulse offset on the cavity loading can be understood from the spectra in Fig2, where the Fourier transform of a short pulse (3ns FWHM) with and without a cw offset is compared to the high-Q cavity transmission spectrum with a cavity lifetime of ~50ns, which we extract via a separate ringdown measurement. The cw-offset adds a sharp peak at the DC component, thus rendering the pulse spectrum more similar to the cavity transmission spectrum.

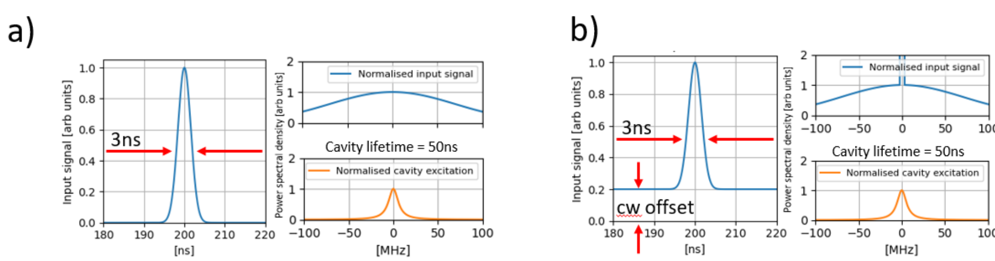

Figure 2: a) Cavity input pulse without offset (left) and the corresponding power spectrum compared to the narrow cavity spectrum (right). b) Cavity input pulse with spectral shaping via 20% offset (left) and the power and cavity spectrum (right)

In Figure 3a we quantify the pulse loading into the cavity by comparing the integrated output pulse (orange area in Fig3b,c) to the integrated input pulse (blue area in Fig3b,c) and plot this normalised ratio of cavity loading, given by *(Input Area – Output Area) / Output Area,* for different intrinsic cavity loss rates (black data points, Fig3a). This is compared to the theoretical ratio extracted from coupled mode theory, with and without a signal offset. Figure 3a shows that this ratio is only weakly dependent on the intrinsic cavity loss rate in the case of an input signal without offset without signal matching (blue curve in Fig3a). However, when adding an input offset of 50% to the input signal the the ratio of cavity loading becomes strongly dependent on the intrinsic cavity loss rate.

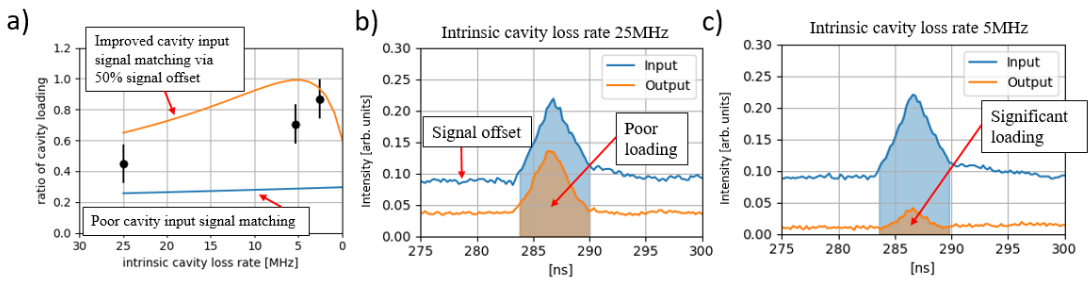

Figure 3: a) normalised ratio of cavity loading as function of intrinsic cavity loss rate. If the input signal is poorly matched to the cavity (blue line) the loading is poor and is weakly affected by a change in intrinsic loss rate. Adding a 50% offset to the input signal (orange line) makes the cavity loading more efficient as well as dependent on the intrinsic cavity loss rate b,c) Pulse loading for high (b) and low (c) intrinsic cavity loss rate.

In summary we show a method of matching the cavity input signal spectrally to the cavity, enhancing the loading of short pulses.

References

[1] G. Trainiti, Y. Ra'di, M. Ruzzene, A. Alù, *Coherent virtual absorption of elastodynamic waves*, Science Advances 5, eaaw3255 (2019)