Sustained GHz Oscillations in Ultra-high Q Silicon Microresonators

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Abstract: We report the experimental observation of long-sustained GHz electronic oscillations resulting from coupled electron-photon dynamics in ultra-high-Q Si microdisk resonators with CW pumping. Theoretical analysis identifies conditions for steady-state GHz oscillations while suppressing thermal oscillations.

Recent advances in fabrication of Si photonic devices have enabled the realization of ultra-high Q silicon resonators in a SOI platform [1]. High Q and low electromagnetic mode volume of these resonators can build up a strong electromagnetic field inside them, even at low optical powers. The high circulating intensities result in free-carrier (FC) generation through two-photon absorption (TPA). As a result, complex dynamics such as self-induced MHz modulation of the optical response of the resonator through the interplay of photons, electrons and phonons (heat) can be observed [2,3]. In this work, we report the observation of long-sustained GHz electronic oscillation (thorough the electron and photon interplay) in the transmission response of an ultra-high Q microdisk resonator which is coupled to a waveguide. The key requirement, to observe this phenomenon, is to have the photon lifetime close or larger than the FC lifetime in the resonator. We also theoretically show the conditions for the generation of pure and self-sustained GHz oscillations.

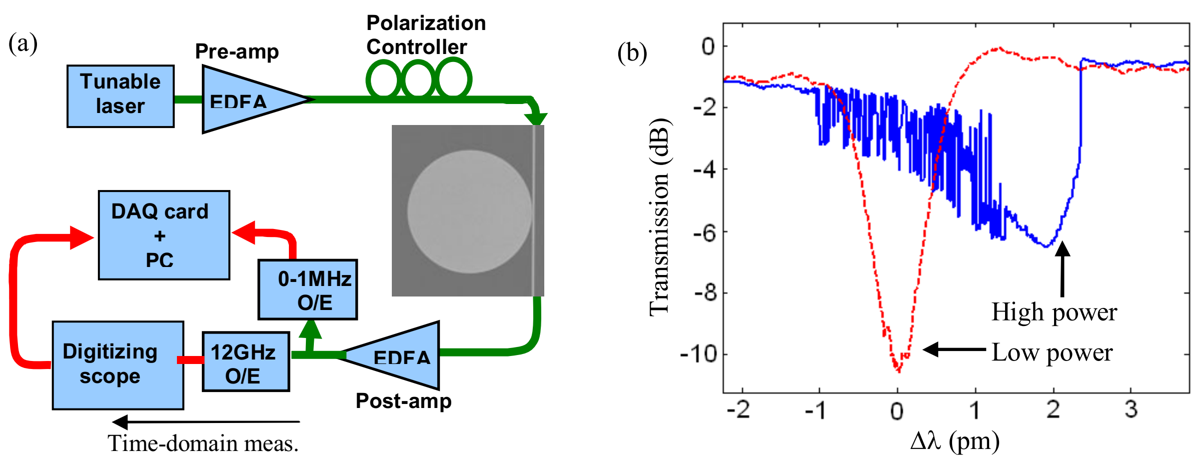

Fig. 1: (a) Diagram of the setup used for monitoring the time domain and spectral domain response the resonator. The SEM image of the measured microdisk is shown in the setup. The microdisk has a radius of 20 mm and a thickness of 230 nm, on an SiO2 substrate and covered by air. (b) Resonance spectrum of the microdisk at low (60 μW) and high (10 mW) input powers coupled from the laser to the waveguide facet. The input facet insertion loss is ~ 15-20 dB. The measured unloaded Q of this resonator is ~ 2.2 millions.

Figure 1(a) shows the diagram of the experimental setup used for measuring the spectral as well as temporal response of the resonator. For the temporal measurements a high-speed optoelectronic (O/E) converter and a high-speed oscilloscope are used. Figure 1(b) shows the measured spectrum of one of the resonance modes of the microdisk at two different levels of low and high powers as specified in the figure. An intrinsic Q_0 ~ 2.2 millions was observed for this mode. The high power spectrum shows the onset of thermal oscillations and lineshape broadening in the transmission response. More details of the temporal dynamic are shown in Figure 2 for a fixed pump wavelength close to the cold cavity resonance. As seen from Fig. 2(a) (the top one), simultaneous steady-state MHz thermal oscillation and long-sustained GHz oscillations (with a frequency of ~ 0.53 GHz and over 110 periods) are observed. The frequency of this oscillation is mainly defined by FC life time, photon lifetime, the input power, and the detuning of pump wavelength from the cold cavity resonance. More details of the long-sustained oscillations are shown in Fig. 2(a) (the bottom one). As a result of the degradation of the Q of the cavity over time,

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as well as resonance shifts due to ambient temperature fluctuations, we noticed the microdisk showed damped oscillations (when tested at a later time). This is shown in Fig. 2(b) (the top one), where simultaneous steady-state MHz thermal and damped GHz oscillations are observed (with more details of the damped oscillation in Fig. 2(b) (the bottom one)). We also theoretically studied the dynamic of this system and found out the good match between the theory and experiments in Fig. 2. As a further step, we performed a detailed theoretical analysis to find the resonator parameters which results in sustained GHz oscillations without the appearance of MHz thermal oscillation. Figure 3 shows an example of such case where steady-state GHz electronic oscillations is observed in the resonator response. Such steady state oscillations generated from a CW pump can enable a variety of applications in analog signal synthesis. More details of this work will be presented in the conference.

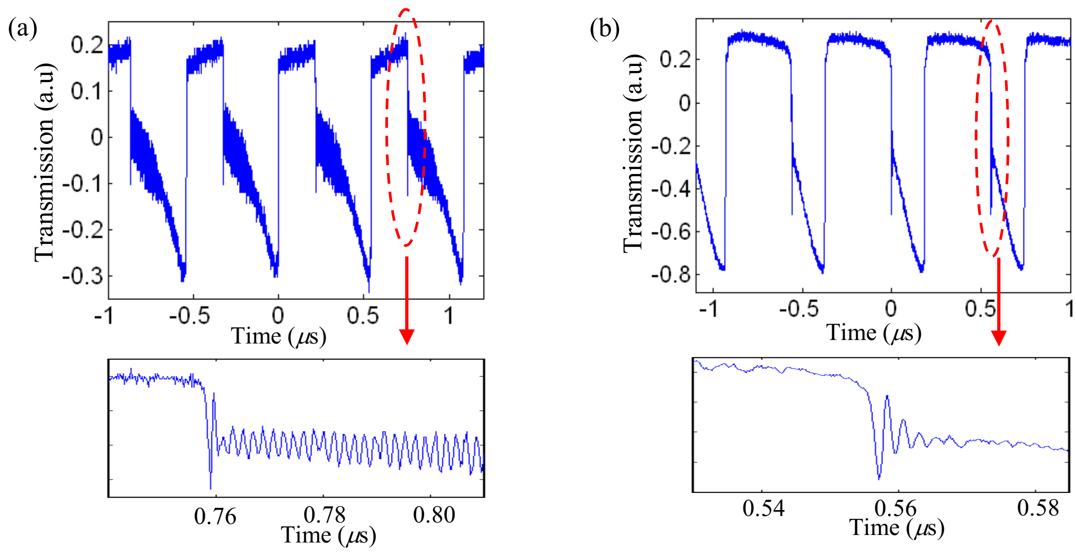

Fig.2: Experimental results for a microdisk resonator with parameters given in Fig. 1. (a) Top: Observation of simultaneous steady-state MHz thermal and long-sustained GHz oscillations. Bottom: A zoomed view of the GHz oscillations which has a frequency of 0.52-0.54 GHz. The oscillation is sustained for over 110 periods. (b) Top: Observation of simultaneous steady-state MHz thermal and damped GHz oscillations. Bottom: A zoomed view of the damped GHz oscillations in the specified zone.

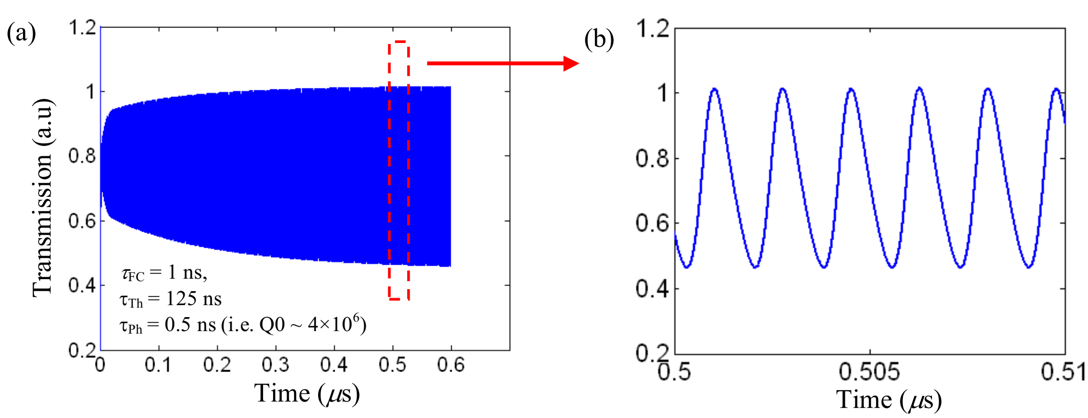

Fig. 3: (a) Theoretical observation of self-sustained oscillations in the time domain response of a Si microdisk resonator with a radius of 20 μm, a mode volume of 190 $(\lambda_0/n)^3$, and an intrinsic $Q_0 = 4\times10^6$ which is critically coupled to a waveguide. The inset shows the other resonator parameters. The input power level in the waveguide is 1 mW. (b) The zoom of this response which shows an oscillation frequency of 0.56 GHz. The pump wavelength detuning from the cold cavity resonance is set to zero.

References

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