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Opto-Mechanical Chaotic Behaviour of Micron-Scaled On-Chip Resonators

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Abstract- **Opto-mechanical vibration of an on-chip oscillator is experimentally excited by radiation-pressure nonlinearity to a regime where oscillation is chaotic. Period-doubling and broad power spectra are measured in spherical- and toroidal-resonators.**

Radiation pressure (RP) can push the boundaries of an optical cavity to change its optical path [1-3]. In the past, the resulting coupling between optical and mechanical motions was shown to induce bistable hysteretic response [1]. Later on, periodic mechanical oscillations [4-6] were shown in the instable regime wherein a periodic analytical solution [7] was recently calculated. In reference [4] it was shown that at higher powers a transition to apparent chaotic behaviour is observed. However, so far there has not been a systematic experimental study of the unstable regime.

Herein we demonstrate how a continuous wave (CW) input excites a non-periodic vibration of the optical-resonator structure. The simple experimental setup (fig. 1a) consists of a CW optical-input that is evanescently coupled to a circular cavity [8] through a tapered fiber [9, 10]. Power is also coupled out of the cavity in the same manner. RP of the intra-cavity light pushes the cavity to inflate, forcing the optical resonance wavelength to expand with this mechanical inflation. This resonance drift (from pump wavelenght) turns off the intra-cavity light. With no light inside to maintain the mechanical flex, the cavity deflates back towards mechanical equilibrium and is charged again with light. The cycle repeats itself then perpetually but not necessarily periodically. The equations describing this dynamic are given in reference [4], and solving these equations confirms the experimental behaviour that will be described here. It should be emphisized that the optical imput is continous; furthermore, no external modulation or feedback are used in this work. At low input intensity (i.e., slightly above mechanical oscillation threshold), the optical power emitted from the spheroid resonator is modulated at 0.538GHz (fig. 1b) by oscillation of a mechanical mode having this same eigen-frequency. As optical power increases, period doubling is observed (fig. 1c). At yet higher input-power levels the power spectrum becomes broad (fig. 1d). In the next experiment the spherical oscillator is replaced with a toroidal oscillator (fig. 2) to illustrate operation in different freqency regime as well as to showing that phenomena are not limited to a specific oscillator geometry. The spectral evolution for the toroid is the same as for the sphere except for the appearance of a period-four cycle (i.e., two times period-doubling). Measuring the modulated power in the temporal domain (fig. 2 middle) allows observation of the phase plot showing evolution

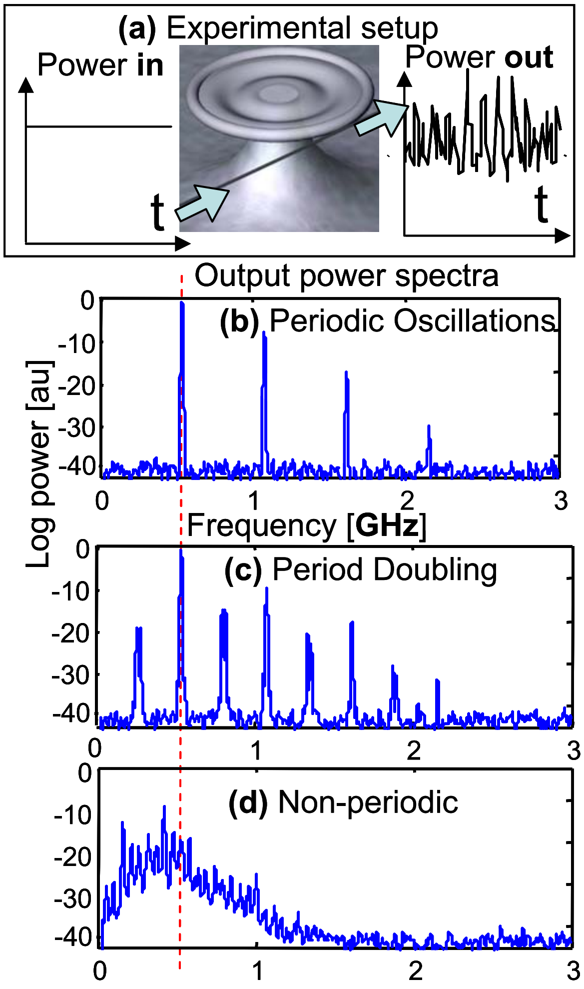

Fig. 1: **Experimental setup and results:** (a) Continuous optical power is fiber coupled to an on-chip micro-resonator wherein the centrifugal radiation pressure excites mechanical vibration (vibration amplitude was exaggerated in drawing). Oscillation in **spherical cavity** starts periodic (b), doubles its period (c), and then turns non-periodic (d) as input power increases.

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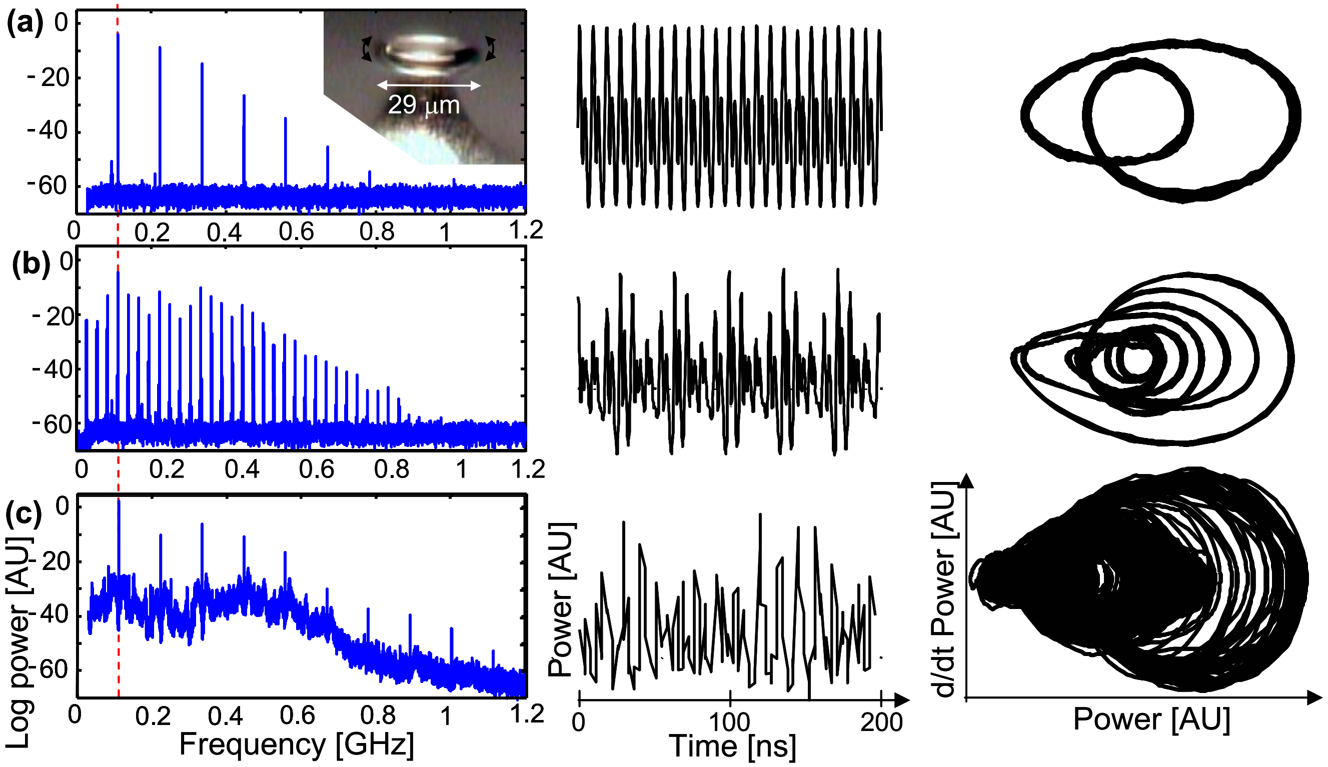

Fig. 2: **Experimental results:** As input power increases, the periodic oscillation (a) of a **toroidal microcavity** doubles its cycle twice (b) and then turns non-periodic (c). Oscillation at output power is measured in the frequency domain as well as in the temporal domain. Phase-space plots of ∂t power versus power are also shown.

from a periodic cycle (fig. 2 a-b) to area-filling plot (fig. 2c) asociated with the vanishing of the periodicity. As for the sensitivity to initial conditions, the Lyapunov exponent derived from the dynamical equations [4] is calculated to change from zero to a positive value as power is increased (e.g. as in fig. 1 b-d); thus further confirming the chaotic character of RP nonlinearity.

In conclusion, there is growing interest in the manifestation of radiation pressure [11-13] as nonlinear mechanism. In this work, we have made the first systematic study of the transition to chaotic behaviour in a microcavity embodiment. Taking into account the continuous trend of miniaturization and loss reduction in optical microcavities of all forms, it is believed that the behaviours observed here will ultimately be observable in many cavity types.

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