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Mechanical idler generation

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Introduction

Micro/nanoelectromechanical systems provide a platform to study quantum effects in macroscopic systems and to realise ultra-precise sensors [1]. Recently attention has turned towards their non-linear properties which can be controllably accessed [2,3]. Non-linear optics demonstrates the successful marriage of non-linearities with optical systems which has given rise to a plethora of new and unexpected phenomena [4,5]. Thus, it is highly desirable to exploit non-linearities in the mechanical domain in order to expand the functionality portfolio of electromechanical systems which could potentially lead to accessing the diverse functionality of non-linear optics in an on-chip electromechanical platform.

The archetypal example of non-linear optics is sum/difference frequency generation which enables the frequency of a laser to be tuned [4]. This is achieved by exploiting the interaction of a high frequency and high intensity pump beam (ω_p) with a low frequency and lower intensity signal beam (ω_s) in a crystal whose nonlinearity is activated by the pump i.e. the Kerr effect. The mixing of photons mediated by the nonlinearity amplifies the signal beam as well as generating an *idler* beam (ω_i) where this process conserves both energy and momentum. Here we realise this phenomenon in an electromechanical resonator by activating a periodic nonlinearity in the mechanical eigenfrequency via piezoelectrically induced strain to create a mechanical idler that is nearly an octave away from the signal and pump excitations (see Fig. 1a).

Results

The experiments were performed in a gallium arsenide based electromechanical resonator shown in Fig. 1b which hosts multiple piezoelectric transducers that permit harmonic actuation as well as enabling controlled manipulation of the mechanical spring constant (and thus the eigenmode) with the introduction of piezoelectric strain [6]. The mechanical resonator exhibits a fundamental mode at $f_0 = \omega_0/2\pi$ = 280720 Hz with a quality factor of Q_0 = 340000 and the first mode at $f_1 = \omega_1/2\pi$ = 764177 Hz with a quality factor of Q_1=90000 respectively.

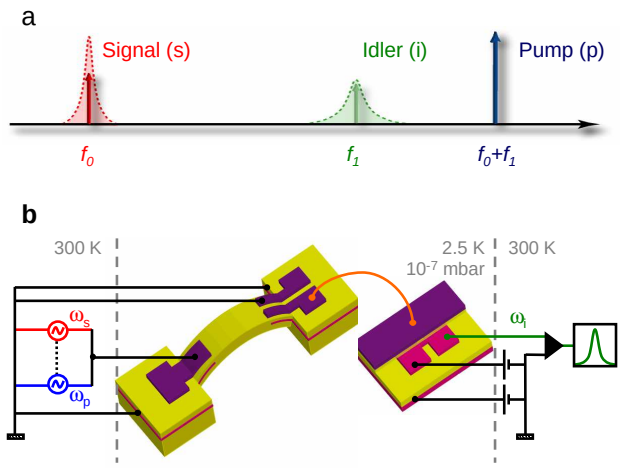

Figure 1: (a) A schematic profile of the measurement where the fundamental and first modes are parametrically coupled via the pump. (b) The signal and pump excitations are applied to the largest piezoelectric transducer on the mechanical oscillator (yellow) defined by the Au top-gate (purple) and the two dimensional electron gas (pink). The mechanical motion induced piezovoltage is measured in a spectrum analyser after being amplified by an on-chip nanotransistor with the source-drain V_{SD}=0.6 V and the back-gate V_{BG}=16.5 V biased yielding a gain of 30 dB and a room temperature amplifier with a gain of 10^6 VA^{-1} [6].

In analogy to the principle of sum/difference frequency generation we apply a weak signal excitation at $\omega_s = \omega_0$ and a strong pump excitation (suffi-

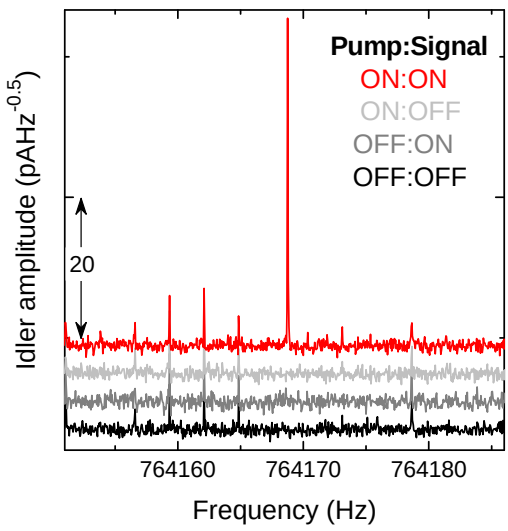

Figure 2: The ω_1 idler measured as a function of pump $\omega_0 + \omega_1$ and signal ω_0 with actuation amplitudes of 200 $\mathrm{mV_{rms}}$ and 300 $\mu\mathrm{V_{rms}}$ respectively where all the traces are offset for clarity. The idler can only be observed when both the signal and the pump are activated and only within the bandwidth of the first mode thus confirming its all mechanical origin.

ciently large so that it can modulate the mechanical eigenfrequencies and thus mix the different oscillation modes) at $\omega_p = \omega_0 + \omega_1$ which results in the creation of an idler at $\omega_i = \omega_p - \omega_s = \omega_1$ as shown in Fig. 2. The idler can only be observed when both the signal and the pump are activated. Detailed measurements of the idler as a function of signal and pump combined with a simple phenomenological model which captures the idler dynamics confirms the all mechanical nature of the idler generation [7].

Conclusions

The mechanical idler generation could be used for digital signal processing applications [6] but more excitingly the parametric intermodal coupling opens up a channel to manipulate the fundamental mode via the first mode or vice-versa which could lead cooling of a given oscillation mode at the expense of heating another oscillation mode in just a single mechanical resonator [8].

References

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