Silicon Optomechanics

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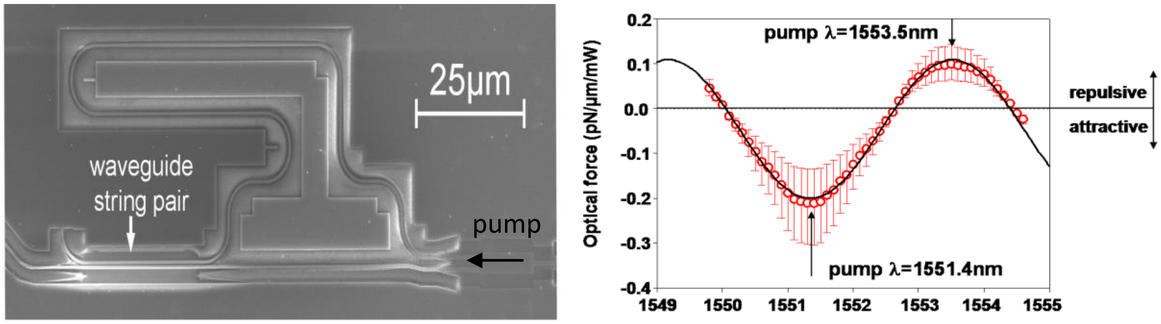
Abstract: Optomechanics might provide the key to realize various signal processing functions on a chip. In this proceeding we focus on silicon Nano-Optomechanical Systems (NOMS) and provide an overview of several types of optomechanical devices.

1. Introduction

Besides the well known optical trapping of microparticles in laser beams [1], the optical gradient force also enables actuation of nanophotonic components [2][3]. Hence a new class of components was created: Nano-Optomechanical Systems (NOMS), an interesting candidate for realizing all-optical functionality such as all-optical switching via a NOMS circuit [4]. On the more fundamental level the recent developments in optomechanics are quickly leading towards intriguing physical phenomena such as observation of quantum mechanical behavior of a micromechanical oscillator [5][6]. On the more practical level full integration (both access waveguides and optomechanical components on a chip) of the devices is needed. Besides all-optical components also on chip reference oscillators and widely tunable RF-filters in the optical domain are possible applications. In this paper, we will review a variety of integrated optomechanical devices designed and fabricated in silicon-on-insulator.

2. Attractive and repulsive forces between parallel waveguides

Using Deep-Ultra-Violet lithography and subsequent RIE etching [7] a passive nanophotonic can be defined in a silicon-on-insulator wafer (top Si layer with 220nm thickness). Buffered HF is used to etch the underlying SiO_2 at some parts of the chip such that freestanding structures are created. Light can be coupled in and out of the chip using two grating couplers. Experiments are performed in a vacuum environment (p<<1mBar) to avoid air damping and achieve a sufficiently high mechanical quality factors. In the simplest configuration when a single waveguide is suspended, an out of plane attractive force towards the substrate will arise when light is sent through [8]. In a configuration with two parallel waveguides a superposition of two guided modes are present (ground mode is attractive in nature while the first mode pushes the waveguides apart). While the ground mode is providing a gap closing force, the first order mode pushes the waveguides apart. If the parallel waveguides are excited through only one waveguide both modes are excited equally which results in a net in plane attractive force [8]. When implementing an asymmetric Mach-Zehnder interferometer in front of the coupler the modes can be controlled by sweeping the wavelength. Both attractive and repulsive forces can be observed experimentally (Fig.1b) [10][11].

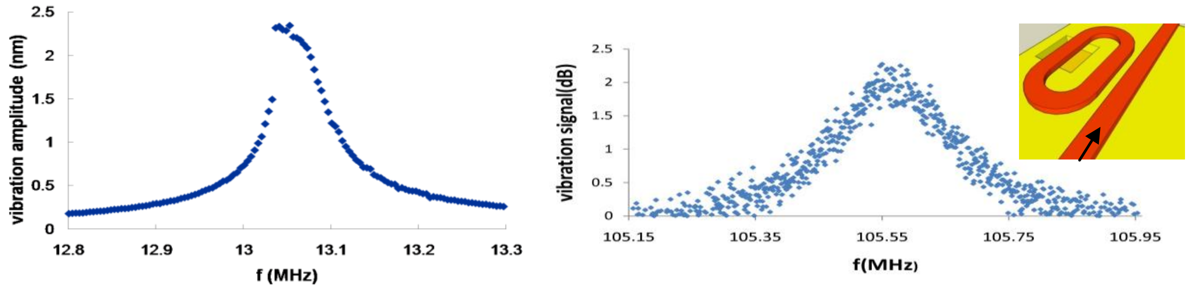


(a) (b)

Fig. 1. (a) SEM picture of the structure used in [10] to select between the two propagating modes. (b) The optical force is varying from attractive to repulsive in function of the wavelength.

3. Enhancing the optical force: slots and resonators

In a slotted waveguide the light is mainly confined in the small air gap. Due to the related strong field gradients slotted waveguides exhibit relatively large optomechanical effects. In Fig. 2a an experimental forced vibration spectrum is shown [12] from a 12µm long freestanding slotted waveguide (beam width 230nm and height=220nm, gap=120nm). The vibration spectrum shows a peak of approximately 2.5nm around 13.05MHz and a jump that is caused by the inset of non-linear mechanical spring hardening at large vibration amplitudes. The slot waveguide was placed in a Fabry-Pérot cavity to translate the vibration induced phase modulation into power modulation.



(a) (b)

Fig. 2 (a) Vibration amplitude spectrum for 1mW modulated optical power in a freestanding slotted waveguide with jump non-linearity.- (b) thermal 'brownian' response of a freestanding beam in a racetrack resonator for λ=1557.5; schematic representation of the structure (inset)

If the micromechanical oscillator is placed in an optical ring or racetrack resonator as shown in Fig. 2b (inset) again out of plane optomechanical interaction is possible between the freestanding waveguide in the ring resonator and the substrate [13], however the interaction is enhanced by the optical resonator (finesse≈200). The brownian displacement noise of the ground mode of such a freestanding beam is shown in Fig. 3b. When light is circulating inside the resonator we can pick up the signal of the fundamental mode (105.55MHz, mechanical Q≈370) of the released beam (length 2.6µm, width 500nm, thickness=220nm) resulting in a displacement sensitivity of 8fm/rtHz.

5. Conclusion

We have demonstrated repulsive and attractive forces between waveguides. Slotted waveguides and racetrack resonators enhance optomechanical effects strongly, possibly leading towards integrated functional NOMS circuits.

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