Optical gradient force in a slot waveguide on a Silicon-on-Insulator-Chip

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We present the fabrication and characterization of a subpicogram micromechanical oscillator in a slot waveguide that is actuated through optical gradient force. The tunable slot width in fact creates an optomechanical phase modulator on a Silicon-on-Insulator-Chip.

I. Introduction

Recently significant progress has been made to control gradient optical forces on a chip [1]. Optomechanics provides an exciting and promising way to realize various optically tunable integrated devices and to control read-out and actuation of micromechanical resonators on a chip. Furthermore better understanding and controlling of on-chip optical forces might have important consequences in the field of optical cooling of micromechanical resonators. In this proceeding we present for the first time optical gradient force in a slotted waveguide. The proposed device is in fact an optomechanical integrated phase modulator. The vibrating slotted waveguide is placed in a Fabry-Pérot cavity (one integrated distributed Bragg Reflector (DBR) before and one after the slot) to translate the induced phase modulation into measurable output power modulation. The slot waveguide tapers to a 1.2µm wide wire in which a grating (20 periods, see Fig.1 for the exact dimensions) is etched. The reflectivity is designed to be around 80%.

II. Device fabrication

A slotted waveguide is defined in the top layer of a SOI wafer (top layer monocrystalline Si: thickness t=220nm + buried oxide layer: thickness h=2µm) using CMOS-compatible Deep-Ultra-Violet lithography. Afterwards a resist mask is applied to define a freestanding region in the slotted waveguide (Figure 1). The underetch is performed with wet buffered HF and the samples are dried afterwards using a CO_2 Critical-Point-Drying process to prevent damage due to surface tension during drying.

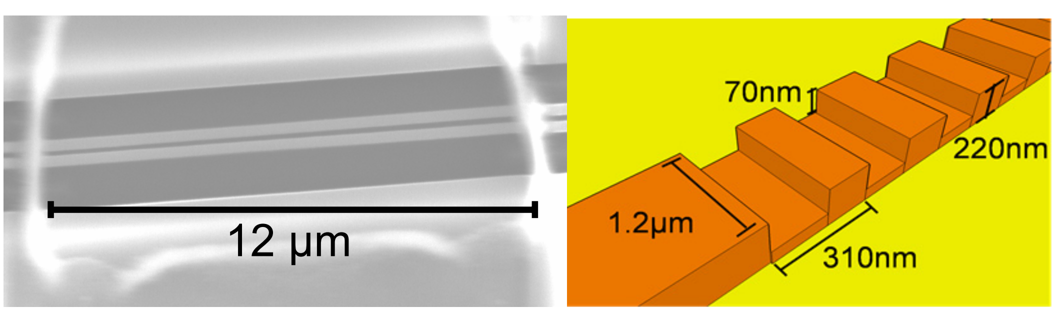

Figure 1: SEM picture of underetched slotted waveguide (left), dimensions of the Distributed Bragg Reflector (right): period 310nm, 70nm etch, waveguide with 1.2µm width, 50% fill factor

III. Working principle

When light is sent through the underetched slot waveguide a force arises between the two silicon beams that form the slot waveguide. This force can be explained through an adiabatic change in the energy carried by the waveguide eigenmode when the spacing between the waveguides changes [2]. In our experiment a pump signal (1510nm) and a probe signal (1524nm) are simultaneously inserted into the device. The pump induces the optical force while the probe simply detects the induced displacement. The pump optical power is modulated such that an AC-force is created. Furthermore the experiment is carried out in vacuum such that a suspended beam responds resonantly to the applied force ($Q_{MECH} \approx 360$). The natural frequency of the beam (length=12µm, width=230nm) is around 11.48 MHz (the signal of only one beam is considered in this proceeding, the other beam vibrates at 12.67 MHz). The obtained signal is calibrated using the thermomechanical "Brownian" noise of the suspended beam.

IV. Optical force characterization

Estimation of the effective spring constant of the beam allows us to obtain the amplitude vibration spectrum and the according theoretical fitting (Fig.2). We also find an estimated normalized force of 3.5pN/µm/mW, close to the theoretical expected value of 5pN/µm/mW. Furthermore our device also shows an excellent displacement sensitivity of 40fm/rtHz which makes it suitable for small displacement sensing.

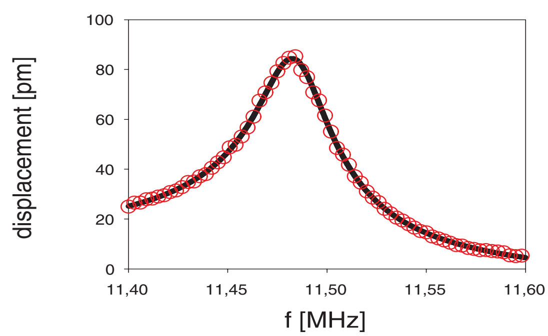

Figure 2: Measured vibration spectrum for pump λ=1510nm (red circles) and theoretical fitting (solid black line)

V. Discussion

We demonstrated in plane optical force in a slot waveguide. Due to the compact cross section of this waveguide large gradient forces per photon are induced. Since no optical resonator is involved the component we describe here is potentially interesting for broadband optically tunable components, such as tunable filters and phase modulators.

VI. Acknowledgement

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References

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[2] M. L. Povinelli et al., Evanescent-wave bonding between optical waveguides, Opt. Lett. 30, pp. 3042-3044 (2005)