Design, fabrication and testing of an opto-mechanical ultrasound sensor based on a sensitive silicon photonic waveguide

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Background, Motivation and Objective

Micromachined ultrasound transducers (MUTs) are used in ultrasonography for their cost-effective wafer-scale fabrication and integration with electronics. However, Capacitive MUTs may have significant coupling to noise and transducer arrays typically require a coaxial wire for each element, or alternatively a heat dissipating ASIC. Optical MUTs have excellent prospects: small, low-noise sensors, wafer-scale fabrication, and remote array read-out using fiber-optic communication. We propose a new OMUS with innovative rib-type waveguide that is extremely susceptible to mechanical deformation of an acoustical membrane. Light is guided by the waveguide which has a slab-part on the membrane and rib-part on the fixed substrate, separated by a tiny gap (Fig. 1a). This waveguide is used in a ring resonator, such that a minute sound-induced change in gap height results in a large shift of the optical ring resonances, which is accurately measured (Fig. 1b). Here, we predict high sensitivity using modeling, we demonstrate successful fabrication, and we present first OMUS characterization by sensing vibrations of the membrane in air.

Methods

The design was optimized using developed opto-acousto-mechanical modelling. The sensors were fabricated in Imec's CMOS pilot line, including wafer-to-wafer bonding to achieve the challenging 15 nm gap and low-stress SiO_2 (~80 MPa) for the mechanical membrane (Fig. 1c). The sensor output due to vibration noise in the lab (via table, air, etc) was recorded for different laser wavelengths.

Results and Discussion

Modeling of a sensor with resonance 15 MHz in water predicted a detection limit of only 2.4 Pa (assuming realistic electronics) and bandwidth of 50%. This is two orders of magnitude better than a corresponding waveguide-on-membrane OMUS as in Leinders et al. (Sci. Rep. 5, 2015). Experimentally, the laser wavelength is stepped across the resonance and the sensor signal is recorded. Indeed, we observed that the signal is high with the laser tuned to the flanks of the optical resonance. The power spectral density of the sensor recordings clearly show membrane vibration for expected resonances frequencies (Fig. 1d,e). We believe a matrix of these sensors combined with passive optical multiplexing may cause a breakthrough in photo-acoustic imaging.

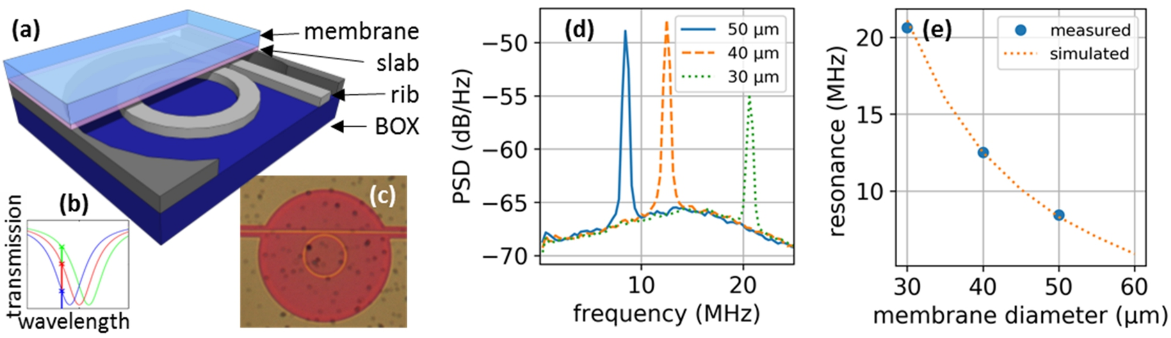

Fig 1. (a) sketch of new opto-mechanical ultrasound sensor. **(b)** Read-out principle: a laser is tuned to the resonance flank. The sound-induced resonance shift translates to an intensity modulation of the transmitted light. **(c)** Optical microscope picture, the membrane is semi-transparent. **(c)** Measured vibration noise power-spectral density (PSD) of the membrane vibration, for 3 membrane diameters and identical photonics. **(d)** measured and simulated resonance frequencies for the 3 membranes.