

**Document Version**

Final published version

**Citation (APA)**

Westerveld, W. J., Leinders, S. M., Pozo, J., van Dongen, K. W. A., Yousefi, M., Jong, N. D., Verweij, M. D., & Urbach, H. P. (2013). *All-Optical Ultrasound Receiver in Silicon-on-Insulator Technology*. Abstract from Optics in Cardiology, Rotterdam, Netherlands.

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# All-Optical Ultrasound Receiver in Silicon-on-Insulator Technology

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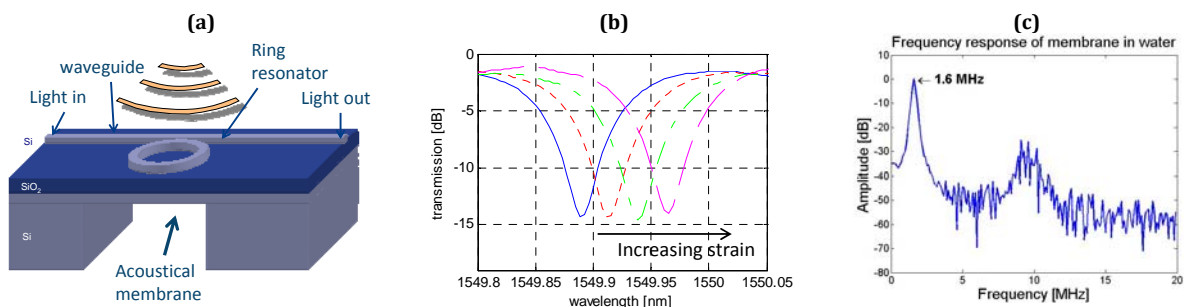
Ultrasonography is a medical diagnostic tool utilized for the imaging of different subcutaneous body structures like heart, liver, kidney or fetus. Nowadays, intravascular ultrasonography is widely used in the diagnostics of cardiovascular disease to assess the level of occlusion, the atherosclerotic plaque burden and the native size of the vessel. By bringing the ultrasonic transducer, mounted on the tip of a catheter, into the artery an image of the vessel wall could be obtained. However, respiratory motion can displace the catheter tip as much as 6 mm, resulting in serious deterioration of images. To improve the image quality, it is advantageous to use an array of many transducers in the arterial direction [1,2]. Because the available size on the catheter tip is limited (~1mm x ~2mm), there is a need for the miniaturization of the transducers themselves and their multiplexing circuit.

We propose a novel type of ultrasound receiver array, in which one sensor consists of an optical resonator which is integrated on an acoustical membrane (see Fig. 1a). Ultrasonic waves efficiently deform the membrane, thereby shifting the resonances of the optical microresonator [3]. The resonance shifts of many sensors can be simultaneously read-out via only two optical fibers, by employing small integrated optical multiplexers. This technology allows for small footprint (~50  $\mu\text{m}$  per sensor) and hence, for maximizing the amount of sensors in the catheter.

In our research towards a proof-of-principle of such a sensor, we have proven the principle of SOI microring resonators operating as deformation sensors. We characterized the influence of physical effects, and performed a study on design choices [3,4]. A set of long racetrack-shaped resonators was designed and fabricated via ePIXfab [5]. The relation between an applied deformation and the resulting shift in optical resonances was measured. Figure 1b shows, as example, how a resonance of a long racetrack-shaped ring resonator shifts due to an applied mechanical strain in its long direction.

Finite element modeling (using COMSOL Multiphysics) has been performed to optimize the acoustical sensitivity of the receiver. The influence of the size, thickness and shape of the membrane on the acoustical behavior was obtained using both static and time domain analysis. The model predicts that for a 2.5  $\mu\text{m}$  thick  $\text{SiO}_2$  circular membrane with 40  $\mu\text{m}$  radius, 1.6 MHz resonance occurs when the receiver is submerged in water (Fig 1c).

The promising results lead to the conclusion that this technology is a suitable candidate for miniaturized ultrasound sensors.



**Fig. 1** (a) Sketch of the proposed ultrasound receiver. (b) Four measured transmittance spectra for an optical resonator with a static elongated from 0 microstrain (blue, solid curve) to 120 microstrain (pink, dashed curve). (c) Frequency response due to a short gaussian pressure boundary load on a 40  $\mu\text{m}$  membrane submerged in water.

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