Minuscule Ultrasensitive Opto-Mechanical Ultrasound Sensor Based on Silicon Photonics MEMS Fabrication Platform for Photoacoustic Imaging: in-vitro Study

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PZT Ultrasound Sensor

- Obsolete technology
- Controllable material size for various application
- Labor-intensive & limited sensitivity
Silicon Photonics Ultrasound Sensor

- Optic-based mechanical detection of the incident ultrasound signal
- Higher sensitivities compared to PZT material-based ultrasound sensors
- Readily compatible to conventional CMOS process for low-cost fabrication
Pioneer Study

- Opto-Mechanical ultrasound sensor based on Silicon Photonics technology
- Fabricated using CMOS-compatible processing
- High sensitivity, broadband detection, and small size

Pioneer Study

• Wafer-to-wafer oxide fusion bonding
  – Simple, Economical

• 1D array-level demonstrated

• Wide choice in membrane material, but limited customizability of mechanical structure

What We Want

Exceptional Sensitivity  Based on Silicon Photonics

Integrability  from Single Cell to Matrix Array Level

Design Flexibility  for Optimization
Capability to Diverse Applications
MicroElectroMechanical Systems

• System integration technology with mechanical compositions in minuscule dimension
• Sensor-specific customizable design for application (e.g., NDT)
Silicon Photonics MEMS Platform

Silicon Photonics
- High sensitivity
- Large scalability

MEMS
- Mechanical sensing components
- High design flexibility

Matrix-level integration available
Great flexibility of sensor design regard to target resonance frequency

Hazan, Y., et al. (2022). *Nature Communications, 13(1).*
The Proposed Sensor

- Silicon Photonics MEMS Platform (SPMP)-based optomechanical ultrasound sensor
- Sub-millimeter dimension
- Flexible design capability & exceptional sensitivity
The Proposed Sensor

- Phase shifter + Cantilever-structure membrane = Acoustically sensitive membrane
- Ring resonator for optical signal modulation
- Convert the acoustic pressure’s modulation into the optical signal’s modulation
Structure

- Acoustically Sensitive Membrane
- Ring Resonator
- Bus Waveguide
- Directional Coupler
- Light
- Phase Shifter
- Vibration
- Ultrasound Signal

<Cross-Section along A-A'>

Bus Waveguide

Ring Resonator

Membrane

220 nm
• Ultrasound-induced membrane’s vibration → Resonance frequency’s modulation
• Detection of optical signal’s intensity modulation @ probing wavelength
Sensor Design Flexibility

- Controllable sensor’s resonance frequency & sensitivity based on the membrane’s design parameters

\[ f_0 \propto \frac{T}{L^2} \]
\[ S \propto \frac{1}{T} \times \frac{1}{f_0^2} \]

\( f_0 \): Resonance frequency of the membrane,
\( t, l \): Thickness and length of the membrane,
\( S \): Sensitivity of the sensor
• Mechanical structure (membrane) composition with lithography & etching process
• Arrangements: PA laser (Stationary), Target located horizontally parallel with the sensor
• Target, PA laser, and the sensor aligned in deionized water bath
• Data acquired by Data Acquisition Card (ADQ7DC, Teledyne)
Sensitivity Comparison

- Hydrophone (HGL-0400, Onda; calibrated with preamplifier (AG-2010, Onda))
- Acoustic pressure: 32.8 KPa
- Sensitivity: 17 μV/Pa (Sensor) vs. 2.5 μV/Pa (Hydrophone)
- Target dimension: 20 x 10 mm
- Scanning position arrangements: Static laser position, Target traveling in snake scan
- Scanning step size: 250 μm
• (Left) Image reconstruction algorithm: Maximum intensity projection algorithm
• (Right) Reconstructed volumetric image based on the data of target location
Conclusion

• Summary
  – SPMP-based optomechanical ultrasound sensor for photoacoustic imaging
  – High design flexibility & Exceptional sensitivity

• Ongoing Direction
  – Design parameter optimization for elevated quality of photoacoustic image
  – Fully integrated matrix-level sensor fabrication & Read-out system development
  – *in-vivo* preclinical imaging
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\[ V_{pp} : 86.9 \text{ mV} \]

\[ V_{pp} : 561.7 \text{ mV} \]

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