Fiber-Optic Ultrasound Sensor

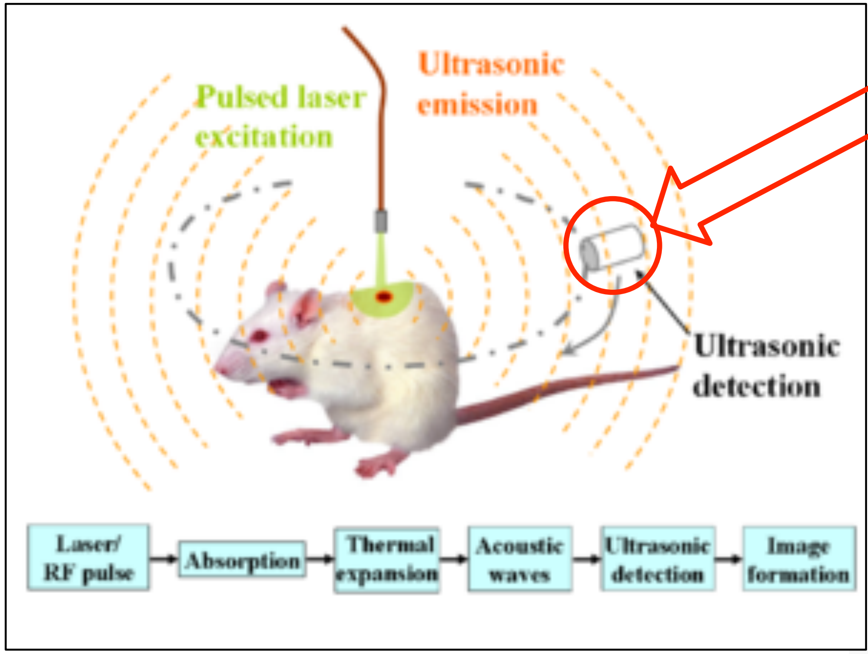
Journal seminar

2015/10/13

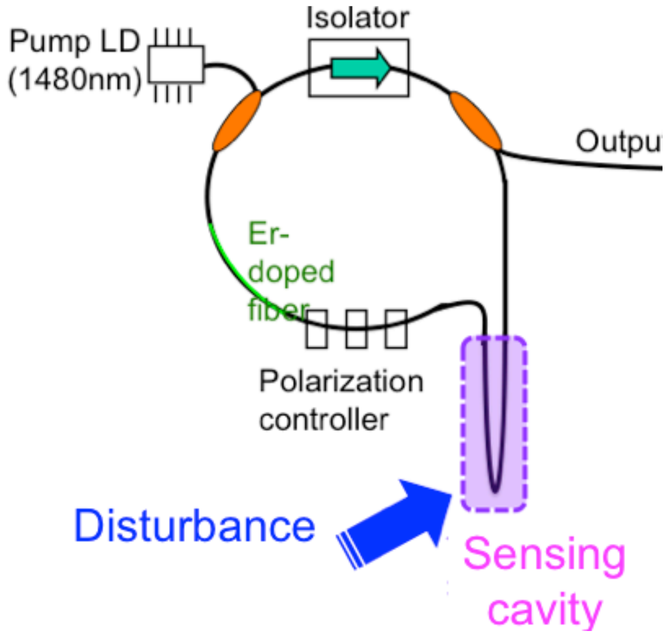
M2 Takashi Ogura

Introduction

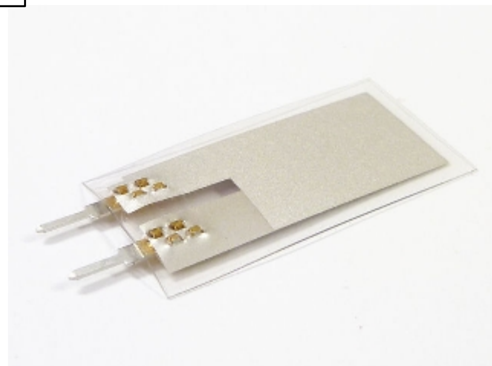
Photoacoustic imaging



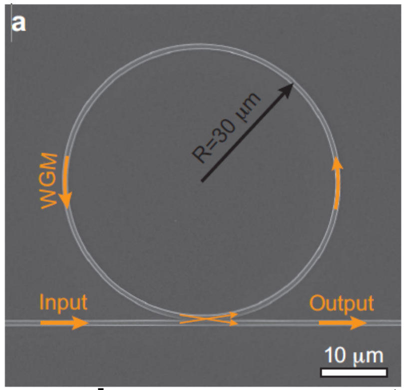
optical comb cavity



Traditional detector for ultrasound



PVDF



Microring resonator

Future plan

①High speed control optical comb
（cutoff frequency>200kHz
②Using for photoacoustic imaging

In this seminar

①How to detect ultrasound signal using optical fiber
②How to compare sensitivity and response

1. H. Wen, *et al*. “High-Sensitivity Fiber-Optic Ultrasound Sensors for Medical Imaging Applications” Ultrason Imaging **20**, 103-112 (1998)

2. Horacio Lamela, *et al*. “Interferometric fiber optic sensors for biomedical applications of optoacoustic imaging” J. Biophotonics. **4**, 3 (2013)

3. Amir Rosenthal, *et al*. “High-sensitivity compact ultrasonic detector besed on a pi-phase-shifted fiber Bragg grating” Opt. Lett. **37**, 13 (2012)

H. Wen, D.G. Wiesler, A. Tveten, B. Danver,
and A. Dandridge

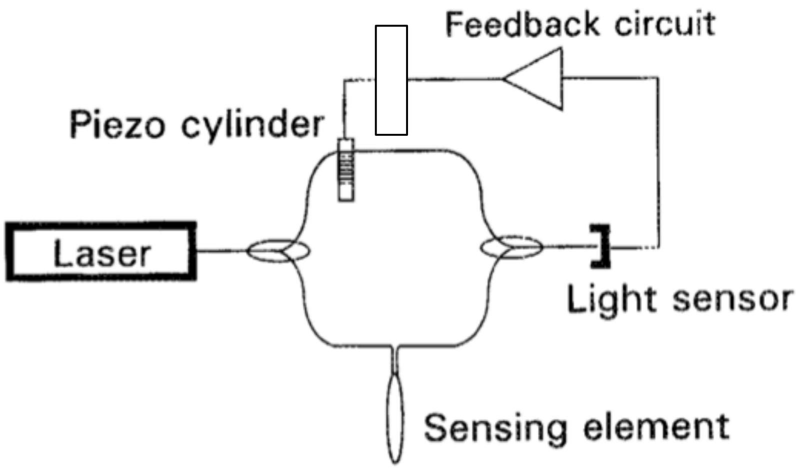
“High-Sensitivity Fiber-Optic Ultrasound Sensors for Medical Imaging Applications”

Ultrason Imaging **20**, 103-112 (1998)

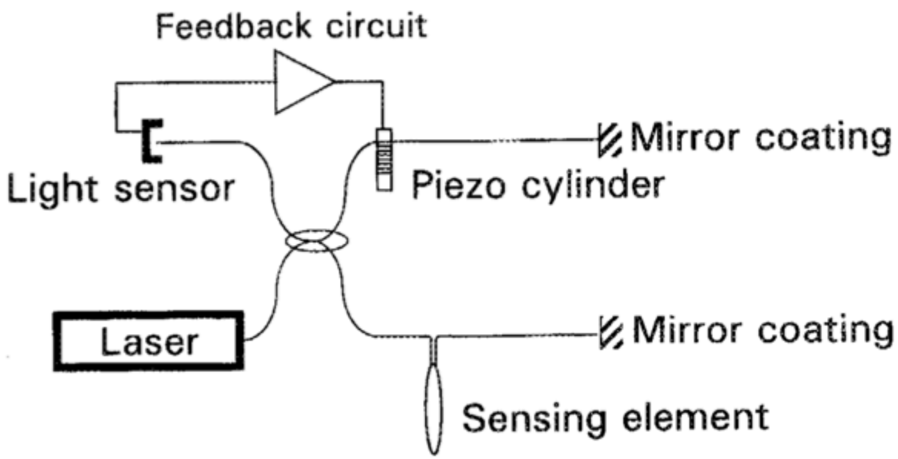
概要

- ファイバーベース干渉計による位相差測定から、超音波センシングを行う。
- 医療応用を目指して、小型な超音波センシングプローブを開発

Principle



(A) Mach-Zehnder Interferometer



(B) Michelson interferometer

The gain and dc offset of the feedback voltage are adjusted to maintain a phase difference of 90° between the two arms. If the light intensity in each arm is I_o, any small strain ΔL induced by the ultrasonic waves results in a phase change $\Delta\varphi$ in the sensing arm and a change in the light output of the interferometer ΔI

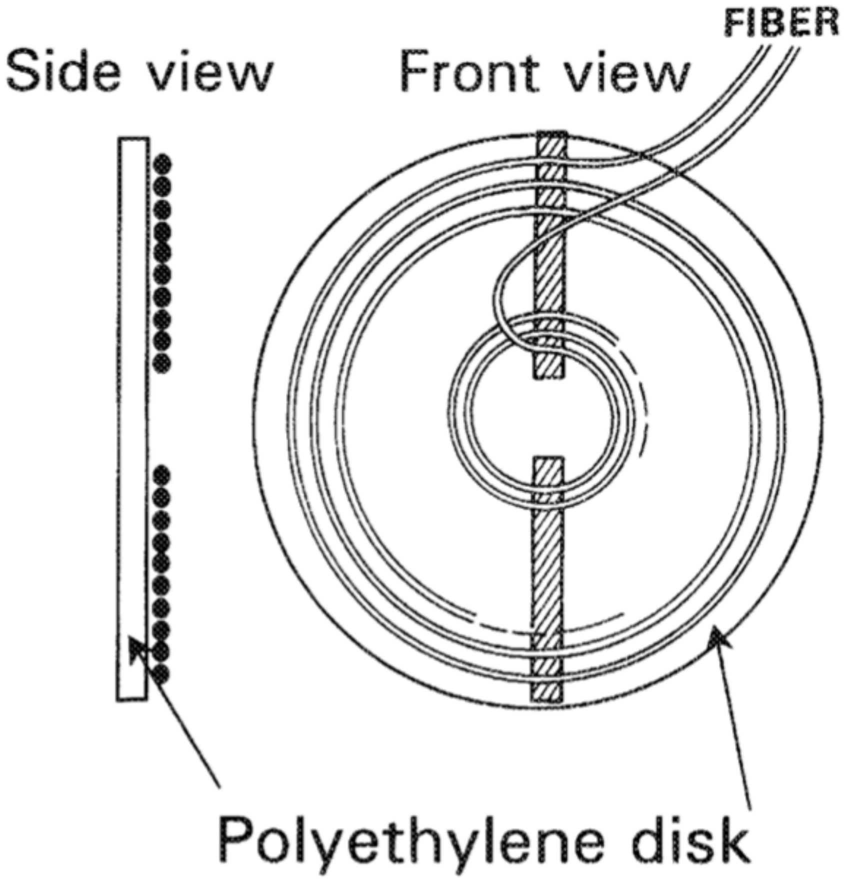
$$\Delta I = 2 I_0 \sin\Delta\varphi = 4\pi I_0 \frac{\Delta L}{\lambda}$$

λ: Laser wavelength

ΔL is much smaller than λ

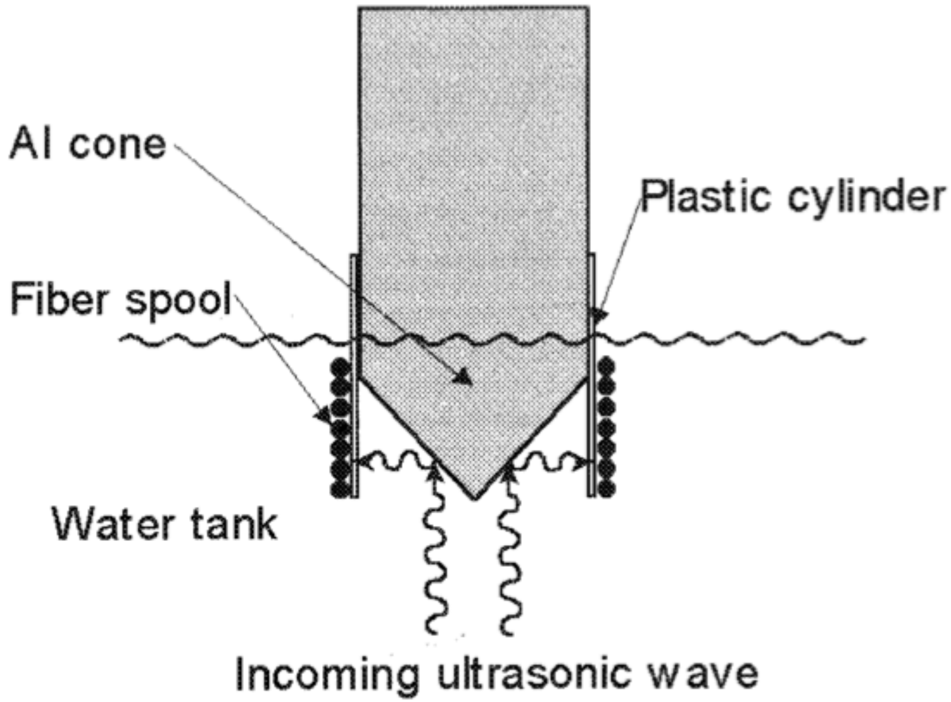
Design of fiber sensor

First design



The diameter of the disk needs to be 25mm or larger

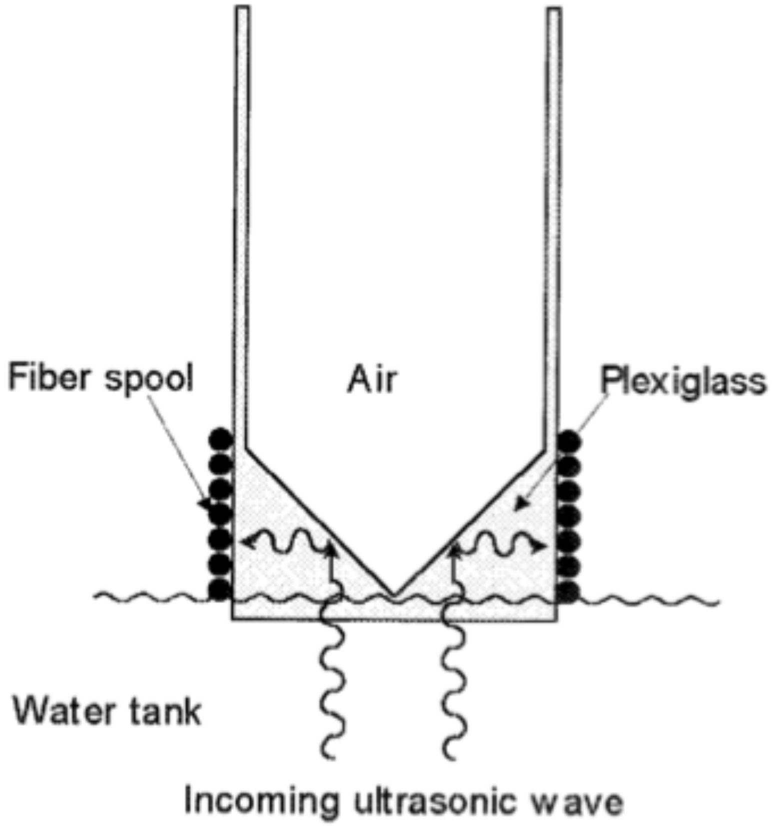
Second design



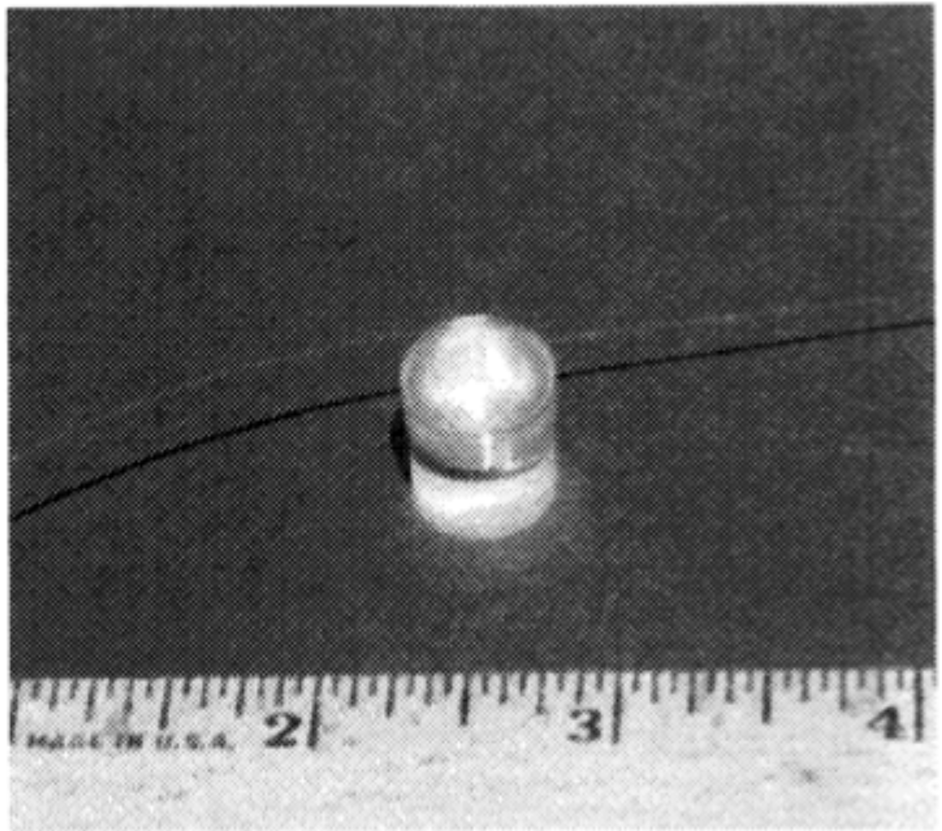
This geometry allows the sensor diameter to be as small as 5mm

Design of fiber sensor(Practical)

Practical construction



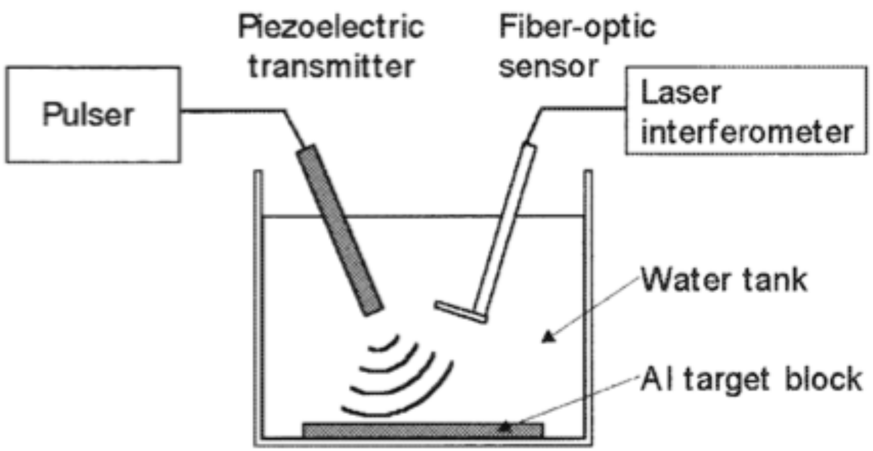
Photograph



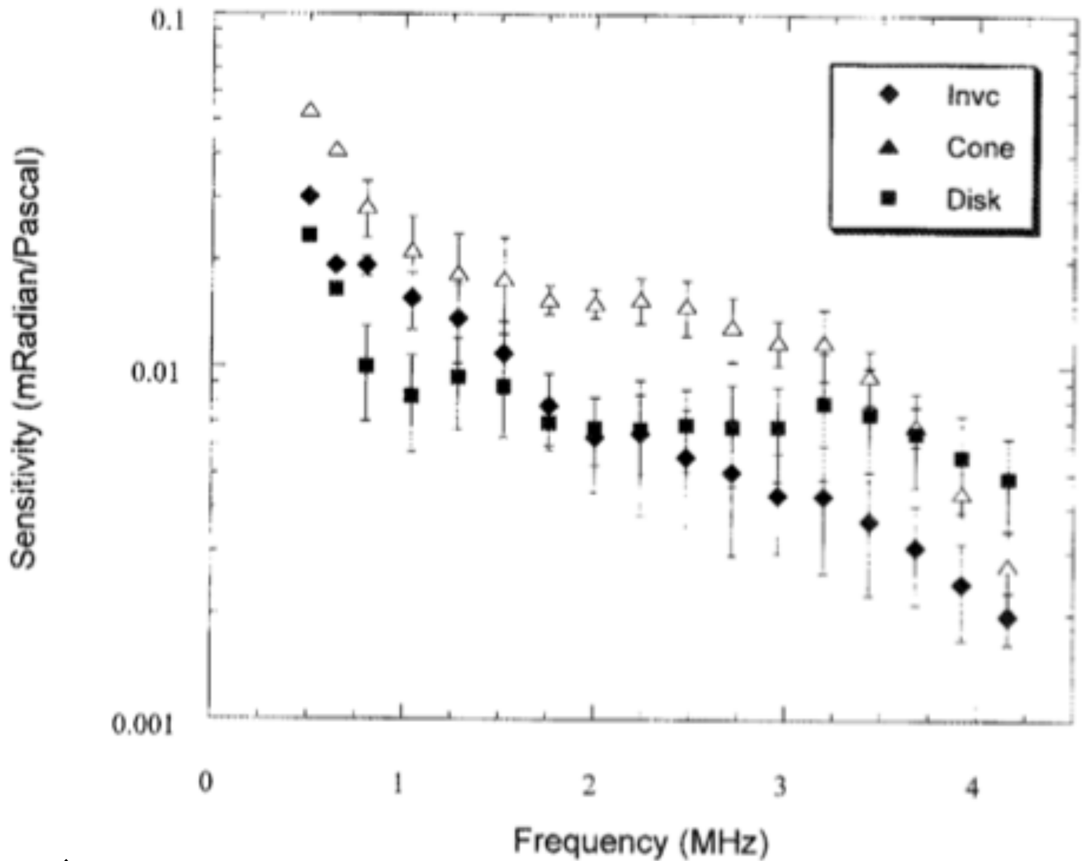
The ruler below is graduated in 1.5mm
The Sensor diametor is 13mm

Experimental setup and result

Experimental setup



Sensitivity of the fiber-optic sensors From 500kHz to 4MHz



◆ **The second sensor design with plexiglass cylinder**
▲ **The second sensor design with aluminum cone reflector**
■ **The first sensor design**

Summary

- This paper presents several designs of high-sensitivity, compact fiber-optic ultrasound sensors that may be used for medical imaging applications
- The sensors are simpler and less expensive to make than piezoelectric sensors, and are not susceptible to electromagnetic interference

Horacio Lamela, Daniel Gallego, Rebeca Gutierrez,
and Alexander Oraevsky

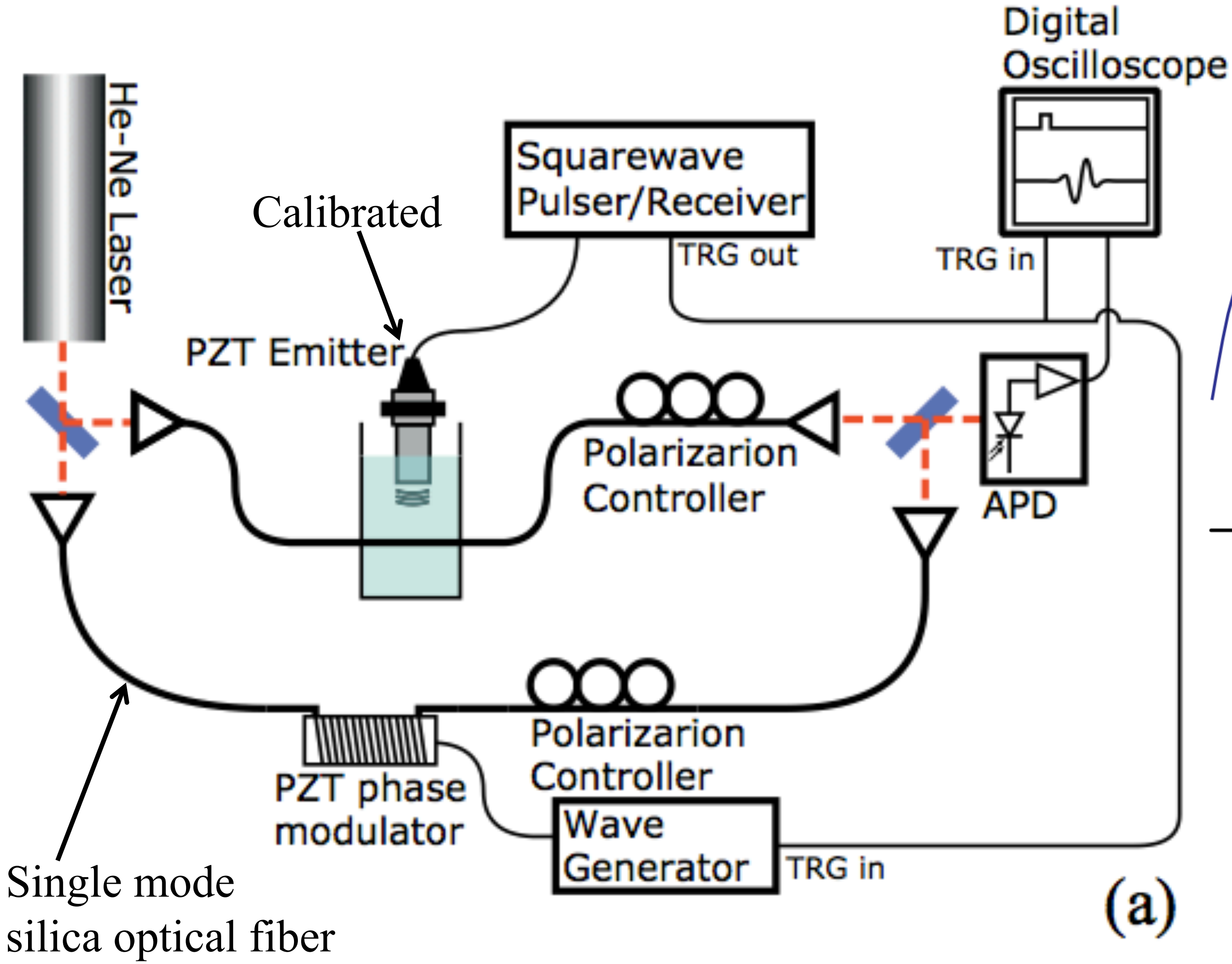
“Interferometric fiber optic sensors for biomedical applications of optoacoustic imaging”

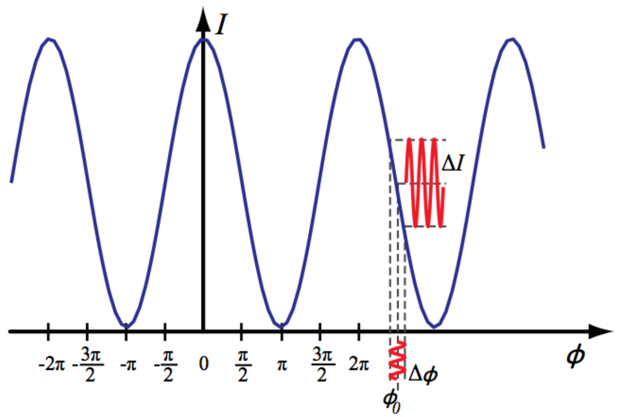
J. Biophotonics. **4**, 3 (2013)

概要

- ファイバーベース干渉計による位相差測定から、超音波センシングを行う。
- 生体内を模したサンプルに対し、PZTトランスデューサとファイバーセンサーとを用いて光音響イメージングを試み、両者を比較した。

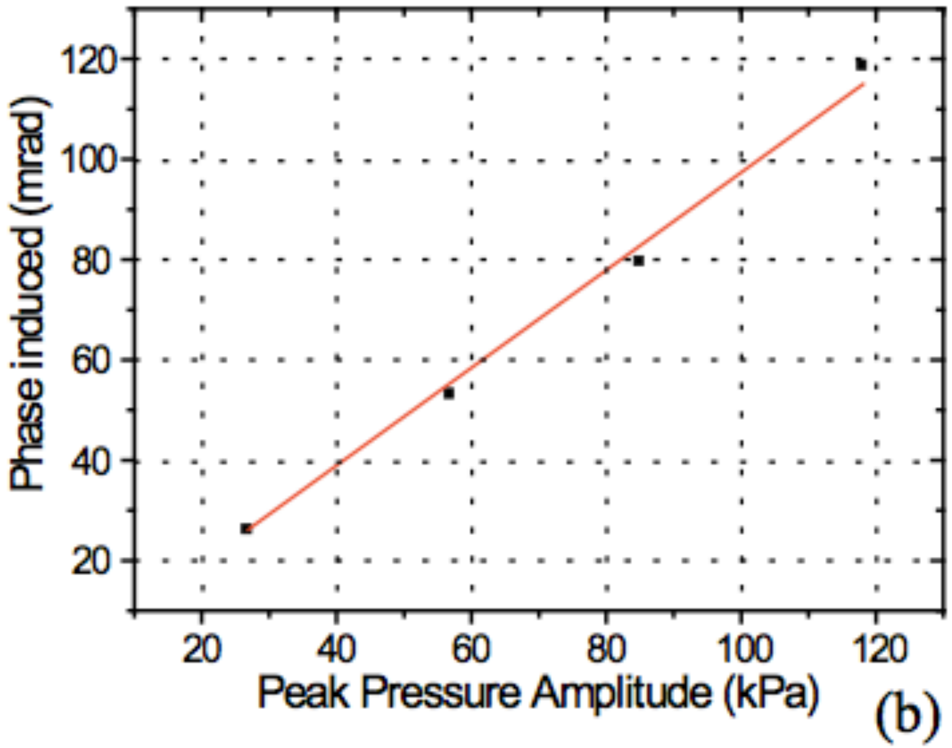
Experimental setup



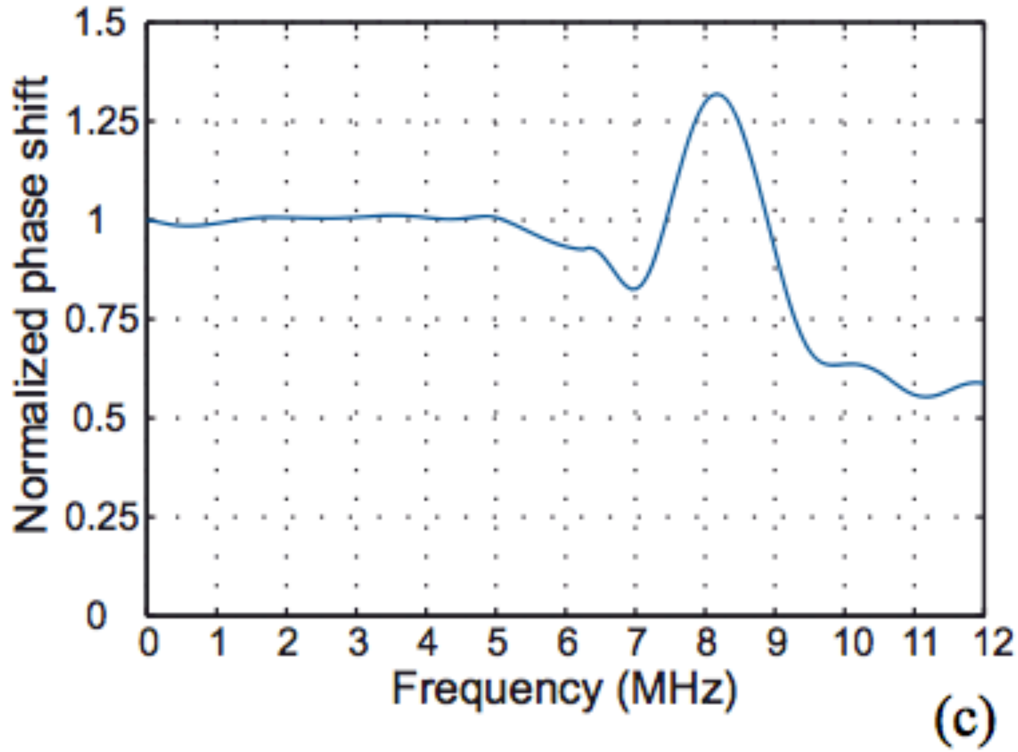


Experimental results

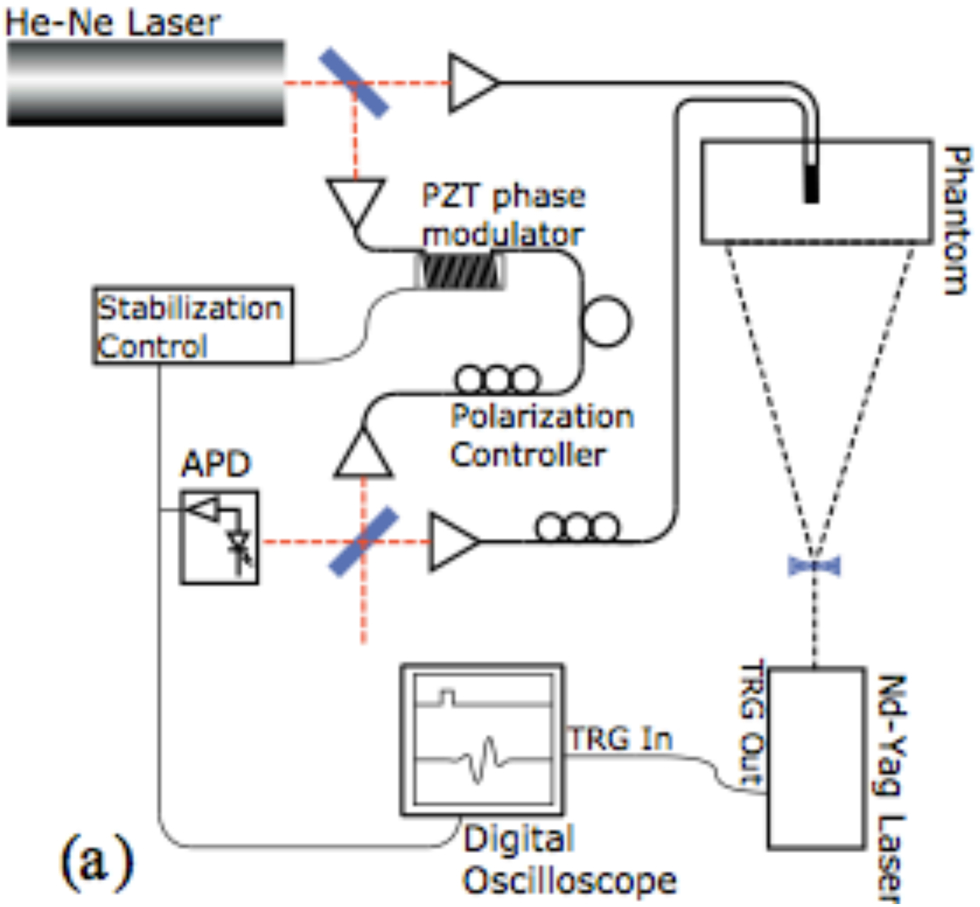
Relation between 1MHz pulse amplitude pressure and phase shift



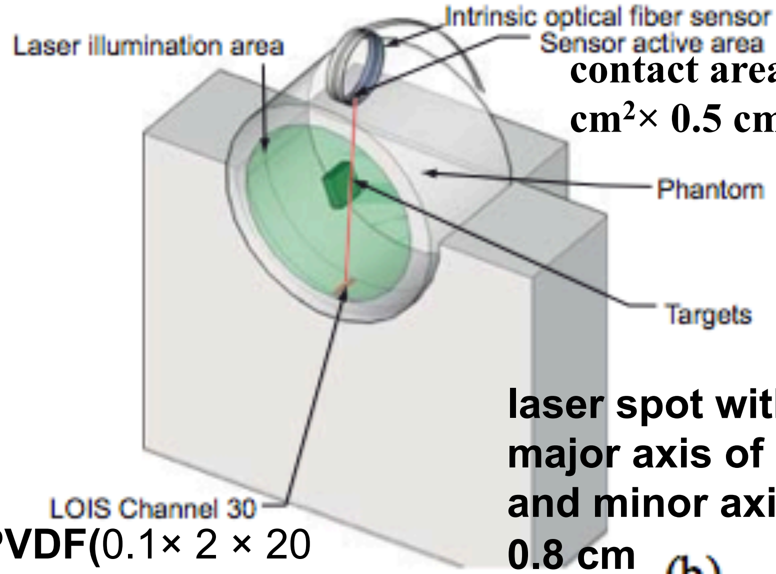
Normalized frequency response



Optoacoustic experimental setup



(a)

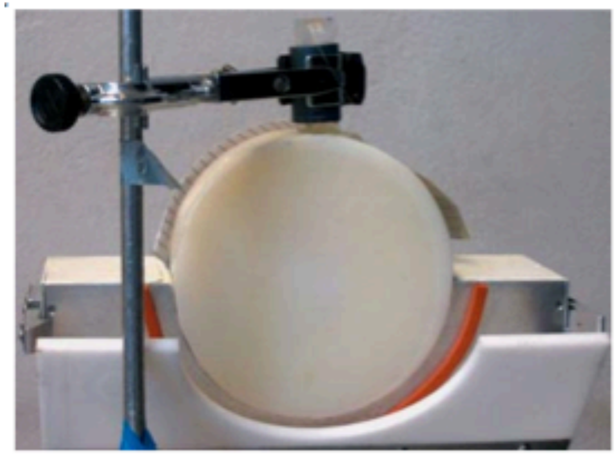


contact area of 0.5 $cm^2 \times$ 0.5 cm^2

laser spot with a major axis of 2.4 cm and minor axis of 0.8 cm

PVDF(0.1× 2 × 20 mm**)**

(b)


(c)

Experimental results

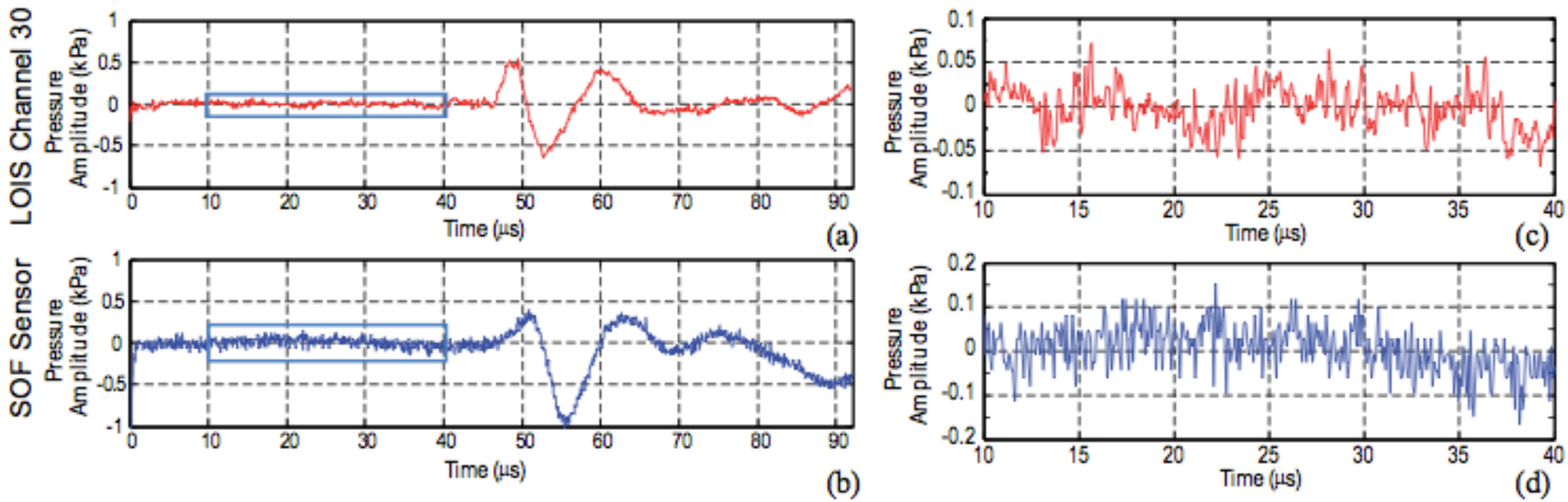
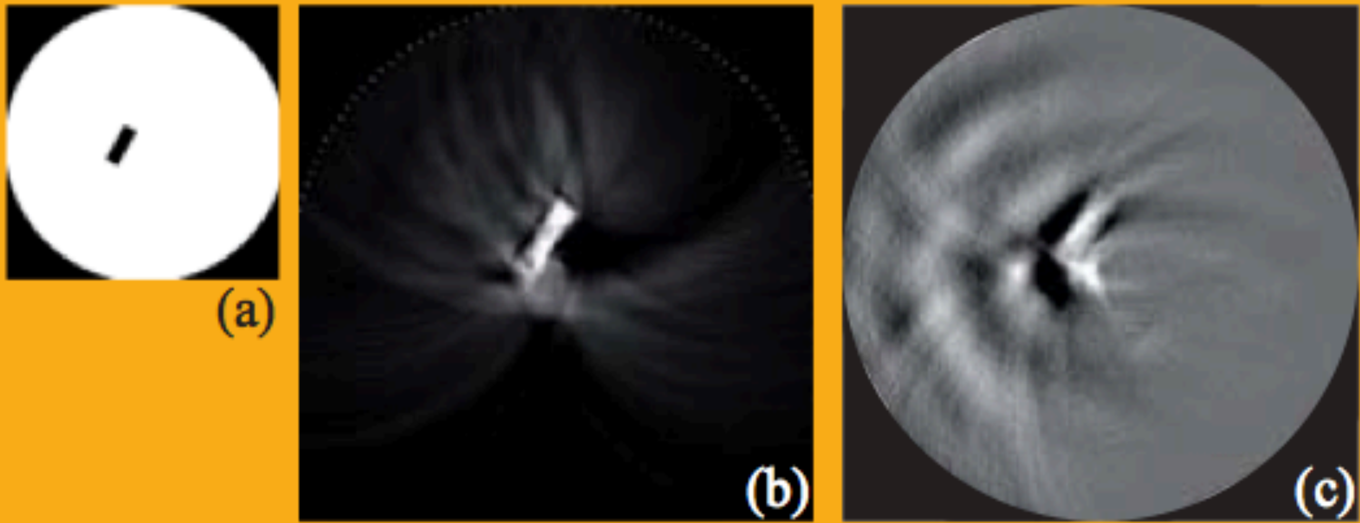


Figure 4 (**a**) Optoacoustic signal received by channel 30 of PZT array expressed in pressure units. (**b**) Signal detected by an extrinsic fiber optic sensor at the same time but on the opposite side of the phantom. (**c**) and (**d**) magnification of the noise that correspond to the marked areas in the Figures (a) and (b) respectively.

a similar pulse shape and time of flight as detected with two different sensors can be observed

In the former case the electronic bandwidth is limited to 2.5 MHz, however in the last case it is limited by the digital oscilloscope low pass filter to 20 MHz.

Experimental results



(**a**) Diagram showing location of the embedded object in the PVCP phantom. (**b**) Optoacoustic image obtained from LOIS utilizing an array of 64 PVDF transducers. (**c**) Optoacoustic image reconstructed from fiber optic sensor signals.

Summary

- They present a non-metallic interferometric silica optical fiber ultrasonic wideband sensor for optoacoustic imaging applications. The ultrasonic sensitivity of this sensor has been characterized over the frequency range from 1 to 10 MHz. The feasibility of our fiber optic based sensor for wideband ultrasonic detection is demonstrated.

Amir Rosenthal, Daniel Razansky,
and Vasilis Ntziachristos

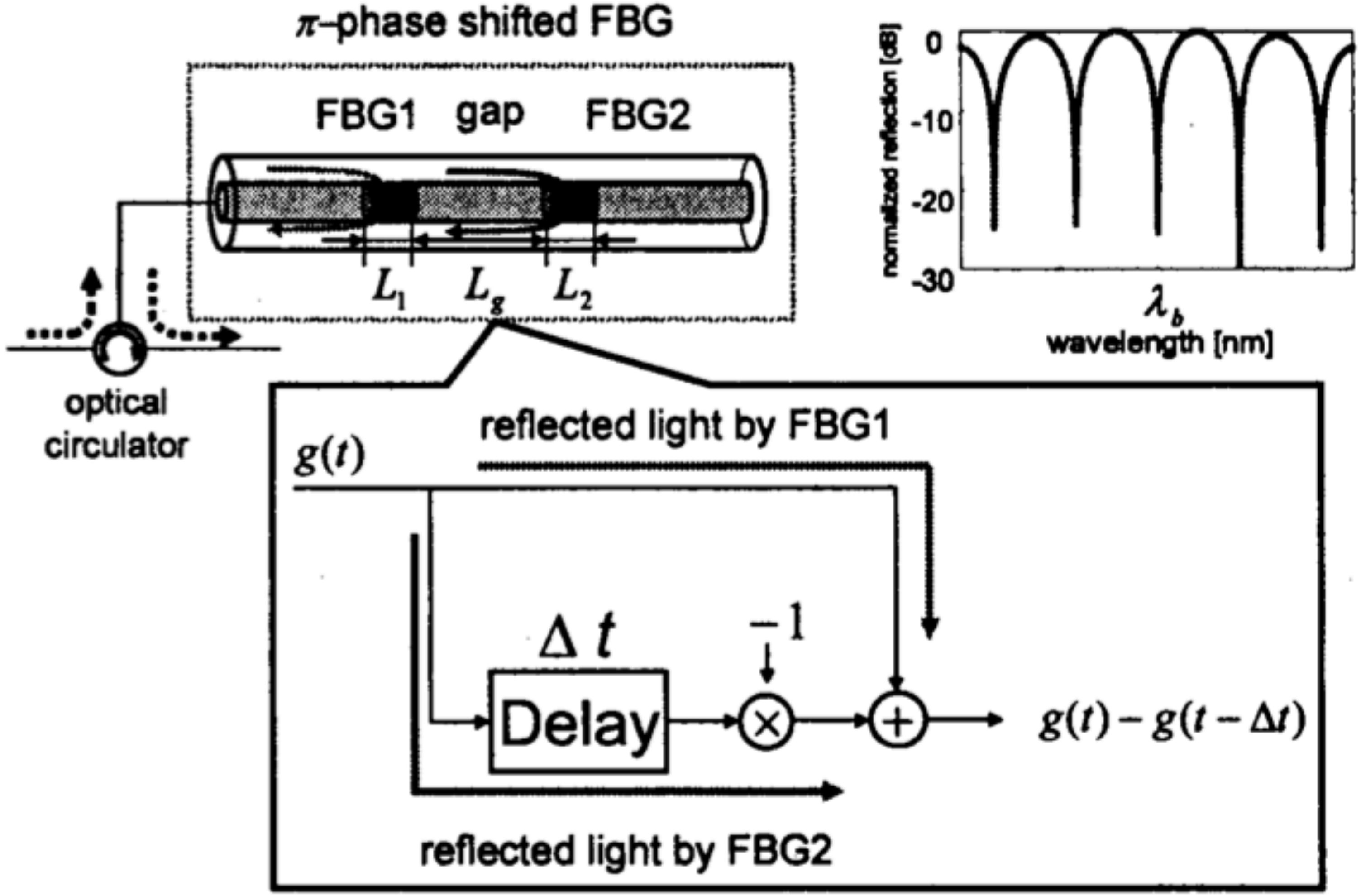
"High-sensitivity compact ultrasonic detector besed on a pi-phase-shifted fiber Bragg grating"

Opt. Lett. **36**, 10 (2011)

概要

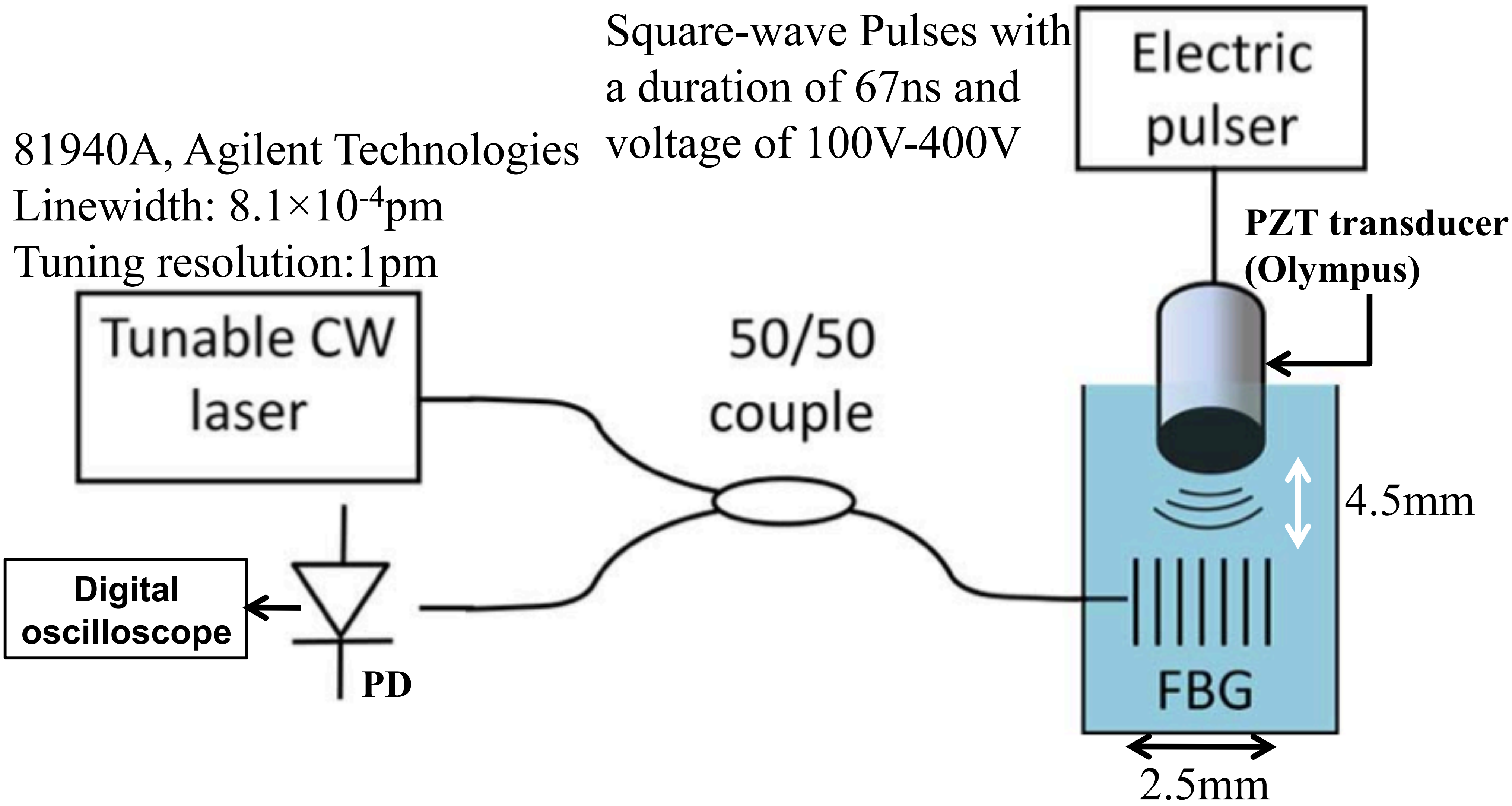
- 波長可変CWレーザーとπ位相差FBGを用いた超音波センシング
- 高感度・広い周波数帯域を示す

Principle(pi-phase-shifted FBG)

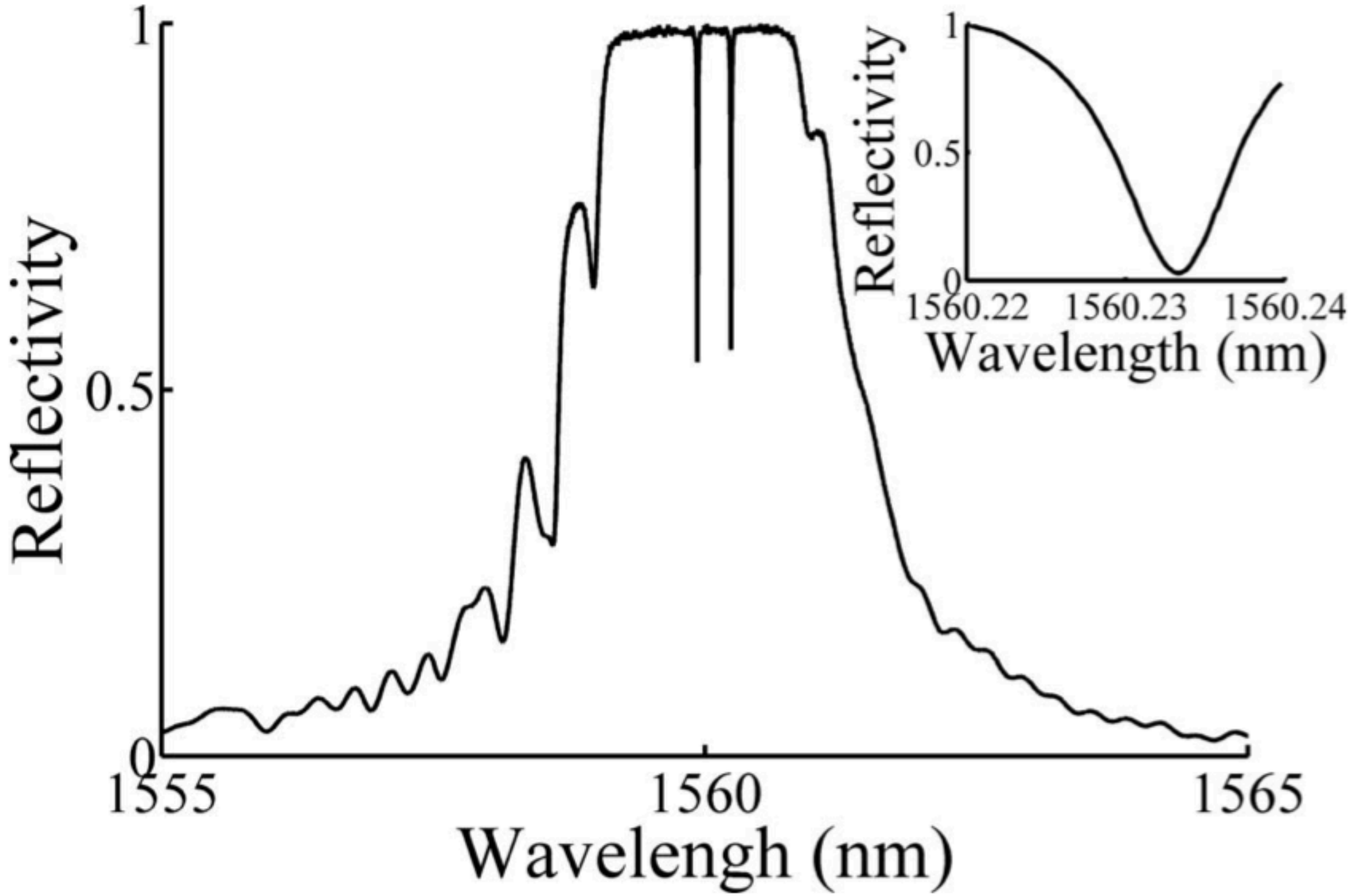


Ref) 塙 雅典他, π 位相シフトファイバグレーティングによる高速NRZ光信号からのクロック抽出、電子情報通信学会　信学技法 (2005)

Experimental setup



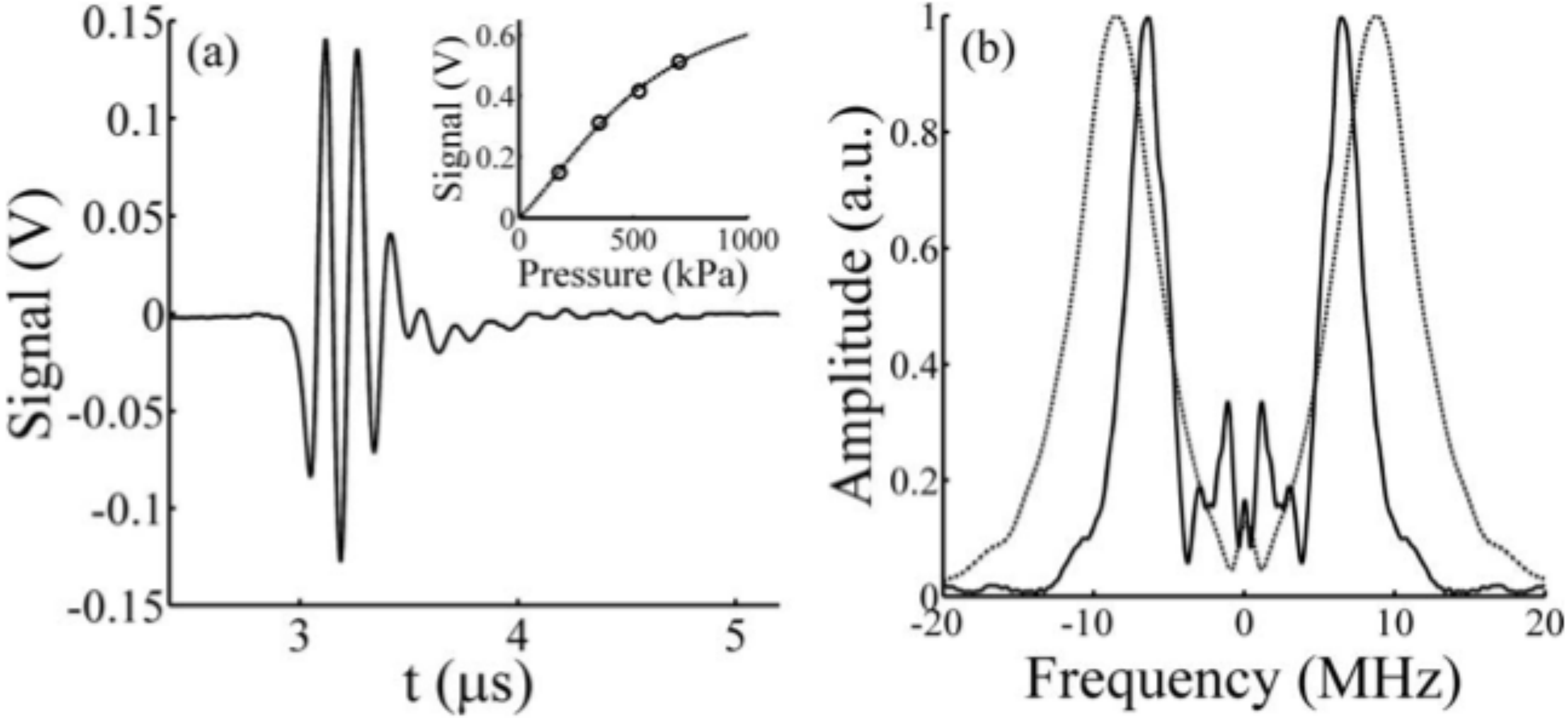
Reflection spectrum of the grating



Temporal and spectral responses

175kPa acoustic pulse

calibrated by needle hydrophone (Model HPM1/1,Precision Acoustics Ltd.)



Solid curve(FBG):peak sensitivity at 6.5MHz

Dashed curve(hydrophone): peak sensitivity at 8.5MHz

Summary

- They demonstrated a compact fiber-optic sensor for highly sensitive wideband ultrasound measurements, suitable for optoacoustic signal detection

- In This system, an effective sensor length of 270 µm, pressure sensitivity of 440 Pa, and effective bandwidth of 10 MHz were achieved