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# Open acoustic resonator photoacoustic imaging
開放型音響共鳴器を用いた光音響映像法

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## 1. Introduction

Photoacoustic (PA) imaging for nondestructive inspection (NDI) or spectroscopic measurements of microscale substances has been studied with gas-microphones[1] and piezoelectric transducers[2]. On the other hand, acoustic resonator such as Helmholtz resonator is useful and is applied to PA spectroscopy dominantly in chemical analysis of gas-phase substances[3]. In the present paper, acoustic resonator was used for PA dtection and imaging in both closed and open resonator configurations.

## 2. Experimental Apparatus

For an acoustic resonator, a prolate spheroid (a=85.5 mm, b= 9.4 mm) was used [4]. The fundamental spheroidal resonant frequency of the cavity was calculated to be 1350 Hz. For a PA cell, one side of spheroid at the focus was cut for an opening attached to a specimen under study. At the other focus, a high-sensitive condenser microphone (Bruel and Kaejer 4166) was attached. And the other hole was drilled as a window for the laser incidence at the side wall of the resonator. For an optical source, a Nd-YAG diode-pumped solid-state laser (DPSSL) with a SHG wavelength of 532nm was used. Laser beam with the power of 125mW was pulse modulated with a function generator. A PA signal was fed into a lock-in amplifier (NF-Circuit Block, LI- 5610B) and detected phase-sensitively. In the case of imaging, a specimen was scanned with a XY-linear motor stages.

## 3. Resonance characteristics

The tuning characteristic of the acoustic resonator under closed resonator configuration was shown in Fig. 1. The measured resonant frequency agrees well with theoretical value (1350 Hz). A relatively large PA signal at the level of 130 μV with an excitation power of 125mW was observed.

The resonant frequency was changed from 1350 Hz (closed resonator / with perfect sealing) to 1460 Hz (open resonator / without sealing). The PA signal without sealing was unexpectedly large to be more than 60% of the sealed one. The results were interpreted as the change of the admittance of the leakage, and can be treated as an open resonator problem and will be discussed in §4 .

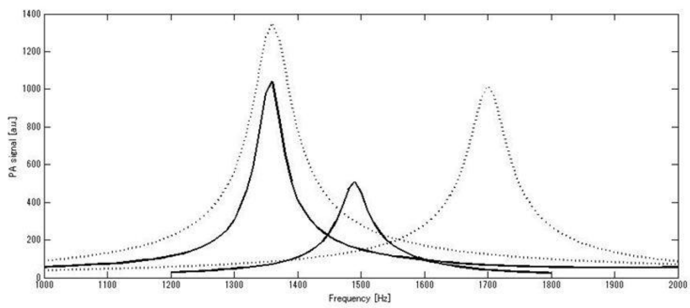


Fig. 1 Tuning characteristics of closed and open resonator configurations

(solid: Experimental, dashed: calculated)

## 4. Theoretical Consideration

### A. Boundary-perturbation method

For the open resonator, the angular frequency shift $\Delta\omega_N$ is given by the formula:

$$\Delta\omega_N = c(K_N - \eta_N) = -\frac{ck}{2V\Lambda_N{}^0\eta_N}\iint \phi_N(r_s)^2 i\beta(r_s)dS$$

where

$$i\beta(r_s) = \sigma(r_s) + i\xi(r_s)$$

means position-dependent specific acoustic admittance defined by the ratio U/p (U: volume velocity, p: pressure) [5].

For the unsealed condition, the existence of a hole corresponds to the integral of the right-hand side. The tuning characteristics are calculating in progress, and will be presented at the symposium.

### B. Acoustical circuit model

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The acoustical cavity resonator system is represented by a corresponding electrical shunt RLC resonant circuit. The $Y_{hole}$ and $Y_{cavity}$ mean acoustical admittance of hole and cavity, respectively. The damped oscillator model, which corresponds to the parallel-resonant circuit $Y_{cavity}$, gives the amount of decrease of the PA resonance peak. For treating hole admittance, an acoustic radiation impedance of a radiation cylinder was used in this model. The calculated tuning characteristics for closed and open resonator were combined to be shown in Fig. 1.They showed a qualitative agreement.

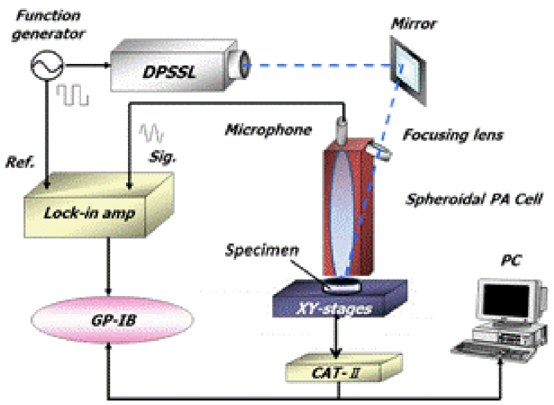


Fig. 2 Experimental setup for PA imaging

**5. Imaging**

Experimental setup for PA imaging was shown in Fig.2. Imaging experiment was performed by scanning the PA cell (spheroidal resonator) with respect to a specimen under study. A 25mm x 25mm aluminum plate painted with four colors (red, green, blue, black) was used for a solid specimen as shown in Fig. 3 (a). The scanned region was 5mm x 5mm, and the resolution was 50 x 50 pixels. Since the specimen should be moved with respect to the resonator cell, the specimen and the acoustic resonator did not contact each other; they were 1mm apart each other to form an open resonator. The obtained PA image was shown in Fig. 3 (b). Since thee PA signal is proportional to the amount of absorption of the excitation green light, the image well corresponds to the difference of the reflectivity of the specimen.

**6. Discussion and conclusion**

This paper describes PA detection and imaging with a spheroidal acoustic resonator as closed and open resonator configurations. Upward resonance frequency shift in tuning characteristics of open resonator was explained qualitatively with the boundary perturbation and acoustical circuit model.

Spheroidal acoustic resonator is useful not only for PA spectroscopic analysis but also for PA imaging. Since open-resonator PA imaging is free from the sealed enclosure, it requires no window for laser beam incidence. Therefore, it is advantageous to use a spheroidal acoustic resonator for PA imaging with wide-range frequency tunable optical source such as optical parametric oscillator (OPO) for spectroscopic applications.

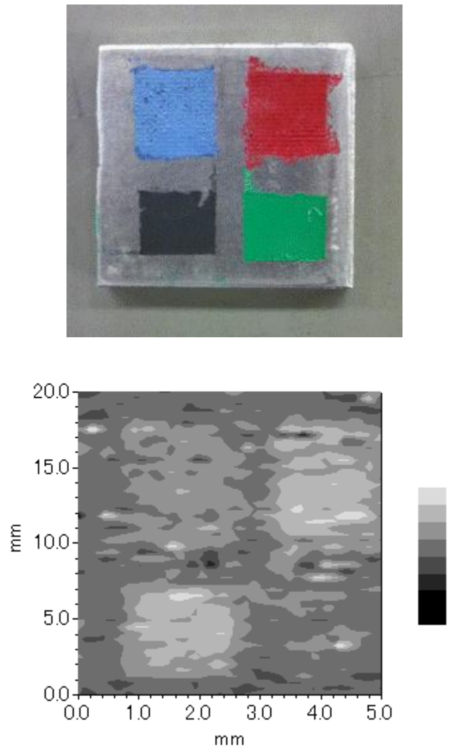


Fig. 3 (a) Specimen with four colored paint (top)
(b) Obtained PA amplitude image (bottom).

**References**

1. R.L.Thomas, J.J.Pouch, Y.H.Wong, L.D. Fabro, P.K.Kuo and A.Rosencwaig: J. Appl. Phys., **51**, 1152 (1980).
2. A.Rosencwaig: Appl. Phys Lett.., **36**, 752 (1980).
3. A. Miklos, P. Hess and Z. Bozoki: Rev. Sci. Instr., **72**, 1937 (2001).
4. C.Chang: J. Acoust. Soc. Amer., **49**, 611 (1970).
5. P. M. Morse and K. U. Ingard: "*Theoretical Acoustics*", (McGraw-Hill, 1968), Chap. 9.