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Evaluation of a prototype levitation device using a spherical resonant cavity with a 40 kHz BLT type ultrasound emitter

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1. Introduction

The use of a large number of small aerial ultrasonic emitters has been studied to achieve non-contact levitation of small objects.[1-2] On the other hand, the authors have tested the operation of a prototype levitation device with a single emitter and a cavity resonator.[3]

Single emitter type levitators can be easily upgraded by replacing the emitter with one that can generate high sound pressure. In this study, a BLT type ultrasound emitter with an integrated flange and transverse vibration section was used (Niterra Co., Ltd., DA215040K001), as shown in **Fig. 1**. This emitter has a resonant frequency of about 40 kHz, the same as that used in many sensor applications, and can generate about 10 times higher sound pressure.[4-5] To make this emitter into a levitating device combined with a spherical resonator, the waveguide as the connecting part and the entire device were analyzed by the finite element method (FEM). Based on the analysis results, a prototype was built, and the levitation of a small semiconductor chip and an oil droplet was experimentally confirmed.

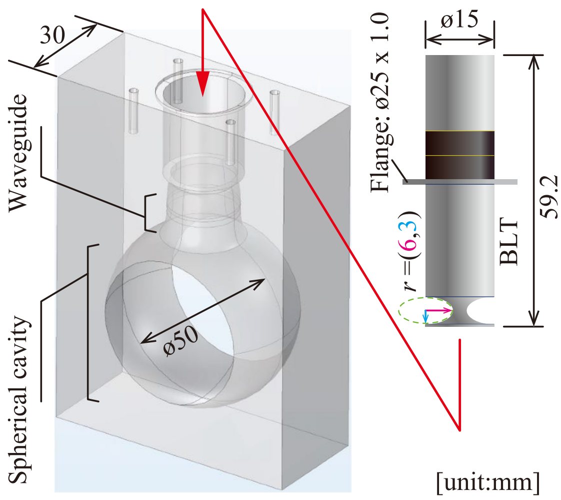

Fig. 1 Spherical cavity resonator and BLT type ultrasound emitter.

2. Analytical trials of waveguide and resonator

The results of the frequency response analysis using the 2D axisymmetric model of COMSOL Multiphysics 6.2 are shown below. **Figure 2**(a) shows the emitter-only case, where the radiated sound pressure is phase-reversed at the center and periphery of the transversal transducer; the SPL also shows the presence of relatively large sidelobes. One of the improvement ideas is to cover the radiating area with a waveguide of approximately one wavelength, as shown in Fig. 2(b), so that the sound pressure phases are nearly aligned at the aperture and

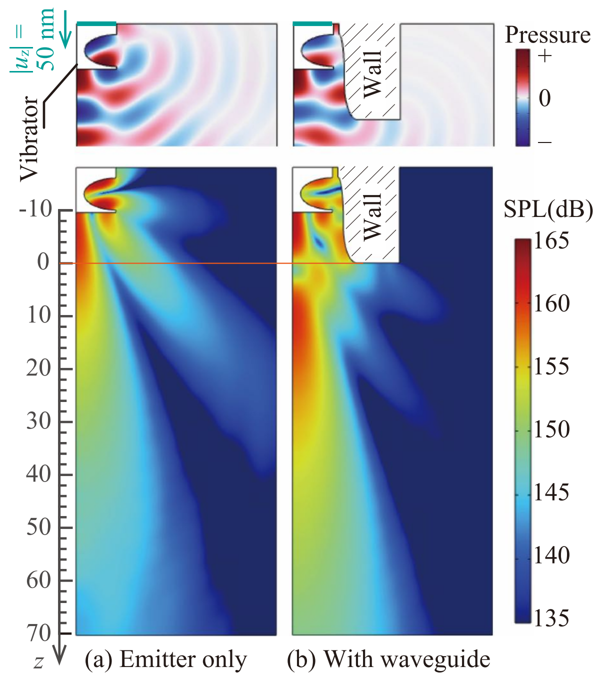

Fig. 2 Adjustment of sound pressure phase and reduction of sidelobes by waveguide.

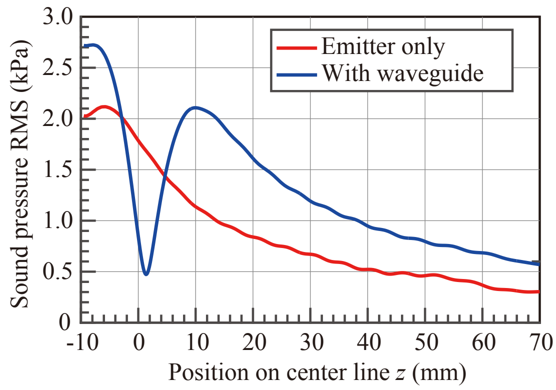

Fig. 3 Variation of sound pressure distribution on the central axis of the emitter with and without waveguide.

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the sidelobes are reduced. The waveguide reduces the attenuation of sound pressure propagating on the emitter center axis, as shown in **Fig. 3**. However, optimizing the shape of the waveguide is a topic for the future.

The frequency response analysis of the solid-acoustic coupling was performed using a 3D model with the waveguide based on Fig. 2(b), the 50 mm diameter spherical air (side cut) shown in Fig. 1, and the emitter transducer. The instantaneous sound pressure results in the cross section through the center of the spherical cavity are shown in Fig. 4; the displacement amplitude $|u_z|$=50 nm at 40.936 kHz was applied to the BLT side of the emitter.

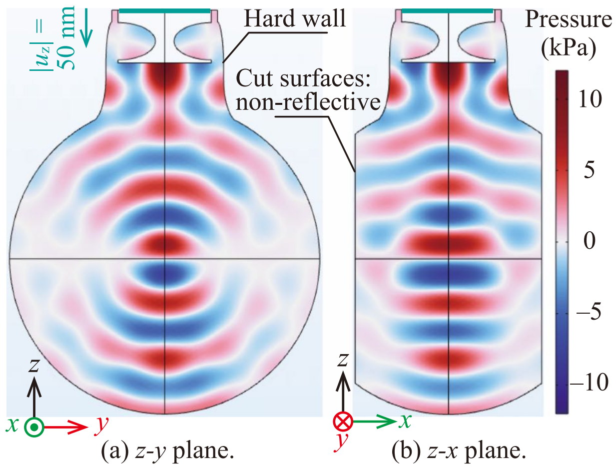

Fig. 4 The distribution of sound pressure in a cross-section through the center of a spherical cavity.

4. Experimental results

The spherical cavity resonator, the waveguide, and the structure supporting the BLT flange, as shown in Fig. 1, were fabricated using an optical 3D printer (ELEGOO, Mars).

Frequency responses of the input admittance of the BLT type emitter alone and with the levitation device assembled is shown in **Fig.5**.

The following objects have been observed to levitate under the conditions in the center of the sphere cavity and elsewhere:

(a) SOT25 [**Fig. 6**(a)], 12.8mg, 40.80 kHz, 21.78 V, 1.38 W.

(b) Chip capacitor, 2.04×1.28×1.25 mm, 19 mg, 40.80 kHz, 25.6 V, 1.86 W.

(c) Oil droplet [Fig. 6(c)], VG100, Oval diameter 2.7×1.8 mm, 40.90 kHz, 32.3 V, 184 mW.

(d) Styrofoam balls, diameter 5.5 mm or less, under various conditions.

On the other hand, Styrofoam beads larger than about 6 mm in diameter could not remain suspended and were ejected from the resonator.

The SOP8 package shown in Fig. 6(b) weighed 80.4 mg and was not captured at the center.

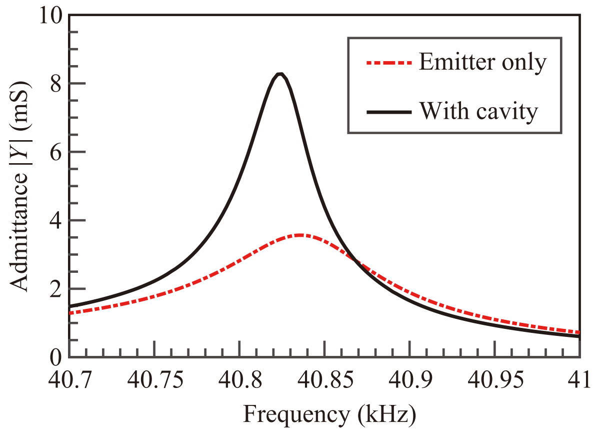

Fig. 5 Admittance frequency response of the BLT emitter and the composite device.

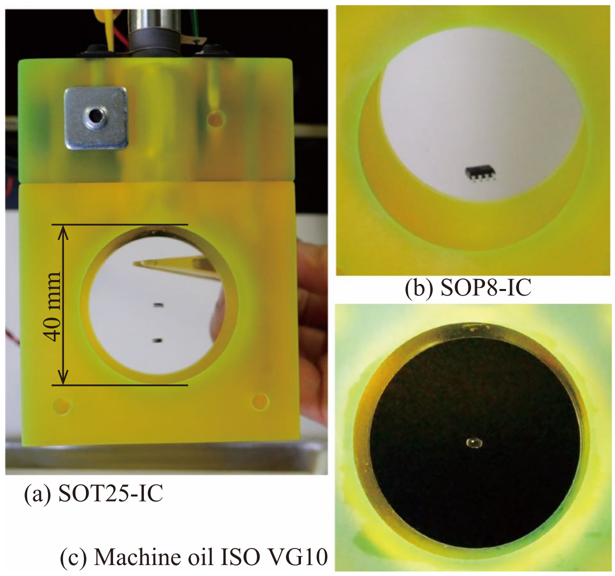

Fig. 6 Observation of small objects floating in the cavity.

However, under the conditions of 40.90 kHz, 50.5 V, and 1.7 W, it was retained at the lower node point in the resonator cavity.

Acknowledgment

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