Generation of Radiation Pressure in Thermally Induced Ultrasonic Emitter Based on Nanocrystalline Silicon

Jun Hirota, Hiroyuki Shinoda¹, and Nobuyoshi Koshida

Department of Electronical and Electronic Engineering, Faculty of Technology, Tokyo University of Agriculture and Technology, Koganei, Tokyo 184-8588, Japan Phone: +81-42-388-7128 Fax: +81-42-385-5395 E-mail: koshida@cc.tuat.ac.jp ¹The University of Tokyo, Bunkyo-ku, Tokyo 113-8654, Japan

1. Introduction

Previously, we reported that nanocrystalline porous silicon (PS) is useful as a key component of thermally induced ultrasonic emission device [1]. This effect is due to a big difference in both the thermal conductivity and the thermal capacity per unit volume between PS and single-crystalline silicon (c-Si). This makes it possible to generate efficient ultrasonic wave only by heat transfer from the surface electrode to air without anv mechanical vibrations. There are many advantageous features in this device over the conventional electro-acoustic ultrasound generators: completely flat frequency characteristics in a wide range (theoretical upper limit is about 1 GHz), a negligible harmonic distortion, and the available scaling effect of device size for enhancing the efficiency [2].

The most important advantage of the PS emitter is the flatness of the frequency characteristics. Based on our previous fundamental work on the dynamic response [3], a possible application of this device to radiation pressure generator is presented in this paper.

2. Experiment

Top view photograph of PS ultrasound emitter is shown in **Fig. 1**. The fabricated device is composed of a thin film surface electrode, a PS layer, and a c-Si wafer. The substrates were p-type (100) c-Si wafers ($3 \sim 5$ cm). The PS layer were prepared by anodization of c-Si in a solution of 55% HF:ethanol = 1:1 at a current density of 20 mA/cm² for 40 min. After anodization, a thin tungsten film electrode is deposited by sputtering. The PS layer thickness is about 50 µm. The tungsten film thickness (about 100 nm) was controlled such that the overall resistance as the electrode is about 10

The radiation pressure induced in the device was evaluated by laser displacement detection system as shown in **Fig. 2**. The electrical input is provided as pulsed current to the electrode pad. Following the induced Joule's heating, the temperature at the device surface fluctuates with significantly large amplitude because of the thermal insulating property of the PS layer. The temperature change is quickly transferred to expansion and compression of air, and then acoustic pressure is emitted. This mechanical effect induces a displacement of the beam (a cover glass is used in this case) located in close to the device surface. The displacement detected optically is used for evaluating the radiation pressure by the conventional mechanics equation. The sound pressure is also measured separately by a microphone located at a distance of 1 mm from the device.

3. Results and discussion

In **Fig. 3** is shown a typical example of the dynamic behavior of the device under a sequential pulsed operation. We can see that due to a flat frequency response capability, the device emits an acoustic pressure with little distortion even for a short pulse input of 10 μ s. Based on this result, the device was driven under a burst input (70 ms) of pulse signal (frequency: 10 kHz, duty ratio: 10%). Under this concentrated power input, the acoustic pressure amplitude is significantly enhanced. Then the radiation pressure is generated at the beam surface as a result of nonlinear acoustic effect, and then a displacement occurs at the beam.

The observed displacement values for different input power are listed in **Table 1** The estimated load, radiation pressure, and corresponding sound pressure are also shown. For an input power of 21 W, the beam shows a displacement of $3.5 \,\mu\text{m}$. The estimated load at the beam is 34.5 Pa. The corresponding sound pressure is given by $(c^2 ? P_{rad}/2)^{1/2}$, where *c*, ?, and P_{rad} are the sound velocity, the density of air, and the radiation pressure, respectively. Thus the obtained value of P_{rad} means that a sound pressure of about 5000 Pa (168 dB) is emitted from the device.

4. Conclusion

It has been demonstrated that the PS ultrasonic emitter is useful not only for a sound source, but also for a radiation pressure generator. This device is widely applicable as functional sound emitter including a non-contact actuator.

References

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Fig. 1. Top view of the nanocrystalline PS . ultrasonic emitter. The emitting area in this case is 1x1 mm.

Fig. 2 Experimental system for measurement of radiation pressure based on the laser displacement detection method.



Fig. 3. Dynamic response of the PS device under a sequential pulsed operation mode. There are neither distortion nor degradation in the output signal.

Input Power	14 (w)	21(W)
Displacement (µm)	2	3.5
Force (N)	1.97×10 ⁻⁵	3.45×10 ⁻⁵
Radiation Pressure (Pa)	19.7	34.5
Peak Sound Pressure (Pa)	3715	4942

Table 1. The estimated load, radiation pressure, and the corresponding sound pressure obtained from the beam displacement for two different input powers.