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Transient and Stationary Characteristics of Thermally Induced Ultrasonic Emission from Nanocrystalline Porous Silicon

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1. Introduction

Because of a complete carrier depletion in nanocrystalline silicon, the thermal conductivity and the heat capacity per unit volume of porous silicon (PS) is extremely low in comparison with those of single-crystalline silicon (c-Si). It can be utilized as thermally induced ultrasonic generation [1,2]. This ultrasonic emission is based on transfer of Joule's heating generated at the PS surface by an ac electrical input into air. It has been confirmed that there are many advantageous features in this device over the conventional electro-acoustic ultrasound generater: emission from still surface without any mechanical vibrations, completely flat frequency characteristics in a wide range, small harmonic distortion, possible enhancement of efficiency by scaling the electrode size [3].

To clarify the fundamental characteristics further, the transient and stationary behavior of the ultrasonic emission is presented in this paper, including the scaling effect on the output acoustic pressure.

2. Experiment

Schematic illustration of cross sectional view of the fabricated device and experimental configuration for sound emission measurements is shown in Fig. 1. The fabricated device is composed of a patterned Al thin film surface electrode, a PS layer, and a c-Si wafer. The substrates were p-type (100) c-Si wafers (10～20 Ω 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/cm^2 for 40 min. After anodization, a patterned Al thin film electrode is deposited by vacuum evaporation. The PS layer thickness (about 50 μm) and the Al thin film thickness (about 30 nm) were controlled such that the overall resistance as the electrode is about 30 Ω.

The electrical input is provided as an ac current to the Al electrode. Following an induced Joule's heating, the temperature at the device surface fluctuates with a frequency of two times higher than the input frequency. It is directly transfered to expansion and compression of air. The induced acoustic pressure is detected by a condenser microphone placed at a distance of 5 cm from the device surface. The input frequency was varied from 5 to 50 kHz.

3. Results and discussion

For the application of the thermally induced ultrasonic emission to acoustic devices, it is necessary to know the transient behavior at the generation of acoustic pressure. As a first step, it is evaluated whether or not there is some delay time in the output signal at the onset of electrical input to the electrode.

As a typical example, the sinusoidal input (10 kHz in frequency) and detected signals are shown in Fig. 2. Taking the propagation velocity of sound into account, there is no intrinsic time delay in the thermo-acoustic conversion, as shown in this figure as a corrected signal. Similar results were observed at higher frequencies. The ultrasonic emission is generated instantly for the electrical input. Because of a fast response, it is easy to control the output signal against the input signal. After the onset of the ultrasonic emission, the output signal amplitude with a negligible noise level remains unchanged for a long time stationary operation.

Another remarkable point of this device is the scaling effect on the efficiency. As demonstrated in Fig. 3, 4, the output pressure is enhanced by a reduction in the electrode size with remaining surface area and overall resistance. Principally, the output efficiency defined as the ratio of the acoustic pressure to the input electrical power should be increased by a scaling factor. The scaling effect should be more apparent if the electrode is assembled as integrated fine arrays.

4. Conclusion

It has been confirmed that from transient and stationary measurements, the thermo acoustic effect in the PS sound emitter is sufficiently fast and quite stable. The scaling merit of this device is also experimentally confirmed. These are very useful for development of novel acoustics and functional integration.

References

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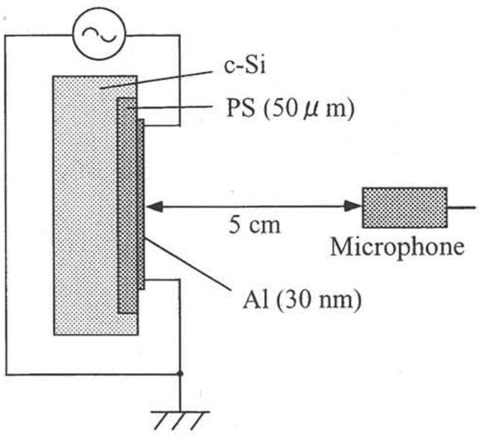

Fig. 1. Schematic illustration of cross sectional view of the fabricated device and experimental configuration for sound emission measurements.

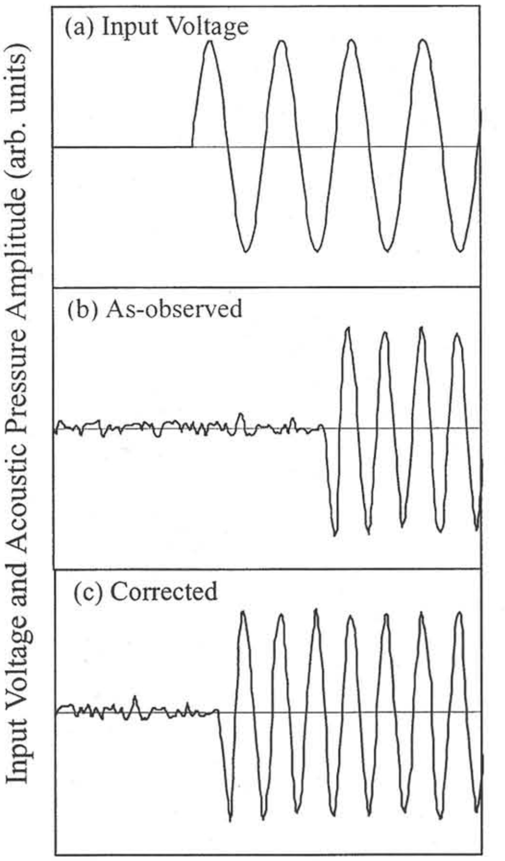

Fig. 2. Trangent behavior of ultrasound generation. (a) Input signal with a frequency of 10 kHz. (b) As-detected acoustic pressure signal. (c) Acoustic pressure signal after correction of a delay due to sound wave propagation.

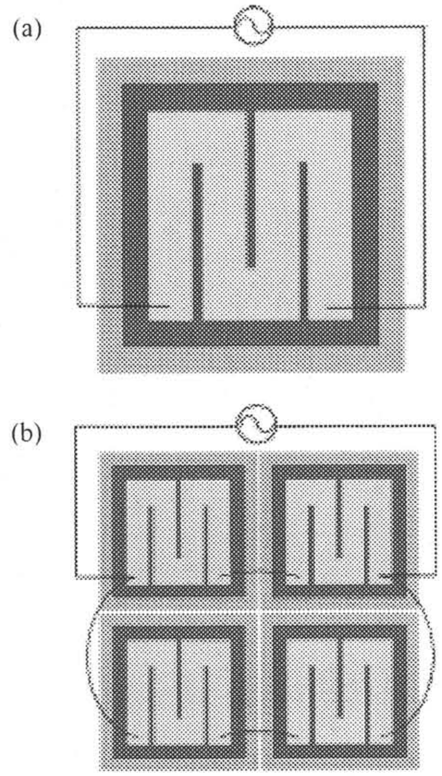

Fig. 3. Schematic illustration of two fabricated devices. (a) The device with a size is 20 × 20 mm. (b) Four arrayed device with a size of 10 × 10 mm. In the case of (b), the electrode size is adjusted such that the overall surface area is the same as that in the case of (a).

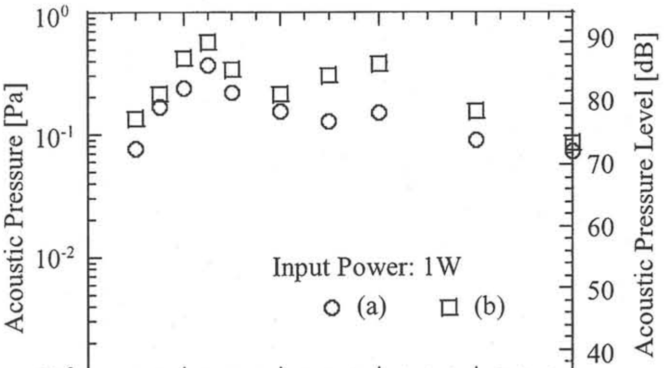

Fig. 4. Comparison of the acoustic pressure amplitudes of two devices as a function of the output frequency. The notations (a) and (b) corresponds to those indicated in Fig. 3.