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Acoustic Emission Characteristics of Nanocrystalline Porous Silicon Device Driven as an Ultrasonic Speaker

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1. Introduction

Due to complete carrier depletion associated with strong quantum confinement effect in nanocrystalline porous silicon (nc-PS), its thermal conductivity and heat capacity per unit volume are extremely low in comparison to those of single-crystalline silicon (c-Si). The exceptionally high contrast in the thermal properties between nc-PS and c-Si induces efficient thermo-acoustic effect by which ultrasound wave is generated without any mechanical surface vibrations [1]. In this device, a dc-superimposed driving mode can effectively enhance the acoustic output amplitude, as reported previously [2]. Effects of the dc-superimposed drive are reported here in more detail for the use as a novel ultrasound generator.

2. Experimental

A schematic of the device structure and the experimental configuration for measurement are shown in **Fig. 1**. The nc-PS device is composed of a thin film heater electrode, an nc-PS layer, and a c-Si wafer. The substrates were p-type (100) c-Si wafers (80-120 Ωcm). The nc-PS layers were prepared by electrochemical anodization of a c-Si wafers in a solution of 55 % HF:ethanol=1:1 at a current density of 100 mA/cm^2. The thickness of the nc-PS layer (2 μm in this case) was adjusted to a value that was considerably larger than the thermal diffusion length in the nc-PS layer at frequencies under study. After anodization, a thin tungsten film (50 nm in thickness) was deposited by RF-sputtering onto the nc-PS layer and used as a heater electrode. The heater electrode size corresponding to the ultrasonic emission area was 5×5 mm^2.

The device was operated under the following two electrical input modes: a simple ac-voltage drive and a dc-superimposed ac-voltage one. The emitted sound pressure was measured as a function of the input power and voltage by using a microphone located at a distance of 10 mm from the device surface. A possible stationary temperature rise at the device surface was also monitored during operation by a radiation thermometer under the situation that the device was mounted on a heat sink with a heat resistance of 0.78 K/W.

3. Results and Discussion

Since the acoustic pressure generated in the nc-PS emitter is principally proportional to the amplitude of surface temperature fluctuations to be induced by Joule heating, the output pressure for a simple ac-voltage input $V_{p\text{-}p}\sin\omega t$ is represented by $\propto V_{p\text{-}p}^2\cos 2\omega t$, where $V_{p\text{-}p}$ is an input voltage in peak-to-peak. When a dc-superimposed voltage $V_{dc}+V_{p\text{-}p}\sin\omega t$ is introduced as the input, on the other hand, the major component of the output signal is given by $\propto 2V_{dc}V_{p\text{-}p}\sin\omega t$, where V_{dc} is an applied dc voltage.

The measured output sound pressures for the two driving modes are shown in **Fig. 2** as a function of $V_{p\text{-}p}$. The respective acoustic outputs exhibit the $V_{p\text{-}p}$ dependencies along the way as expected above. It should be noted that in the dc-superimposed drive, the output frequency is the same as the input one. In addition, a stationary temperature rise is kept constant independent of $V_{p\text{-}p}$ in contrast to the case of the ac-voltage drive. As indicated in **Fig. 3**, the linear relationship between the output and V_{dc} has been fairly confirmed in the dc-superimposed drive.

The advantageous feature in the dc-superimposed drive over the ac-voltage drive can also be seen in the input power dependence of the acoustic output, as shown in **Fig. 4**. Obviously the power efficiency is significantly enhanced in the dc-superimposed drive without affect on the temperature rise.

4. Conclusion

It has been shown that the dc-superimposed drive is more useful for efficient operation of the nc-PS ultrasound emitter in comparison to the conventional simple ac-voltage drive. The present result ensures the technological potential of the nc-PS ultrasound emitter for applications to functional devices such as a super tweeter and a parametric speaker.

References

[1] H. Shinoda, T. Nakajima, M. Yoshiyama and N. Koshida: Nature **400** (1999) 853.
[2] A. Kiuchi and N. Koshida: Jpn. J. Appl. Phys. **44** (2005) 2080.

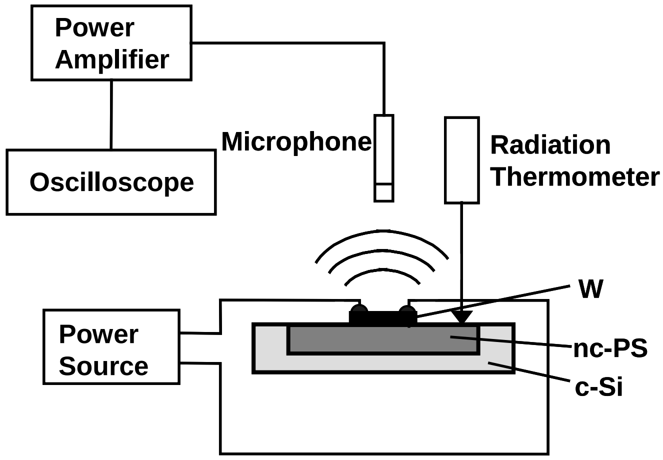

Fig. 1. The device structure and experimental configuration. A microphone is located at a distance of 10 mm from the device surface. A stationary temperature rise at the device surface is also measured using a radiation thermometer during operation.

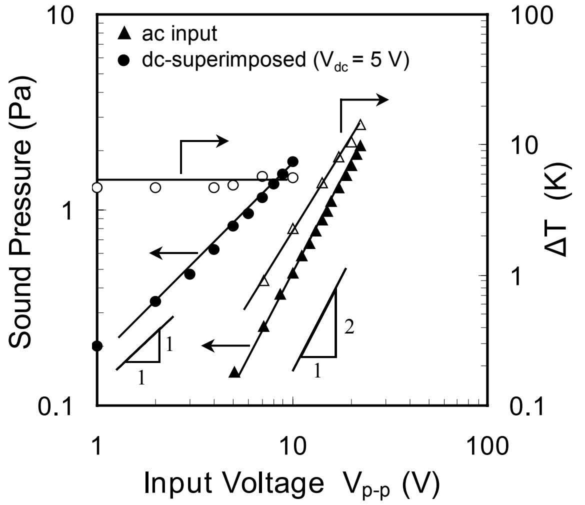

Fig. 2. Measured output sound pressures as a function of the input voltage (in peak-to-peak) under a simple ac-voltage drive mode (input frequency: 25 kHz) and a dc-superimposed drive one (input frequency: 50 kHz). Detected stationary temperature rises at the device surface under the two drive modes are also shown by the open plots.

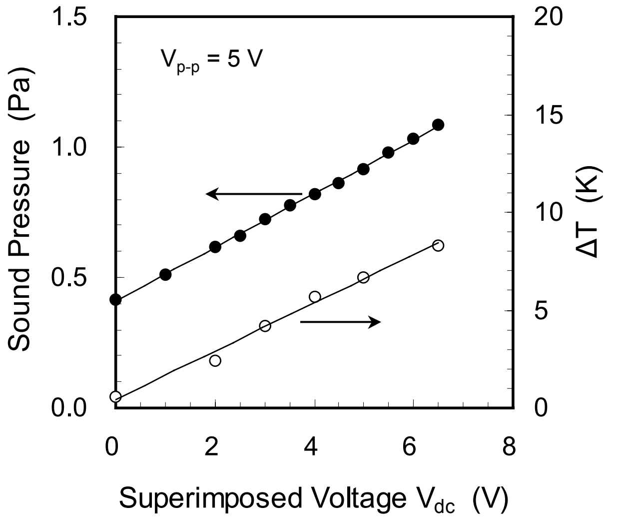

Fig. 3. Measured sound pressure output and stationary temperature rise at the device surface as a function of dc-superimposed voltage V_{dc}. The input voltage Vp-p and the input frequency are 5 V and 50 kHz, respectively, in this case.

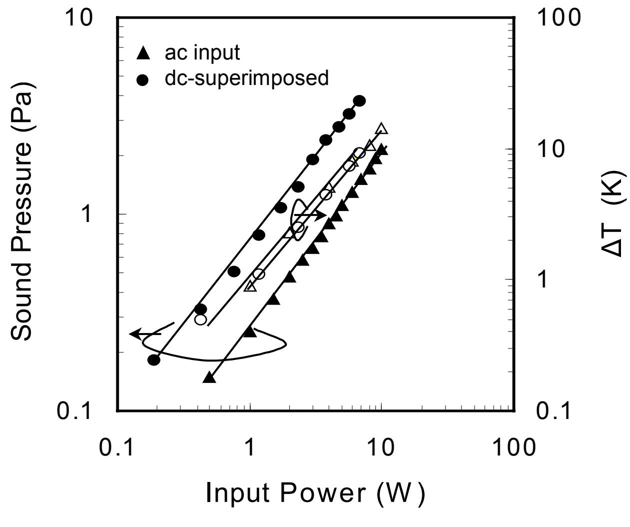

Fig. 4. Input power dependencies of measured output sound pressures under an ac-voltage drive mode (input frequency: 25 kHz) and a dc-superimposed drive one (input frequency: 50 kHz). In the case of dc-superimposed operation mode, V_{dc} is adjusted to $V_{p-p}/2$. Detected stationary temperature rises at the device surface under the two drive modes are also shown by the open plots.