Extended Abstracts of the 2004 International Conference on Solid State Devices and Materials, Tokyo, 2004, pp. 328-329

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New Operation Mode of Nanocrystalline Silicon Ultrasonic Emitter for the Use as an Audio Speaker

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1. Introduction

Previously, we reported that nanocrystalline silicon (nc-Si) 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 nc-Si and single-crystalline silicon (c-Si). This makes it possible to generate efficient ultrasonic wave only by heat transfer from the electrode surface to air without any mechanical surface 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 availability of the device size scaling for enhancing the acoustic emission efficiency [2].

Based on our previous fundamental work, a new driving technique suitable for application of this device to an audio speaker is presented in this paper.

2. Experiment

Top view photograph of nc-Si ultrasound emitter is shown in **Fig. 1**. The fabricated device is composed of a thin film surface electrode, an nc-Si layer, and a c-Si wafer. The substrates were c-Si wafers (p-type (100) ones with a resistivity of 3~5 Ωcm in this case). The nc-Si 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 20 min. After anodization, a thin tungsten film electrode is deposited by rf sputtering. The nc-Si layer thickness is about 25 μm. The tungsten film thickness (about 100 nm) was controlled such that the overall resistance as the electrode is about 10 Ω.

In this work, the electrical input is provided as dc-superimposed voltage 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 nc-Si layer. The surface temperature change is quickly transferred to expansion and compression of air, and then acoustic pressure is emitted. The acoustic pressure emitted by the device was measured by microphone as shown in **Fig. 2**. The experimental results are compared with those observed under the conventional simple ac-voltage input mode.

3. Results and discussion

In **Fig. 3** is shown waveforms of input and output for two operation modes. In the case of operation without dc bias, the frequency of output acoustic pressure is two times higher than that of supplied voltage. When dc-superimposed voltage is supplied, in contrast, there is no difference in the frequency between input and output signals. This can be explained as follows. For the input of $V=V_0\sin(wt)$, the induced Joule's heating T is given by

$$T \propto V_0^{\,2} - V_0^{\,2}\cos(2wt) \qquad (1)$$

that consists of the $2w$ component alone. When a dc bias V_{DC} is superimposed on ac voltage, on the other hand, the quantity of T corresponding to $V=V_{DC}+V_0\sin(wt)$ is represented as

$$T \propto 2V_{DC}^{\,2} + V_0^{\,2} + 4V_{DC}V_0\sin(wt) - V_0^{\,2}\cos(2wt)\,. \quad (2)$$

Note that the w component with considerably larger amplitude is involved. The observed acoustic pressure is shown in **Fig. 4** as a function of input power. In this case, the V_{DC} value is adjusted to V_0. Improvement in acoustic pressure is attained by dc-superimposed drive. This is due to increased thermal fluctuation.

The acoustic output pressure is plotted in **Fig. 5** as a function of input ac voltage. In this case, superimposed V_{DC} was 11 V. Under the dc-superimposed mode, the linearity between input and output signals can be seen as expected. This is an important advantageous feature for the application to speakers. Based on the above result, the usefulness of this device as audio-band speaker has been confirmed under the operation in which a dc bias is superimposed to the output of commercial CD player and is introduced to the device.

4. Conclusion

It has been demonstrated that the nc-Si ultrasonic emitter is useful not only as an ultrasonic generator, but also as an efficient audio speaker.

References

[1] H. Shinoda, T. Nakajima, M. Yoshiyama and N. Koshida, Nature **400**, 853 (1999).

[2] N. Koshida et al, Proc. Int. ECS Symp. PV **2000-25**, Phoenix, 2000, pp.326-332.

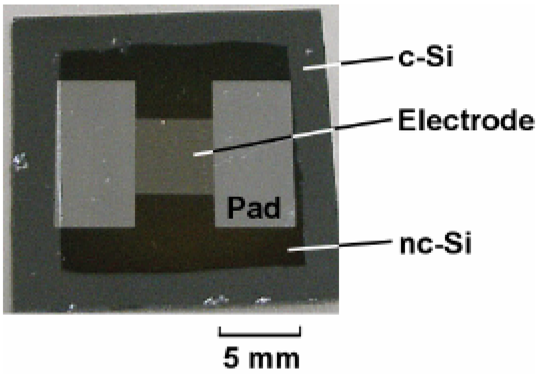

Fig. 1. Top view photograph of the nanocrystalline sillicon ultrasonic emitter. The emitting area in this case is 5x5 mm.

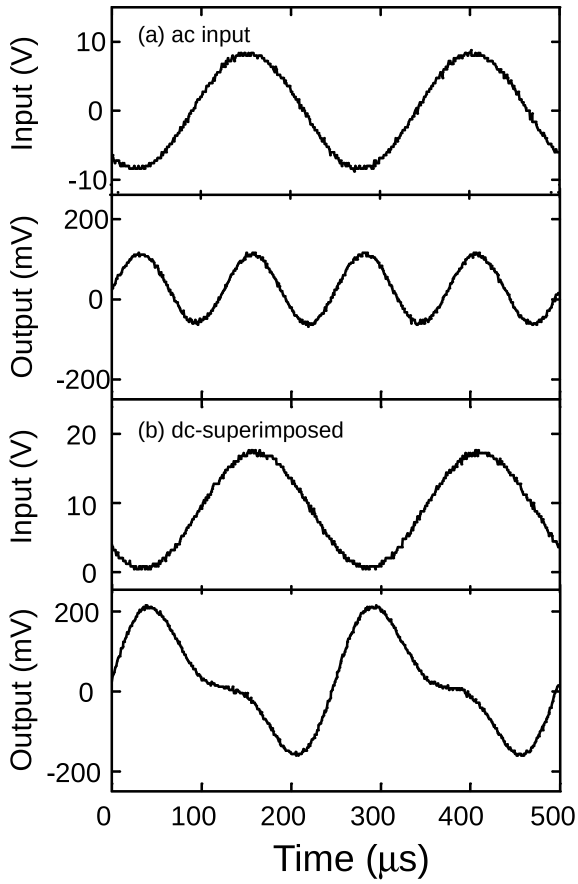

Fig. 3. Waveforms of the input and output signals. (a) Conventional ac input scheme. (b) dc-superimposed input scheme. Agreement of the frequency between input and output signals is observed.

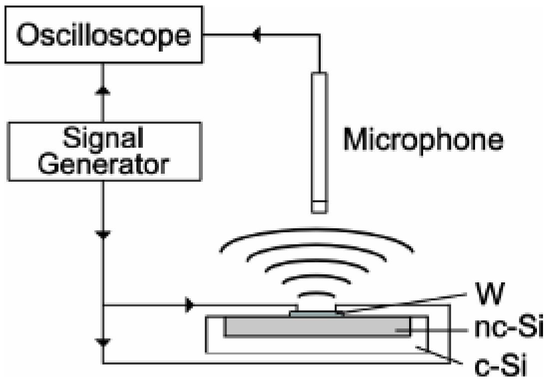

Fig. 2. The device structure and experimental arrangement for measurement of the acoustic output pressure.

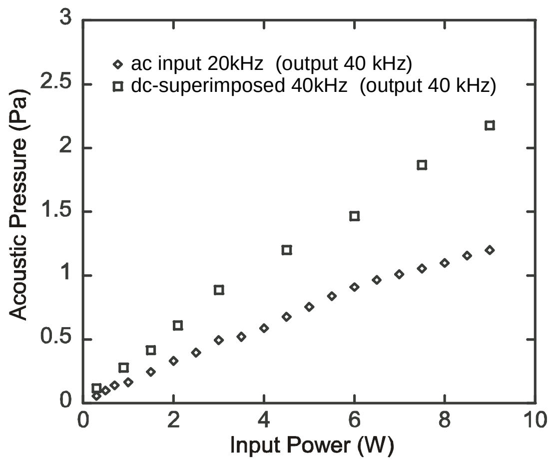

Fig. 4. Input power dependence of acoustic pressure for two operation modes.

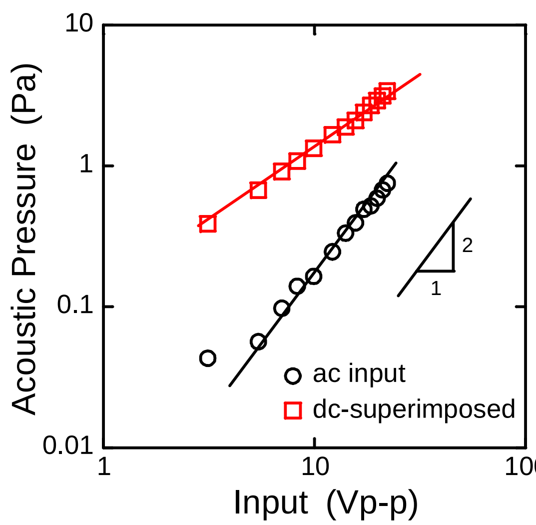

Fig. 5. Input voltage dependence of acoustic pressure for two operation modes.