P-13-1

Extended Abstracts of the 2009 International Conference on Solid State Devices and Materials, Sendai, 2009, pp707-708

High thermo-acoustic property of Carbon-nanotube speaker

K. Suzuki[1], S. Sakakibara[1], S. Shimizu[1], M. Okada[1], Y. Neo[1], H. Mimura[1], Y. Suzuki[2], Y. Minami[2], A. Murakami[2], J. Muramatsu[2] and Y. Inoue[2]

[1]Research Institute of Electronics, [2]Department of Electrical and Electronic Engineering, Shizuoka University, 3-5-1 Johoku, Naka-ku, Hamamatsu, Shizuoka 432-8011, Japan
Phone: +81-53-478-1315 E-mail: katsunori.suzuki07@nifty.com

1. Introduction

Carbon nanotubes (CNTs) have been investigated as a key nanomaterial for a wide range of applications [1], since their discovery in 1991 [2]. Their small tubular structure is responsible for diverse features, such as highly mechanical strength [3], strongly electric properties [4], good heat conductance [5], and high electron emission [6], which are of interest for academic researchers and industries [7,8]. With good heat properties, Xiao et al. have found that just a piece of CNT thin film can be a practical magnet-free loudspeaker simply by applying an audio frequency current through it, where the oscillations by rapid temperature lead to pressure oscillations in the air next to the film. Thermally induced pressure oscillations are important for the sound [9]. They demonstrated that their CNT loudspeakers can generate sound with wide frequency range, high sound pressure level, and low total harmonic distortion.

So far we have reported a simple and easy growth method of ultra-long, vertically aligned multi-walled carbon nanotube (MWNT) array by chloride mediated chemical vapor deposition (CM-CVD)" [10]. By tuning the growth conditions, the highly spinnable MWNT array samples are synthesized. The nanotube yarns are easily drawn by just pinching and pulling out MWNT from array edge. Here we report significantly high acoustic properties of the CNT speaker fabricated with the MWNT yarns.

2. Experimental

Vertically aligned MWNT array was synthesized using a conventional thermal CVD system. A schematic diagram of the experimental setup is shown in Fig. 1. This setup consists of quartz tube furnace (40 mm in diameter and 30 cm in length). A smooth quartz substrate was placed in the center of the horizontal quartz tube with iron chloride

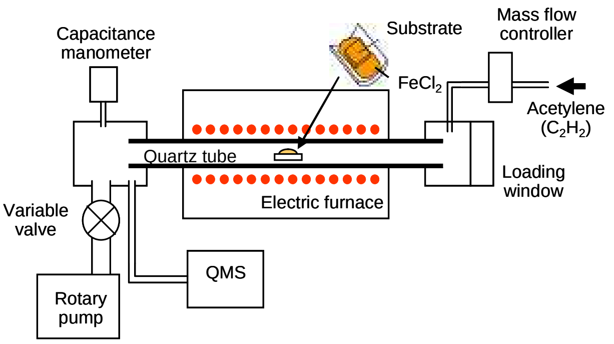

Fig.1 Schematic of CM-CVD system

($FeCl_2$) powder (99.9 %) using a quartz boat. Typically, a thin metallic film deposited on a substrate is widely used as a catalyst; however, no pre-deposited treatment is needed in the present work. During heating, the sample was kept at a vacuum of 1×10^{-3} Torr, and once the optimal growth temperature was reached, acetylene (98 %) was introduced into the tube using a mass flow controller. CVD growth was carried out at a furnace temperature of 820 ^{o}C. The length of the MWNT is upto 2 mm with the growth rate of 100 μm/min.

Our MWNT array sample has a high spinnable feature. To prepare the high spinnable MWNT array, the growth conditions were optimized. The CNT yarn is easily spun using tweezers or appropriate tools by pulling out the array, as shown in Fig. 2(a). We obtained over 20 m-CNT bundle ribbon (yarn). The CNT bundle-areal-density and the linear density of the inter-CNT connections via migrant CNTs were also confirmed experimentally as key parameters needed for sheets or yarns spinability.

The CNT speakers were fabricated using low revolution motors as shown in Fig. 2(a). The CNT speakers consist of two electrodes and parallel-aligned CNT yarns in the drawing direction. Conductive adhesives were used for the electrical contact between the electrodes and the CNT yarns. To investigate thermo-acoustic properties, two kinds of CNT speakers were fabricated with changing impedance between electrodes. The impedance was changed with number of CNT yarns. The impedances are 37 Ω and 82 Ω, respectively. The speaker size is 50 mm by 50mm, as shown in Fig. 2 (b).

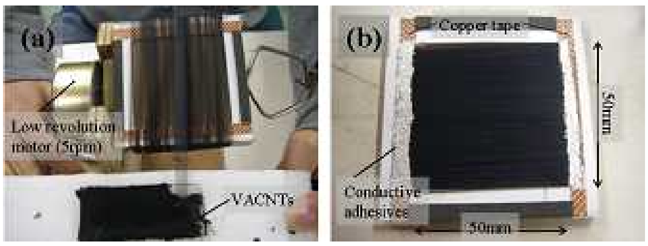

Fig.2 (a) Fabrication of thermo-acoustic CNT speaker and (b) the thermo-acoustic CNT speaker

Acoustic measurements were conducted in an anechoic chamber. Schematic illustration of the experimental setup is shown in Fig. 3. Pulse Width Modulation (PWM) waveforms were used as the input signal. The distance between the CNT speakers and the microphones was

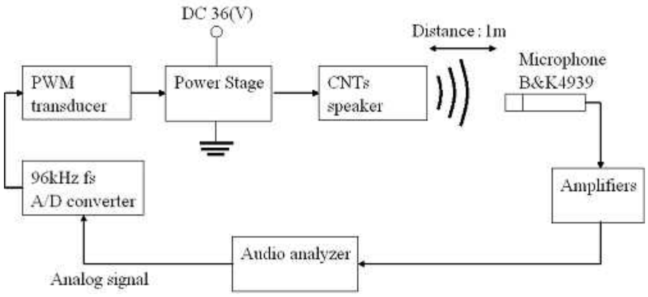

Fig. 3 Experimental setup for acoustic measurements

1 m. Note that, when a simple alternate current (AC) signal input with an angular frequency of ω is provided into the CNT speaker, acoustic pressure is generated with an angular frequency of 2 ω. Because the surface temperature oscillations arising from Joule heating double the input signals. To avoid this problem, the direct current input signals were biased using a direct current (DC) power supply to modulate the signals. By the DC biasing, CNT speaker was hot during the measurements.

3. Results and Discussion

Figure 4(a) shows the relationship between sound pressure level (SPL) and frequency (100-40kHz) for two CNT speakers, 37 Ω and 82 Ω. Their input signal voltages are both 30 $V_{o\text{-}p}$, where input powers are 12 W and 5.5 W, respectively, including the DC biases. Figure 4(b)

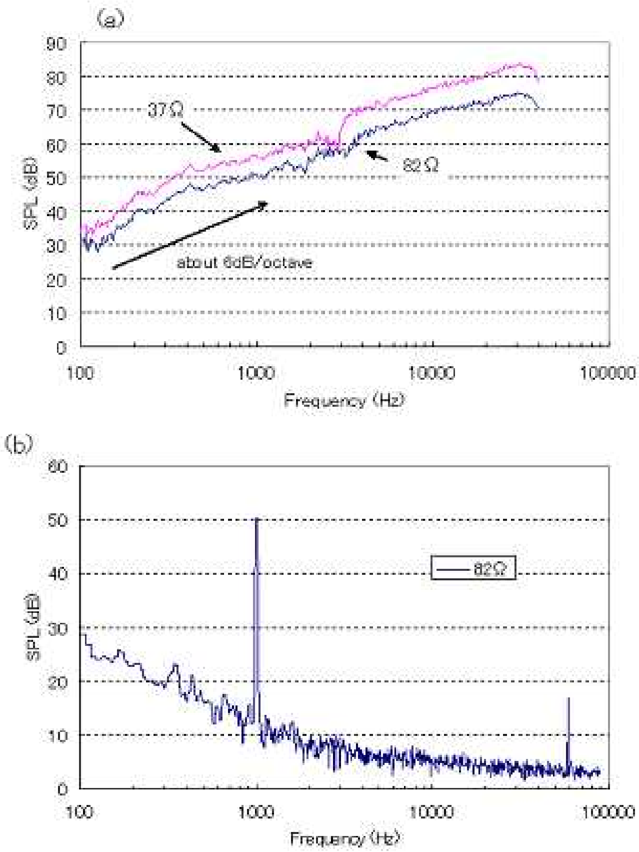

Fig. 4 (a) SPL versus frequency. (b)FFT at 1kHz

shows the FFT results at the frequency of 1 kHz obtained from 82 Ω speakers. The generated SPLs are proportional to the frequency (6 dB/octave). As shown in Fig. 4(a). The low impedance speaker shows high SPLs at the same input voltages.

The loud sounds of CNT speaker depend on the heat capacity per unit area (HCPUA) which is an important parameter for the sound-generating efficiency on the thermo-acoustic speaker system. From the viewpoint of thermal source in the speaker, we think that contact resistance between each nanotubes generates heat. A long CNT yarn used in the speaker consists of a large number of short nanotubes about 1 mm in length. In the literature, the nanotubes are considered to be connected at the both ends each other [11]. Therefore the speaker impedance may arise mainly from contact resistance rather than CNT itself. In the present experiment, since low impedance speaker was prepared with much amount of CNT yarns, the speaker should have much more nanotube contacts (heat sources) rather than higher impedance one. Thus higher SPLs was obtained from lower impedance speaker.

Here we also point out that the present speakers have good thermo-acoustic property. One can hear our speaker playing sounds without using microphone with wide frequency range. These good speaker characteristics are considered to be due to good thermal property of CNT.

4. Conclusions

High productive and high quality CNT speakers were demonstrated. The CNT speakers were fabricated using long CNT yarns spun from high spinnable MWNT array. A constant practical acoustic output was shown in a wide frequency range from 100 Hz to 40 kHz. In the future, suppression of constant surface heat, caused by DC bias, is needed to be improved. Furthermore, the relationship between SPLs and the distance between speaker and microphone might be investigated.

References

[1] R. H. Baughman et al., Science **297**, 787 (2002).
[2] S. Iijima, Nature 354, **56** (1991).
[3] M. M. J. Treacy et al., **381**, 678 (1996).
[4] T. W. Ebbesen et al., Nature **382**, 54 (1996).
[5] P. Kimet al., Phys. Rev. Lett. **87**, 215502 (2001).
[6] W. A. de Heeret al., Science **270**, 1179 (1995).
[7] N. S. Lee et al., Diamond Relat. Mater. **10**, 265 (2001).
[8] Y. Saito and S. Uemura, Carbon **38**, 169 (2000).
[9] L. Xiao et al., Nano Lett. **8**, 4539 (2008).
[10] Y. Inoue et al., Appl. Phys. Lett. **92**, 213113 (2008).
[11] X. Zhang et al., Adv. Mater. **18**, 1505 (2006).