LIQUID ENERGY HARVESTING DEVICE USING CARBON NANOTUBE THIN FILM

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Abstract: This paper reports the liquid energy harvesting with carbon nanotube film (CNF) devices. Different from the voltage generation by flowing water or other liquids across the carbon nanotube or graphene thin film, it was found that the electricity can also be generated by immersing or wetting the carbon nanotube film (CNF) with some liquids such as isopropyl alcohol (IPA) and soap water. The observed voltage can be as high as 300 mV for a CNF device measured 2 cm long, 0.8 cm wide and 100 μm thick as far as sufficient amount of solution presents and can keep the CNF wet, which might be attributed to the liquids' dynamic flowing process among the tangled CNTs due to the evaporation.

Keywords: Carbon nanotube film, carbon nanotube thin-film device, liquid energy harvesting

INTRODUCTION

Carbon nanotubes (CNTs) with unique electrical, mechanical, thermal and optical properties provide attractive building blocks for many types of devices for a variety of interesting applications in different fields. For instance, the carbon nanotube film (CNF) has been used for harvesting thermal and solar energy successfully [1-3]. In addition, several groups have reported that by flowing liquid across CNF or aligned CNTs, electrical voltages, typically in the range of 10 μV- 10 mV [1-3], can been generated due to the direct forcing of the free charge carriers in the CNTs by the fluctuating Coulombic field of the liquid flowing along the carbon nanotubes [4-6]. Recently, similar phenomena (i.e., voltage generation) have also been observed and reported on the graphene thin film by flowing the liquid such as water or other liquids across the graphene thin film [7-8].

Herein, we report that the CNF devices can also generate voltages and produce power by simply immersing or wetting the CNF with some liquids.

DEVICE DESCRIPTION & FABRICATION

A basic schematic of the CNF device and a photo of fabricated device are shown in **Fig 1(a-b)**. The CNF is obtained by using a simple vacuum filter method [1-3]. Specifically, in order to obtain a 100 μm film thickness of CNF, 50 mg of CNTs is mixed with 500 ml of IPA. To achieve uniform dispersion of the CNTs, the mixture is put into an ultrasonic agitator for 20-24 hrs. Once the agitation is complete, the mixture is vacuum filtered. A mixed ester filter membrane with pore thickness 0.2 μm and a diameter of 47 mm is used to filter out the CNTs. When the entire IPA seep out of the membrane a uniform thickness of CNF is formed on top of the filter membrane. Separating the filter membrane from the film is a critical step.

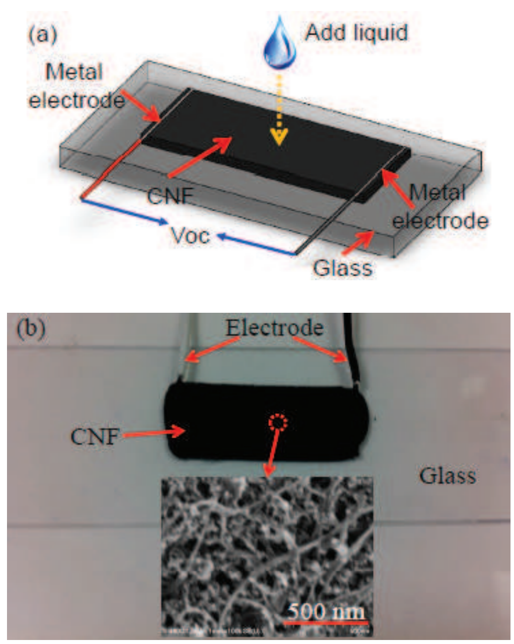

Fig. 1: (a) Sketch of the CNF-based device; (b) Photo of a fabricated CNF device; Inset is the SEM image of the CNF. The thin-film device measures 2 cm long, 0.8 cm wide and 100 μm thick

The membrane with the film on top is placed on a clean silicon wafer (the wafer provided a support to the film), then immersed in an acetone bath for 10-15 minutes. The mixed ester dissolved in acetone, the wafer is then taken out and allowed to dry for a few minutes; white patches of the dissolved membrane can be seen on the wafer, these patches are cleaned up. The wafer with the film is again dipped in a fresh acetone bath to remove the remaining membrane residue. Handling the film during this cleaning process is critical; the film can crack very easily due to handling stress. The SEM image of CNF is given in **Fig. 1(b)**, the tangled CNTs can be clearly visible. Once the desired dimensions (2 cm long, 0.8 cm wide and 100 µm thick) of CNF are cut, the CNF is transferred and attached onto a glass slide. Then the Cu electrodes are connected to both ends of the film by using Cu conductive glue (Anders Product, Inc), forming a two-terminal thin-film device.

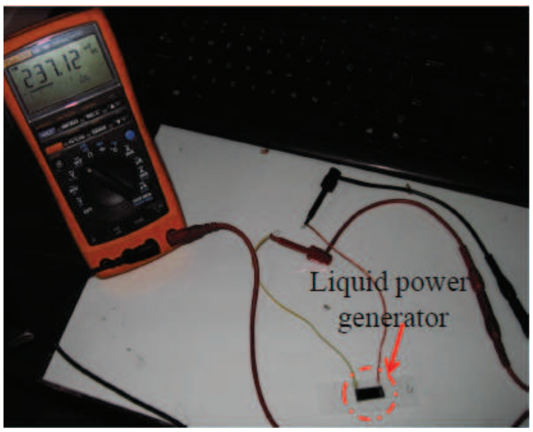

Fig. 2: Photo for the typical experiment setup to measure the open circuit voltage and power generation

Several newly fabricated devices with the same dimensions have been fabricated. The measurement setup is shown in **Fig. 2**. The Cu electrodes of the device are connected to a multimeter (Agilent UA1252A) through a pair of alligator clamps. The multimeter is connected to a personal computer to record data. Since the polarity of the voltage generated by the device is unknown at the start of the experiment, the Cu electrodes of the sample can be connected to any pole of the voltmeter. The liquid is then dropped on the CNF surface using a pipette or a syringe. The liquid is dropped until the entire sample is completely wet. The voltage generation capability of the devices have been examined with different types of liquids inclduing water.

RESULTS AND DISCUSSION

The control experiments have been carried out on the CNF device without applying any liquids. As shown in **Fig. 3,** the measured open circuit voltage (OCV) is typically in the electrical noise range of ± 0.01 mV, which is basically the noise range of the thin-film device.

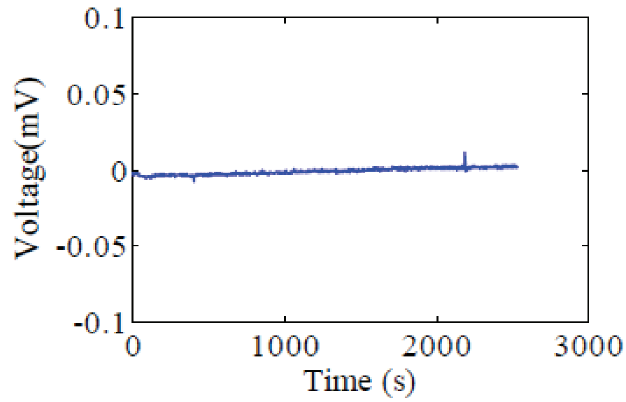

Fig. 3: Control experiments on a CNF device without applying any liquids: Measured open circuit voltage is essentially zero

Fig. 4 shows the measured open circuit voltage (OCV) of the CNF device when isopropyl alcohol (IPA) solution is applied on the CNF. The open circuit voltage can be maintained between ~250 mV to ~300 mV as far as the CNF can be kept wet. After the device becomes dried, the OCV becomes very small, essentially in the noise range. The OCV can be recovered if IPA solution is added. It has been observed that the OCV has some significant fluctuations when the IPA is applied on the fresh device for the first time as shown in **Fig. 4**. The OCV becomes much more stable when the IPA is applied for the second time after the device becomes dried.

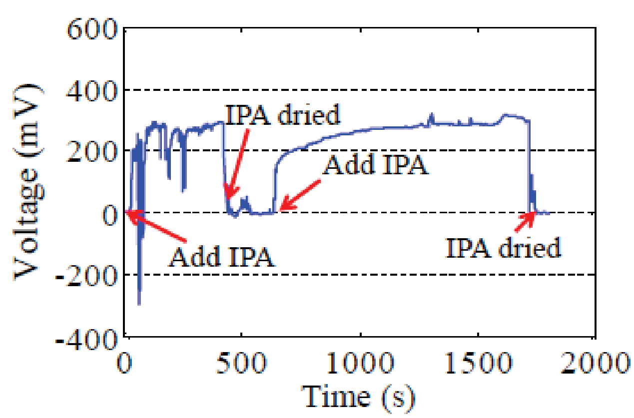

Fig. 4: Measured open circuit voltage (OCV) of a CNF device when the IPA solution was applied. It was found that when the PIA dried, the voltage became essentially zero. By adding IPA, the voltage can be recovered

Fig. 5 shows the measured open circuit voltage (OCV) when soap water is applied on the CNF region of the device. Similar to the measurement in **Fig. 4**, even though there are some voltage fluctuations during the measurement, but overall the voltage can be maintained between ~200 mV to ~300 mV during most of the time for over 18-hour continuous measurement.

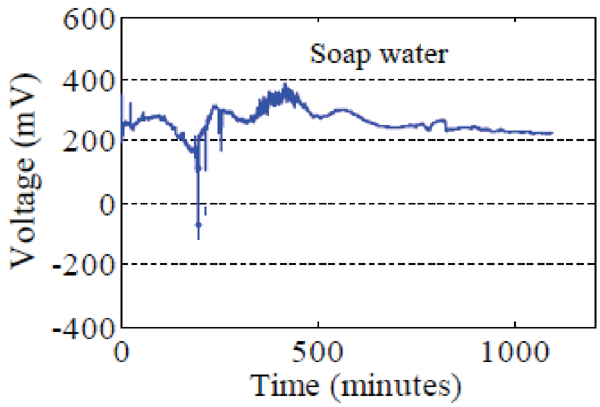

Fig. 5: Measured open circuit voltage (OCV) of a CNF device when soap water was applied

The power generation measurements of the device have been carried out by changing the load resistor connected to the device. **Fig. 5** gives the measured power generation by the CNF device with applied soap water. For this measurement, the maximum output power is ~ 22.5 nW.

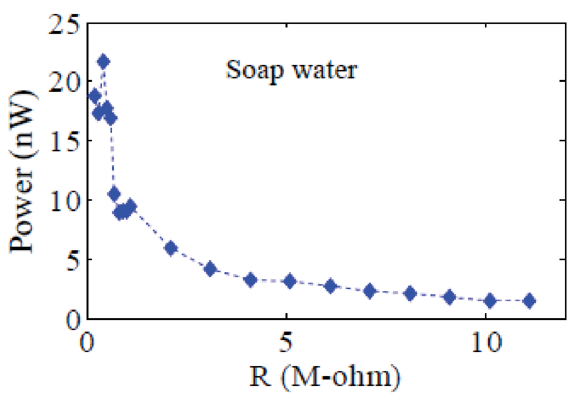

Fig. 6: Measured power generation of the CNF device when soap water was applied by changing the loading resistance

It has been found that no voltage/power can be generated by this type of devices by applying water. It should be noted that the thickness of the carbon nanotube film (CNF) plays an important role this type of liquid energy harvesting device. Specifically, experiments find that the optimum thickness for this type of energy generator is around 100 μm.

The contact angle of the CNF has been measured before and after the device is used for the experiment. The newly fabricated devices typically have contact angles close to 50^0. After a few seconds the solution droplets slowly gets absorbed by CNF.

It has also been observed that previously used devices perform better than the freshly fabricated devices for voltage/power generation. In some cases, some new devices cannot produce any voltage during the first time experiment, but when the devices are allowed to dry and then reused by applying the IPA or soap water, the voltage can be generated. *It has also been observed that the same device can still generate voltage/power when the IPA or soap water was applied on the device one year later based on our recent experiments immediately before submission of this full manuscript to the conference, even though the voltages (fluctuation from 50 mV to 150 mV) were not as high as those measured one year ago.*

The physical mechanism behind the voltage/power generation has not been really understood yet for this type of devices. For instance, why there is an optimum thickness of this type of devices (e.g., ~100 μm) for voltage/power generation is still unknown. Based on the previously reported and related research [4-5], the voltage generation might be due to the liquids' dynamic flowing process among the tangled CNTs due to the evaporation. However, since the evaporation of the liquids is a "*random*" process through the tangled CNTs inside CNF to all different directions, hence the physical mechanism for the voltage generation could have some significant difference from the previously reported research [4-8], in which the liquid always flows along the same direction across the CNF or graphene film. Another interesting observation is that why some freshly fabricated devices cannot produce voltage/power when IPA or soap water is applied for the first time, but can produce voltage/power up to over 200 mV-300 mV as far as the device can be kept wet when the same liquids are applied later on. Further basic studies are definitely needed to understand the voltage generation process.

CONCLUSION

The voltage and power generation of the carbon nanotube film (CNF) devices have been observed and demonstrated by applying some liquids such as IPA and soap water to CNF. It has been found the thickness of the CNF is critical for the voltage generation, which is ~ 100 μm for this type of devices in our experiments. It is also found that the previously used devices may perform better than the newly fabricated devices. The physical mechanism for this type of devices is not really clear at current stage and requires further studies. Obviously, this observed phenomenon is very intriguing and could be useful for liquid energy harvesting, and thus potentially operating some micro/nanodevices and micro/nanosystems.

REFERENCES

[1] V. Kotipalli, Z. Gong, P. Pathak, T. Zhang, Y. He, S. Yadav and L. Que, "Light and thermal energy cell based on carbon nanotube films," *Appl. Phys. Lett.* 97, pp. 1241021-1241023, 2010.

[2] Z. Gong, A. Tseng, Y. He, and L. Que, "Studies of self-reciprocating characteristic of carbon nanotube film-based cantilevers under light and thermal radiation," *J. Nanosci. Nanotechnol*. vol. 12, no. 1, pp.350-355, 2012.

[3] Z. Gong, Y. He, A. Tseng, C. O'Neal and L. Que, "A micromachined carbon nanotube film cantilever-based energy cell," *Nanotechnology*, 23 (2012) 335401

[4] S. Ghosh, A.K. Sood, N. Kumar, "Carbon nanotube flow sensors," *Science*, 299 (2003), pp. 1042-1044.

[5] P. Kral, M. Shapiro, "Nanotube electron drag in flowing liquids," *Physical Review Letters*, 86(2001), pp. 131-134.

[6] S. Lee, D. Kim, S. Kim, C. Han, "Flow-induced voltage generation in high-purity metallic and semiconducting carbon nanotubes," *Appl. Phys. Lett.*, 99 (2011), pp. 1041031-1041033

[7] P. Dhiman, F. Yavari, X. Mi, H. Gullapalli, Y. Shi, P. Ajayan, N. Koratkar, "Harvesting energy from water flow over graphene," *Nano Letters*, 11 (2011), pp. 3123-3127.

[8] J. Yin, Z. Zhang, X. Li, J. Zhou, W. Guo, "Harvest energy from water flow over graphene?" *Nano Letters*, 12 (2012), pp. 1736-1741.