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Morphology and Electrical Characteristics of Single-Walled Carbon Nanotubes Film Prepared by Air Brush Technique

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Abstract: This study is to investigate the morphology and electrical characteristics of single-wall carbon nanotubes (SWCNTs) thin film deposition using air brush technique. A deposition setup consisting of a conventional artist air brush was developed and used to deposit SWCNT thin films and therefore the resulting film's characteristics need to be investigated to gauge its suitability in producing uniform monolayer. The SWCNTs used were synthesized via Direct Injection Pyrolytic Synthesis (DIPS) method, with diameters ranging from 0.8 to 3 nm. The substrate was deposited using an airbrush with varying nozzle to study its effect to the resulting SWCNTs thin films' characteristics. Subsequently, scanning electron microscope (SEM) were used to inspect the morphology and surface topography, and followed by preliminary electrical measurements. The result shows that good dispersion promotes uniform distribution of SWCNTs over large area of glass substrate. Moreover, the electrical measurement revealed that at 1 V, best morphology produced highest current at a nozzle distance of 10 mm (15.3 μA) and the lowest current at a nozzle height of 4 mm (3.24 μA). From the results presented, it is demonstrated that conventional artist airbrush setup can be effectively used to deposit monolayer thin film of SWCNT with high degree of uniformity. This research is necessary for the process of depositing-controlled CNT thin film network, which can influence the material characteristics and performance of the variety of CNT-based device applications.

Keywords: Carbon nanotubes network, morphology, air spray, nozzle height, current

1. Introduction

The electrical conductance, carrier mobility, flexibility, and environmental resilience of a carbon nanotube-activated thin film transparent conductor are all outstanding [1]. Furthermore, this material is excellent for new technology applications such as photovoltaic electrodes, organic light emitting diodes (OLEDs), touch panels, field emitters, smart windows, and smart fabrics when combined with a range of simple production processes [2] [3] [4][5]. Low-cost spray processes are dependable, repeatable, and produce extremely uniform CNT films that are similar to state-of-the-art CNT films manufactured on substrate [6].

For scientists who want to deal with CNTs in a liquid state, creating a stable and homogeneous dispersion is a challenge [7] [8][9][10]. Bundles or ropes made from individual tubes that are attracted to each other by van der Waals forces are the explanation. Although the chemical technique is more convenient for dispersion preparation, the final dispersion contains another chemical ingredient that can affect the physical properties of CNTs [11]. Sonication and

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centrifugation of CNTs are part of the mechanical method. However, depending on the sonication force, the tubes may be broken [12] [1].

Producing uniform homogenous layers is another factor to consider when making great devices [13]. The capability to provide huge amount and generation of thin layers are the two most important variables to consider when choosing a deposition method [14]. Thin layers, as opposed to dense layers, have several advantages. Thin layers have far higher homogeneity than thick layers. Furthermore, the electrical output will improve with good thin layer [15].

There are many techniques to deposit thin film of SWCNTs such as spin coating, dip coating, chemical vapor deposition (CVD). However, the study uses the air spray method because it is simple, inexpensive and has the potential to be used by the industry. This paper reports the morphology and electrical properties of SWCNTs thin film that relate to the nozzle distance. SEM was used to analyze the morphology of the SWCNT thin film, while 2-terminal IV readings were used to evaluate the electrical properties.

2. Methodology

Nikkiso Japan provided the SWCNTs, which were made using a direct injection pyrolytic synthesis (DIPS) technology and contained 90% metallic SWCNTs [16]. 1 mg SWCNT was mixed with 20 ml DIW and 1% TX-100 to form a stable solution, with the TX-100 acting as a solvent to enhance dispersion. This mixture was then tip-probe sonicated in an ice bath for 2 hours at 90% power using a tip 300 V/T ultrasonic homogenizer [17].

The SWCNT solution then was sprayed using a standard artist air brush with the pressure of 8.0 psi on a glass substrate set on a heating plate at 80°C. The hotplate was needed to speed up the drying of the liquid so that the SWCNT network could be pinned to the area of interest and avoiding bundling due to surface tension[18]. At 200°C, the samples were baked for 10 minutes to improve adhesion [19].

Nozzle distance was measured from air brush nozzle to target spot of substrate. The distance between nozzle and substrate can effect of network SWCNTs due to air pressure [20][15][21][22][23]. In this experiment, difference samples were chosen based on nozzle distance (Figure 1). The distance measured using bundle glass slide of 4, 7, 10 and 13 mm, respectively. For instance, 4 glass slide is equal to 4 mm height. We can say that 95% measurement is accurate because thickness of the glass very precise and the error may have originated from inclined air brush. However, this procedure has to be very meticulously observed since minor mistake can affect the final result.

The characterization was done using scanning electron microscope (SEM) JSM-6510LV and electrical measurement using Keithley 2635B. Figure 1 shows devices with different nozzle-substrate distance. Prepared samples were then subjected to characterization using scanning electron microscope (SEM) JSM-6510LV and electrical measurement using Keithley 2635B.

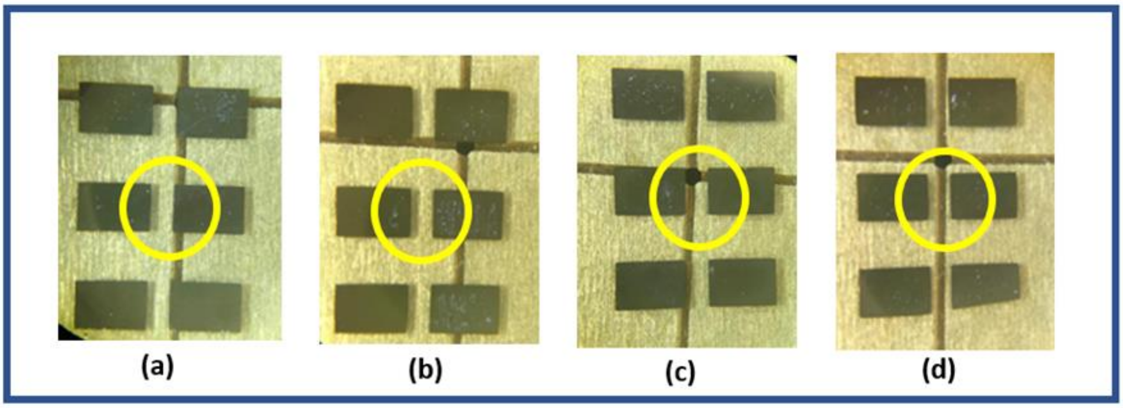

Fig. 1 - Glass samples depositing SWCNT with 4 differences spray nozzle distance. Round circles is the location to inspect SWCNT morphology; (a) 4 mm nozzle distance; (b) 7 mm nozzle distance; (c) 10 mm nozzle distance; (d) 13 mm nozzle distance.

3. Result and Discussion

3.1 Morphology Characterization by SEM

DIPS type of SWCNTs has diameter 0.8 to 3 nm thickness [24] . To observe the SWCNT network across the channel, morphological characterization was performed. The shape of the SWCNT network in four samples is shown in Figure 2. This SEM picture was captured at resolutions of x500 and x3000 during the adjustment of air brush nozzle distance. Figure 2 (a) clearly shows SWCNT network that did not disperse well as compared to Fig. 2 (b). However, Fig. 2 (c) and 2 (d) did not show significant differences of dispersion apart from the latter showing slightly higher concentration of SWCNT distribution on the surface. Overall, due to high air spray pressure, the dispersion capabilities of SWCNTs are limited, necessitating spray nozzle distance adjustment.

From Fig. 2 (a) and (b), bright contrast spots that appear at 500x magnification are observable indicating surface charging of the glass substrate. The charging effect occurred around areas with lacking SWCNT coverage, which suggest non-uniformity of the film. Furthermore, at 3000x magnification we can see bundling SWCNT all over the surface. For Fig. 2(c) and 2(d), the surface did not show obvious difference between them but from electrical characterization (Table 1) confirm samples with 10 mm nozzle distance is the optimized condition. Overall, Figure 2 is based on quantitative analysis from estimation SWCNTs on the area of exposed substrate surface. With that reason we need to further analysis by electrical characterization to confirm effectiveness of nozzle distance change [20] [25]. The distance between the spray nozzle and the substrate can effect of the air velocity as well as spray pressure that can affect the film uniformity of thin films [23].

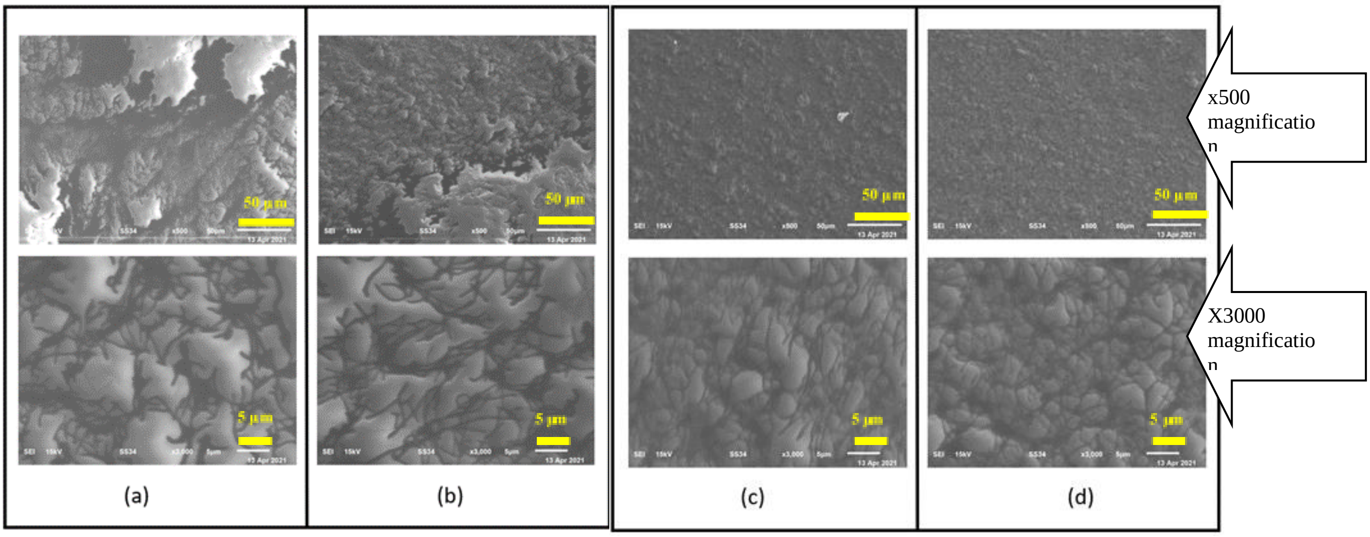

Fig. 2 - SWCNT magnification at x500 and x3000 of CNTs spray at different nozzle distance; (a) nozzle distance of 4mm - appear glass and CNTs bundling; (b) nozzle distance 7 mm - appear glass and CNTs bundling; (c) nozzle distance 10 mm; (d) nozzle distance of 13 mm.

3.2 Electrical Measurement

The current between the source and drain was used to characterise the SWCNTs network thin film previously. Table 1 shows electrical measurements in each sample for every nozzle distance. From Table 1 clearly shows sample C with nozzle distance of 10 mm is the optimized condition to do an air brush spray, which produced the highest current at 1 V.

Table 1- Electrical measurement at 1V for 1 mm and 2 mm channel length with different nozzle distance

Sample	Nozzle Distance (mm)	Current at 1 V (µA) 1 mm channel length	Current at 1 V (µA) 2 mm channel length
A	4	3.2	1.13
B	7	8.82	1.36
C	**10**	**15.30**	**2.2**
D	13	10.30	1.23

Fig. 3 shows the IV plot from 32 devices with 2 different channel length which is 1 mm and 2 mm. From Fig. 3, 32 devices have divided into 2 groups which was 1 mm and 2 mm. For each group, 4 devices were spray either nozzle-to-substrate distance at 4 mm, 7 mm, 10 mm or 13 mm respectively. As we can see the result, average for both groups showed 10 mm (bold line) nozzle-to-substrate consistently produced highest current output.

By comparing 1 mm and 2 mm channel distance, it was proven that shorter channel length device produces higher due to electron travel distance [26][27][28][29]. However, to reflect the morphology of CNTs and electrical, based on basic CNTs structure, the electrical effect also due to CNT chirality and tube to tube potential barrier. Even though same amount of CNTs on channel length, electrical output is different due to tube-tube junction resistance. In other words, a result based on numbers of junctions or level of CNTs tube bundling [30]. It means that the uniform CNTs morphology (ie. 10 mm nozzle distance) can produce higher current than bundling CNTs morphology (ie. 13 mm nozzle distance).

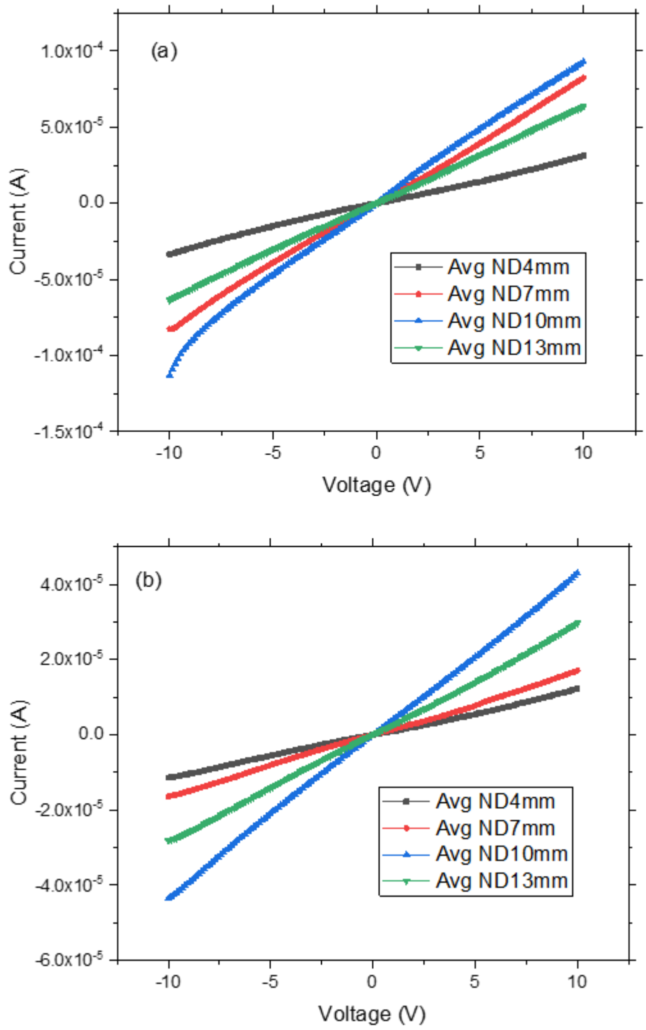

Fig. 3 - *IV* plots from 32 devices from 2-terminal measurementsdevice. It shows consistents highest current reading for 10 mm nozzle distance that reflect to morphology of SWCNT; (a) 1 mm channel devices; (b) 2 mm channel

Figure 4 shows conductivity CNTs devices according to nozzle distances with 2 different channels. The conductivity of a SWCNTs thin film is due to length and area of conductive paths. For example, a longer path has a higher electrical resistance than a wire with a bigger surface area, which has a smaller electrical resistance. These electrical flow effects are caused by the surface area-to-volume ratio. When the surface area to volume ratio is larger, electrical resistance is reduced. Most nanomaterials have an extraordinarily high surface area-to-volume ratio due to ultrathin layer architectures like SWCNTs [31]. It is again proved the best conductivity produced from 10 mm nozzle distance due to uniformity of SWCNTs layer.

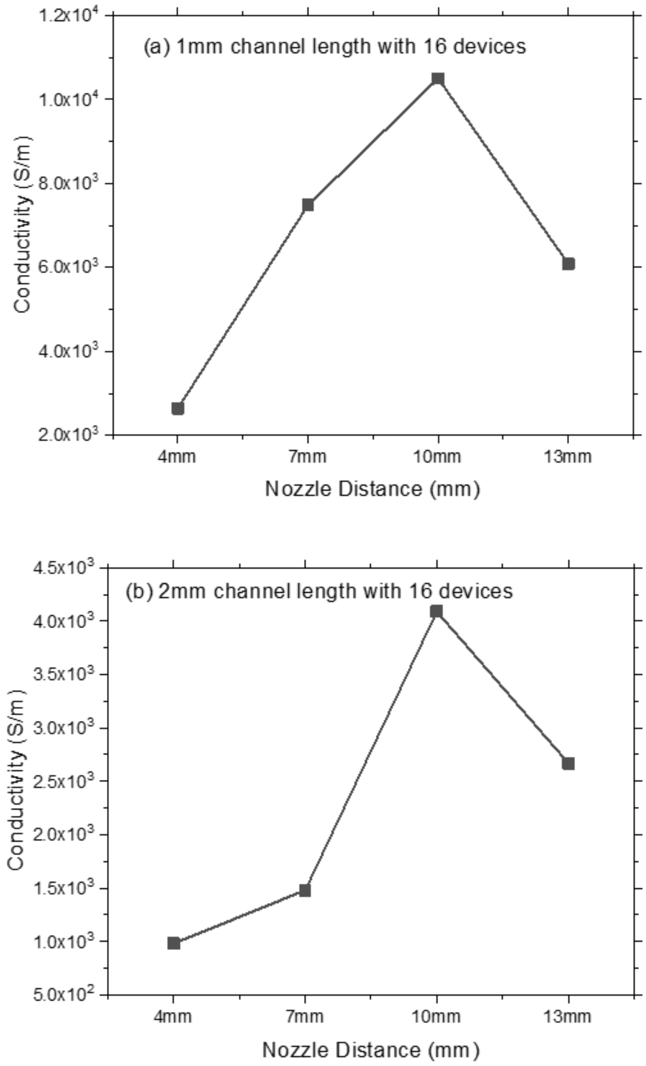

Fig. 4 - Average conductivity at different channel length (a) 1 mm; (b) 2 mm.

4. Conclusion

The effectiveness of SWCNTs network morphology is one of the indicators for good thin film on glass samples. In order to get good morphology, experiment setup such as nozzle distance has to be done in advance. From this experiment, it was proved by electrical measurement that 10 mm nozzle-to-substrate distance is the optimum height for producing good devices. Thus, at 1 mm channel length, the conductivity produced highest at 10 mm channel is 10500 S/m, 7 mm nozzle distance (7480 S/m), 13 mm nozzle distance (6080 S/m) and 4 mm nozzle distance (2640 S/m) respectively. Meanwhile, in 2 mm channel length device, 10 mm nozzle distance also produced highest conductivity which is 4090 S/m, followed by 13 mm nozzle distance (2670 S/m), 7 mm nozzle distance (1480 S/m and 4 mm nozzle distance (980 S/m) respectively.

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