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Surface Modification of Carbon Nanotubes by Ar Plasma Jet

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Surface Modification of Carbon Nanotubes by Ar Plasma Jet

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Abstract—Atmospheric pressure low temperature plasma jet (APPJ) is a technical direction that has attracted much attention in recent years. In this paper, argon is used as the working gas to produce highly active ions through funnel shaped glass tubes to modify the surface of carbon nanotubes. After the carbon nanotubes treated for 4 mins, SEM, water contact angle and FTIR detection results were compared before and after the experiment. The results showed that the hydrophobicity of carbon nanotubes was enhanced and the surface dispersion was improved after DBD plasma jet treatment.

1. Introduction

Carbon nanotubes, a novel type of nanomaterial, have been widely used in environmental protection, food safety, sensors, composite materials, and other industries in recent years because of their good physical and chemical capabilities[1-6], such as remarkable electrical, thermodynamic, and optical qualities. Carbon nanotube surface modification can increase surface characteristics and eliminate the dispersion problem.

Chemical and physical procedures are the most common traditional surface treatment methods for carbon nanotubes, however these methods are complicated and harm the environment[7]. Because to its simple operation, practical economics, and lack of vacuum equipment, the low temperature plasma jet treatment method stands out as a technology.

A steady plasma plume loaded with active material is produced by an atmospheric pressure DBD jet. A typical Atmospheric pressure plasma jet (APPJ) consists of a tiny tube (in the mm diameter range) through which gases like helium, argon, nitrogen, air, and their combinations are supplied to form plasma, which is then expelled into the surrounding environment. The plasma plume, which is the contact area between the plasma and the sample, is the plasma outside the tube. The surface treatment of carbon nanotubes with a low-temperature plasma jet at atmospheric pressure offers good material properties, but the technology is still in its early stages of development and has to be improved.

2. Materials and Methods

2.1. Experimental Setup

Figure 1 depicts the DBD jet device, which includes the needle electrode, funnel glass tube, glass ring electrode, and bottom and ground plate electrodes. The needle electrode has a diameter of 1.6 mm and a length of 40 mm from the glass tube mouth. The funnel glass tube has a 4 mm top input diameter, a 2 mm inner diameter, a 19 mm outlet diameter, and a 17 mm inside diameter. The entire glass tube measures 60 mm in length. The bottom glass plate has a thickness of 1 mm and a space of 1 mm between the glass tube mouth and the bottom glass plate. Figure 2(b) depicts an apparatus that is used to treat carbon nanotube powder in a closed environment for 4 min. Around the funnel glass tube is a glass baffle with a thickness of 1.5 mm, a diameter of 45 mm, and a height of 23 mm. The discharge is filled with the entire closed chamber, and the top is constructed with an air outlet. The working gas is argon, and the gas flow is 3 slm. An ac power supply (CTP-2000K) provides the applied voltage, and the working frequency is 18.20 kHz. The high voltage end is linked to the needle electrode, the ring electrode and the plate electrode are connected to ground. The high voltage was measured through a Tektronix high voltage probe (P6015A). The current was recorded by measuring the voltage on a 100Ω resistance though a Tektronix voltage probe (RP3030). The voltage and current waveforms were recorded by an oscilloscope (Tektronix TDS2024C). The discharge image was recorded by a camera.

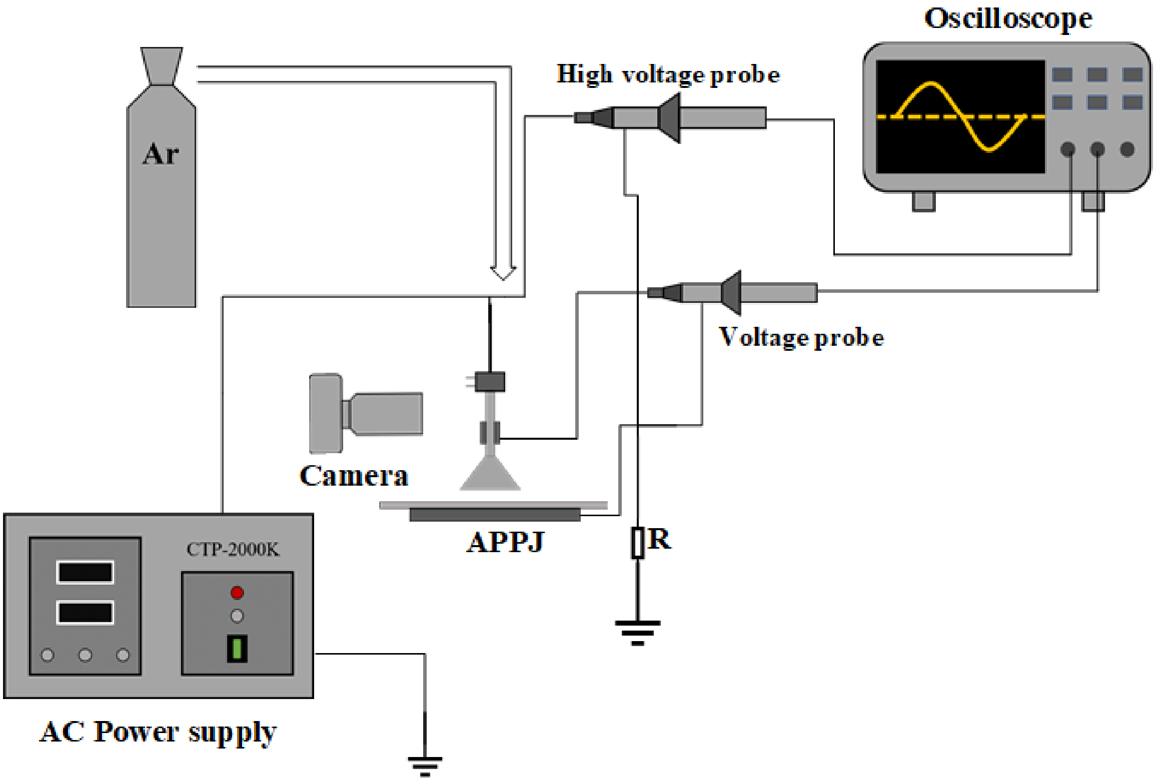
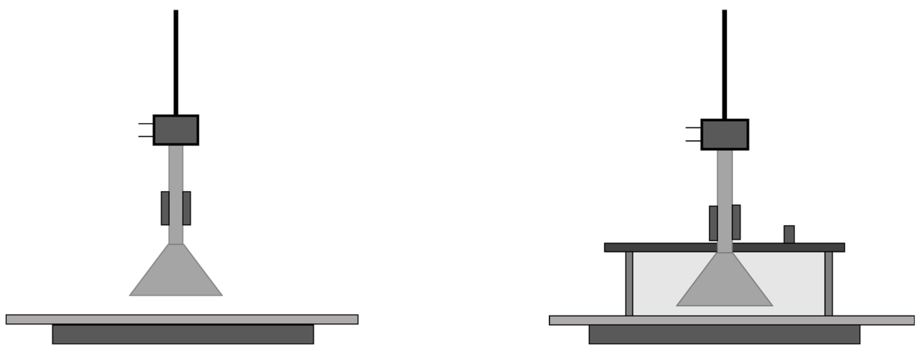


Fig.1 Experimental Setup



(a) Discharge characteristic setup (b) Material modification setup

Fig.2 DBD APPJ setup

2.2. Testing Method
The material used in this study is made up of 95 % pure multi-walled carbon nanotube powder that is deposited on a glass substrate in a closed environment with an applied voltage of 6.24 kV, a working frequency of 18.20 kHz, and a gas flow of 3 slm. For 4 minutes, a plasma jet was created by a gas discharge to treat carbon nanotubes. The materials were detected by SEM, water contact angle, and FTIR before and after treatment. To understand the microscopic changes in the properties of carbon nanotubes before and after alteration, the detection findings were compared.

3. Test Results and Discussions

3.1. Discharge characteristics
The image of plasma jet is shown in Figure 3. The jet diffuses downward down the funnel wall as the applied voltage is increased, eventually filling the whole glass chamber. The evident discharge filament can be seen between the upper end of the funnel and the glass bottom plate, indicating a strong discharge effect. Figure 4 depicts the average power variation as a function of applied voltage. The voltage amplitude increases from 8.08 kV to 9.12 kV, but the power decreases, indicating that the plasma discharge switches to a different discharge mode at this point, which is compatible with the discharge phenomenon seen in Figure 3. In the power diagram, you can see the voltage and current waveform at 11.9 kV. The discharge exhibits DBD properties, and numerous current pulses arise within half a cycle, as can be seen in the diagram, because the discharge current is created by a current pulse.

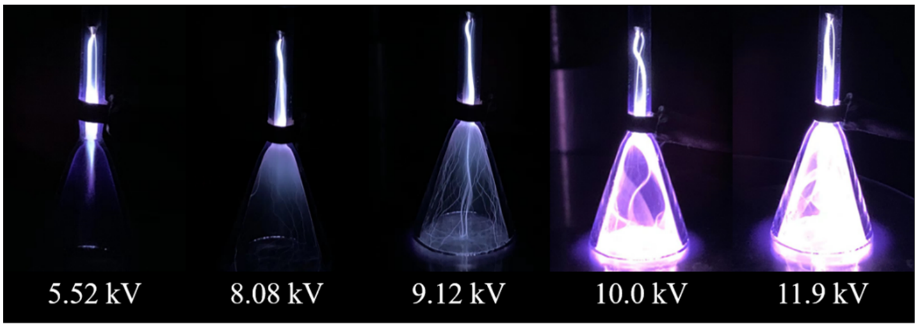


Fig.3 Discharge images at different voltages

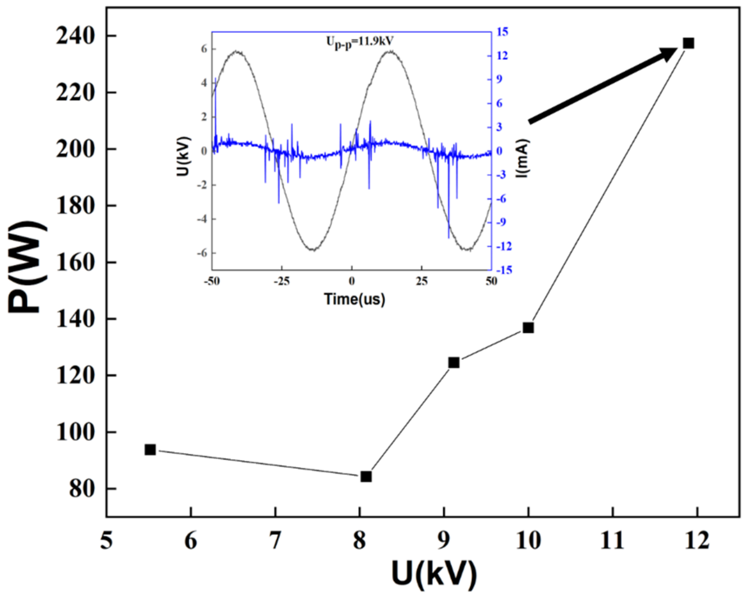
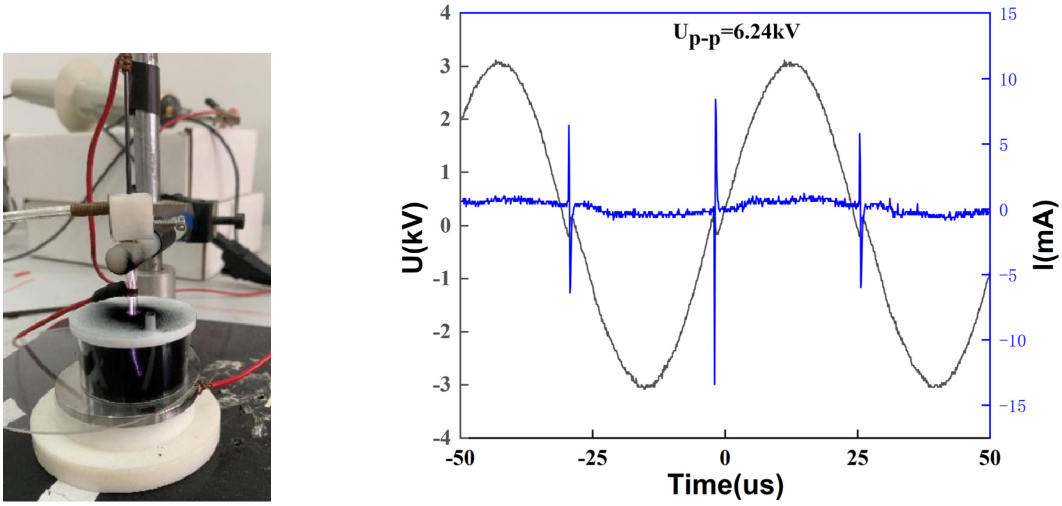


Fig.4 Discharge power diagram and voltage and current waveform at U_{p-p}=11.9 kV

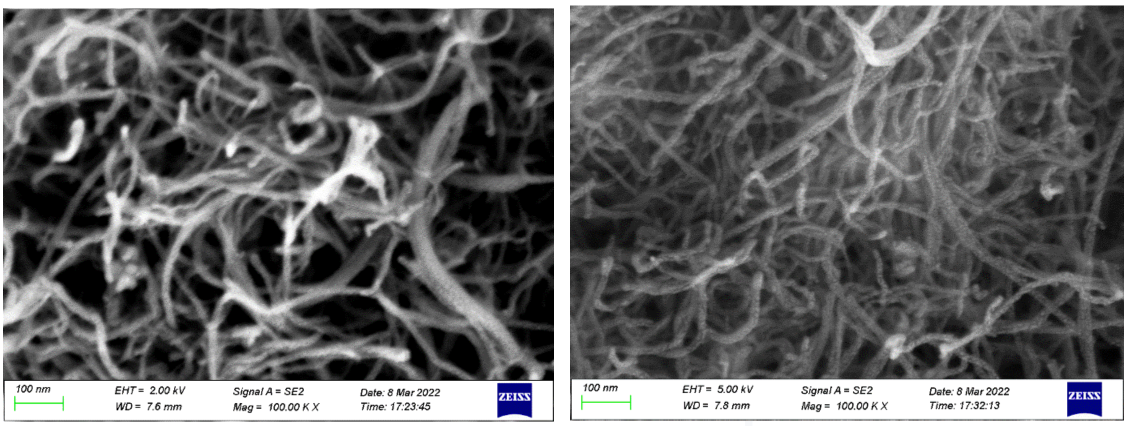
3.2. Material treatment results

Figure 5(a) shows the material processing device, the applied voltage is 6.24 kV, and Figure 5(b) shows the voltage and current waveform. It took 4 minutes to process the data. There are considerable changes between carbon nanotubes before and after treatment, as seen in Figure 6-8. The dispersion of carbon nanotubes improves after treatment, as shown by the SEM results in Figure 6, and the carbon nanotubes are more agglomerated before treatment. Carbon nanotubes have a smooth surface before alteration and a rough surface after modification. According to the water contact angle results in Figure 7, the water contact angle was 128.81° before modification and 158.47° after modification, an increase of 29.66°. Carbon nanotubes' hydrophobicity was improved. The FTIR data in Figure 8 show that carbon nanotubes are insensitive to FTIR before modification, but the conversion rate increases nearly threefold after modification, owing to the -C≡N bond and the N=C=C bond.



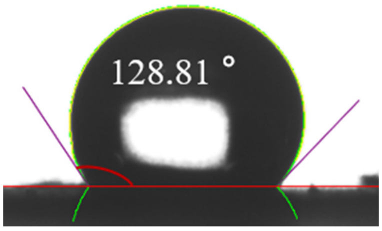
(a) Experimental photographs (b) Voltage and current waveform during material processing

Fig.5 Photographs of experimental conditions and waveforms

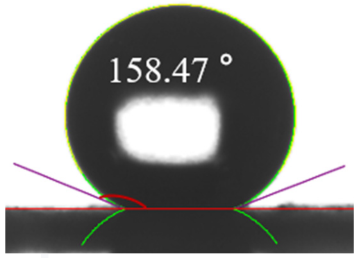


(a) Before material processing (b) After material processing

Fig.6 SEM images before and after material processing

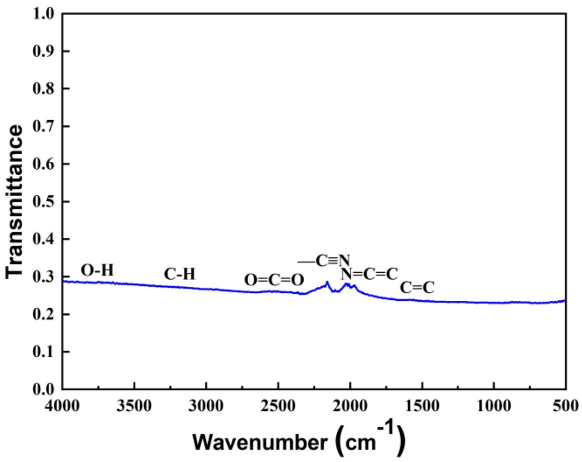


(a) Before material processing

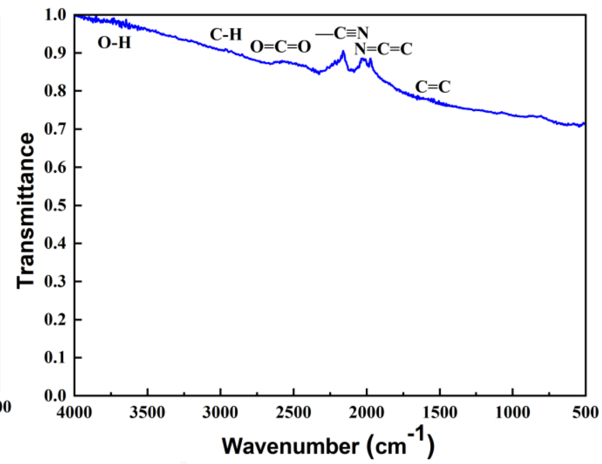


(b) After material processing

Fig.7 Water contact Angle changes before and after material processing



(a) Before material processing



(b) After material processing

Fig.8 FTIR changes before and after material processing

4. Conclusion

The electrical features of a funnel-shaped DBD plasma jet were investigated in this study, and this device was used to modify multi-walled carbon nanotubes. Before and after the experiment, the results of SEM, water contact angle, and FTIR were compared. After DBD plasma jet treatment, the hydrophobicity of carbon nanotubes was increased, and the surface dispersion was improved.

Acknowledgments

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