A Study on The Assembly and Improvement of Electrical Contact Between Carbon Nanotube and Microelectrode

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Abstract. Nowadays research on nano-electronic device based on carbon nanotube (CNT) raises much interest among researchers, but in the fabrication process, crucial problems exist in making and improving the electrical contact between CNT and microelectrode. Here pulse gas alignment method, combined with nanomanipulation technology based on atomic force microscope (AFM) if necessary, is proposed for the first time to assemble and make electrical contact between CNT and microelectrode. After the assembly, a processing technique of applying sweeping voltages is performed for producing electrical current induced local Joule heat, which will decompose and remove the sodium dodecyl sulfate (SDS) molecules adsorbed on the CNT and at the interface region, or even have some annealing effect, to reduce the contact resistance between CNT and microelectrode and thus to improve the electrical contact. Experiments of assembly and improvement of electrical contact between multi-wall carbon nanotube and microelectrode are performed to verify the effectiveness of the proposed methods.

1 Introduction

Due to its unique electrical properties, such as large current transport capability, high electron mobility, to be semi-conduct or metallic and nanometer scale size, carbon nanotube (CNT) becomes an important component in fabricating nano electronic devices, such as nano transistor, nano sensor, and even simple nanoelectronic logic circuit [1-3].

In the fabrication process of nano electronic device by CNT post-synthesis method, one of the key problems is to realize the assembly and electrical contact between CNT and microelectrode. Several methods were proposed for realizing it [4-6], such as directly spreading and depositing CNT on microelectrode [4], actuating CNT to microelectrode by AC di-electrophoresis [5], and fabricating microelectrode on CNT by focused ion beam [6]. Although these methods presented some capability of assembly and forming electrical contact, they have certain shortcomings, such as very low success rate [4], CNT bundles usually assembled [5] and even destroy to CNT by high energy ion beam [6], and an effective method without destroy to CNT is needed to assemble single CNT with microelectrode.

After the assembly, as the measured contact resistance between CNT and microelectrode is usually much higher than CNT’s intrinsic resistance which is only about 6.5Kohms (h/4e²) [7], it prevents the CNT based device from realizing the full potential of CNT, and several methods have been presented for trying to solve the problem [8-12]. The contact resistance can be decreased by selective irradiation of electron beam [8] or laser pulse [9]. However, the CNT could be destroyed or even burn out by the high energy of the electron beam or laser. And contact resistance can also be reduced by rapid thermal annealing at 600–800°C [10]. However, such high temperature limits the selection of substrate materials and sometimes the CNT with defect or very small diameter will not keep chemically stable at so high temperature. And the contact resistance can even be decreased by the treatment of a kind of special oxidizing agent solution [11], but it might introduce additional impurity or aborbates to the CNT. Thus, a simple and effective method has to be developed for reducing the contact resistance and thus to improve the electrical contact between the CNT and microelectrode.
For overcoming the two barriers mentioned above, we recently developed a series of simple and effective methods to realize the assembly and improve the electrical contact between CNT and microelectrode. For realizing the assembly of CNT, pulse gas alignment method with substrate downward-tilt is proposed, by which the well-dispersed CNTs will be aligned along defined direction at the microelectrode region, and thus CNTs will contact the electrode with one or two ends, or at least some CNTs will align near the microelectrode, which can be further assembled with microelectrode by an AFM based nanomanipulation technology. After the assembly, the electrical contact between CNT and microelectrode can be improved by electrical current induced Joule heat, caused by a new processing technique of applying sweeping voltages, to decompose and remove the sodium dodecyl sulfate (SDS) absorbed on the CNT or at the interface region between the CNT and the microelectrode. In this way, the contact resistance will be much reduced and the improvement of electrical contact between single CNT and microelectrode will be realized. Experiments will be performed to verify the effectiveness of the proposed methods.

2 CNT assembled by pulse gas alignment method with substrate downward-tilt

Raw materials of small-diameter Multi-wall carbon nanotube (MWCNT) is added in di-ionized water with sodium dodecyl sulfate (SDS) as additives, after accurate mass weighing of 0.1% CNT and 1% SDS, the mixture solution in test tube is sonicated to disperse CNTs with frequency 40kHz for two hours [13].

Then, a simple alignment method, namely pulse gas alignment with substrate downward-tilt, is applied as shown in Fig. 1(a), where a micro droplet (about 1~2μL) of the well-dispersed CNTs suspension is pipetted on the substrate, then N2 pulse gas with pressure about 0.15Mpa is applied to the micro droplet on the substrate which is tilted downward at about 20 degree. After the alignment process, the CNTs will always align on the predefined location as shown in Fig. 1(b).

By the proposed alignment method, some CNTs will be aligned on the microelectrode region with two ends always contacted the microelectrode as shown in Fig. 2, or one end contacted the microelectrode as shown in Fig.3, or at least some CNTs aligned near the microelectrode, which can be assembled with the microelectrode by a modified nanomanipulation system based on atomic force microscope (AFM system, Model Dimension 3100 of Veeco Co., is modified according to the method previously presented in [14-16]).
With one end contacted the microelectrode shown in Fig. 3, the other end can be manipulated to be assembled with the microelectrode by AFM based manipulation system as shown in Fig. 4.

Besides, if some CNTs align near the microelectrode without any contact with the microelectrode, the AFM based manipulation system can be used to assemble the CNT with the
microelectrode as previously presented [17].

3 Improvement of electrical contact

3.1 Property of the measured system

After assembly, for measuring the current–voltage (IV) property of the CNT, a precise measurement system is built up with a home-made probe station with reliable shield of interrupt signals and a semiconductor parameter analyzer (Model 4155C, Agilent Co.). And in the measurement of CNT’s I/V property, the measured resistance consists of CNT resistance, contact resistances and additional resistance which includes the contact resistance between the testing probes and the microelectrodes, the resistance of conduct lines and even Au microelectrodes. The configuration of the measurement system for CNT electrical property is shown in Fig. 5.

For ascertaining the additional resistance, a specially-designed microelectrode without gap as shown in the inset of Fig. 6(a), is contacted with testing probes and the measured IV property is shown in Fig. 6(a). According to the IV curve shown in Fig. 6(a), it can be calculated that the additional resistance is about 50ohms as the current is 20 mA to 1V voltage. Besides, for making sure of the shielding property of the measurement system, the gapped microelectrode without CNT is also measured, which shows that the current of signal interrupt limits in 10pA as shown in Fig. 6(b). Thus, it can be concluded that the measurement system fits the requirement of feeble CNT signal measurement with high accuracy and reliability.

As to CNT shown in Fig. 2, during the sweeping process the voltages was swept from -4V to 402

3. 2 Improvement of electrical contact by applying sweeping voltages

As the intrinsic resistance of CNT is only about 6.5 Kohms [7] and the additional resistances are only about 50 ohms, the measured resistance mainly resulted from contact resistances between nanotube and microelectrode. And for the contact resistance is always much larger than the intrinsic resistance of the CNT, local Joule heat caused by electrical power would mainly occur at the interface region between CNT and microelectrode. To avoid high heat at the interface region to destroy the CNT, sweeping voltages instead of a constant voltage were applied to provide local Joule heat at the interface region.

As to CNT shown in Fig. 2, during the sweeping process the voltages was swept from -4V to
4V with a sweeping interval 0.08 V and interval time 0.01s for about 20 times, then from -5V to 5V with a sweeping interval of 0.1 V and interval time 0.01s for many times, and the measured IV curves are selectively shown in Fig. 7.

![IV curves](image)

Fig. 7 IV curves of the assembled CNT shown in Fig.2 (the signal of the current is negative)

From the measured IV curves shown in Fig. 7, it can be seen that the maximal current appears at about a little above 3V which is the saturated current as that in [18], and it continues to increase from about 15uA at positive voltage in Fig. 7(a) to about 18uA in Fig. 7(b), and eventually to about 28uA in Fig.7(c). In images Fig. 7(a) and (b), the arrows show the rising direction of the current, and it is obvious that the current continues to increase with the sweeping voltages applied continually. And in Fig. 7(c), the characteristics of IV curves change from nonlinear to linear, which is believed to be caused by the removal of SDS [19] absorbed on the metallic CNT or at the interface region between the metallic CNT and the microelectrode.

As to another MWCNT assembled with microelectrode shown in Fig. 4, the sweeping voltages are applied from -1V to 1V with the sweeping interval of 0.02V and interval time 0.01s for many times, and the measured IV curves are shown in Fig. 8.
To the $I-V$ curves shown in Fig. 8, it can be seen that the maximal current is about 90 nA with 1V voltage applied on the CNT shown in Fig. 8(a), and it continues to increase from 90nA to 110nA as shown in Fig. 8(b), and eventually to about 250nA as shown in Fig. 8 (c) after the same sweeping voltages are applied for about 100 times, and the nonlinearity characteristics demonstrates that the CNT is a semi-conducting CNT.

According to the experimental results shown in Fig. 7 and 8, it is obvious that the current increased much more with sweeping voltages continually applied on the CNT, and the plausible explanations for these experimental results are as follows. Firstly, Joule heat caused by electrical current occurs locally at the interface region, and the energy generated by the local Joule heating process causes the decomposition and removal of the SDS molecules adsorbed on the CNT or at the interface region little by little, and thus the contact area between CNT and microelectrode increases, which results in the increasing maximal current. Besides, it can be seen that the current in Fig. 8 is much less than that in Fig. 7 to the same voltage 1V, for the contact area between CNT and microelectrode shown in Fig. 4 is only the end of CNT and much less than that shown in Fig. 2, which in other side verified that the allowable maximal current is dependent on the contact area. Secondly, as Joule heat occurs at the interface region between CNT and microelectrode, certain annealing could occur at the contact region and thus significantly improves the electrical contact.

For other seven MWCNTs assembled with microelectrode by the proposed method, after the process of applying sweeping voltages we got the same conclusion that the allowable maximal current increased significantly as shown in Table 1, which means that the contact resistance reduced and the electrical contact is improved significantly.

| CNT | Before the process of applying sweeping voltages | After the process of applying sweeping voltages |
|-----|-----------------------------------------------|-----------------------------------------------|
| 1   | 8nA                                          | 25nA                                         |
| 2   | 5uA                                          | 12uA                                         |
| 3   | 3uA                                          | 18uA                                         |
| 4   | 180nA                                        | 460nA                                        |
| 5   | 550nA                                        | 2uA                                          |
| 6   | 320nA                                        | 870nA                                        |
| 7   | 9uA                                          | 35uA                                         |

Table 1 Comparison of the maximal current before and after the process of applying sweeping voltages

Compared with other methods to improve the electrical contact described above, or removing the absorbates on CNT by UV radiation [20], the experiments demonstrate that this method of applying sweeping voltages can significantly improve the electrical contact without introducing impurity or destroy to the measured CNT.
4 Conclusion

In summary, the successful assembly experiments showed that the pulse gas alignment method, combined with AFM based manipulation technology if necessary, is an effective method in assembling and making electrical contact between CNT and microelectrode. And for improving the electrical contact after assembly, sweeping voltages is applied to produce local Joule heat, which will decompose and remove SDS molecules absorbed on the CNT or at the interface region, and thus to increase the contact area and improvement of the electrical contact between CNT and microelectrode. With the realization of assembly and improvement of the electrical contact between CNT and microelectrode, nano electronic devices, such as CNT based field effect transistor (FET) or sensor with perfect electrical performance, will be fabricated in the next step.

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