SYNTHESIS OF CARBON NANOTUBES BRIDGING METAL ELECTRODES

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1. Introduction

We can consider carbon nanotube as one graphite layer that is rolled up into a cylinder having diameter of nanometers and length of micrometers. CNTs are prepared by many techniques but chemical vapor deposition (CVD) is the simplest and probably the most widely used technology for their growth. In this process the thermal decomposition of hydrocarbons is achieved in the presence of metal catalysts on the substrate surface.

Due to their unique structure, carbon nanotubes (CNTs) offer many possible applications in nanoelectronics such as FET transistors, memory elements and chemical sensors. Therefore, the electrical contact between carbon nanotubes and metal electrode is most important step in fabrication of these devices. There exist several methods for connecting carbon nanotubes with metal electrodes. The most frequently used is a deposition from a droplet of dispersed solution containing SWNTs [1–3]. Carbon nanotubes are produced by a laser ablation or an arc discharge method. Synthesis is then followed by cleaning of carbon nanotubes. After evaporation of solvent carbon nanotubes lay on the electrodes. Disadvantage of this is high contact resistances between CNTs and electrodes [4]. The second widely used method is dielectrophoresis [5], [6]. In this method an electric field is applied across electrodes for achieving deposition of carbon nanotube from a solution. This method can be used for large distances between electrodes (more than 500 μm) and for large density of carbon nanotubes. The third method is a Direct CVD method [7–9]. Carbon nanotubes are directly synthesized on the top of the electrodes from metal catalysts. This method is based on the fact that carbon nanotubes grow between metal nanoparticles and conductively connect them (Fig. 1). In our experiments we are using this approach because of its simplicity and reliability. Moreover this method is suitable for fabrication of chemical sensors. Disadvantage is that electrode material has to withstand the high temperatures required for growing the nanotubes.

In our work we demonstrate growth of carbon nanotubes that can conductively bridge the metal electrodes. The role of different catalysts was examined. Interdigitated metal electrodes are made from copper and we are using bimetal Al/Ni as catalyst for growth of carbon nanotubes. We are using this catalyst composition for growth of the singlewalled carbon nanotube network.

2. Experiments

First a 3 mm by 3 mm Cr/Cu interdigitated electrodes were deposited on the top of the SiO2 by using photolithography and lift-off. Then Al/Ni two-layered films were evaporated as a catalyst layer in two ways – 1) after removing of the resist, catalyst was evaporated on the surface of interdigitated electrodes (catalyst in composition Al 11 nm/Ni 1 nm was evaporated to the surface of the electrodes as well as to the area laying between them) 2) catalyst in composition Al 8 nm/Ni 0, 8 nm was evaporated only to the surface of electrodes and then the resist was removed. Carbon nanotubes were grown by chemical vapor deposition. Experiments were carried out in a tube furnace with quartz tube with inner diameter of 40 mm in atmospheric pressure. Methane (CH_4) was used as a source of hydrocarbons. The temperature of the furnace was ramped up to 1 000 °C and stabilized. After that the samples were moved into the furnace and annealed in the flow of Ar/H_2 mixture (200/30 sccm) for 10 min. The growth of carbon nanotubes was performed then in the flow of $Ar/H_2/CH_4$ mixture (200/30/100 sccm) for 10 min. Both processes (annealing and growth) were run at the same temperature - 850 °C. After CNT growth, the samples were moved out from the furnace center and the quartz tube was continuously purged with flow of Ar until the temperature has reached 90 °C.

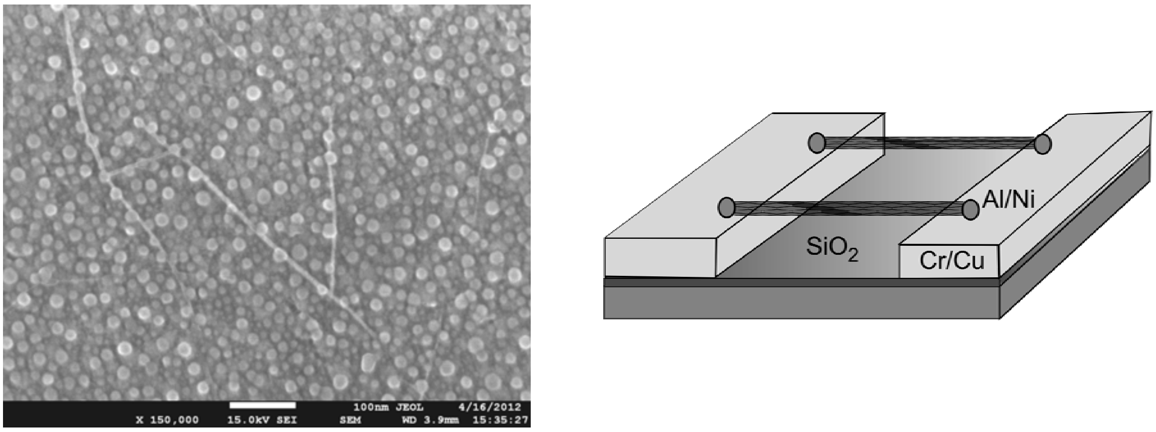
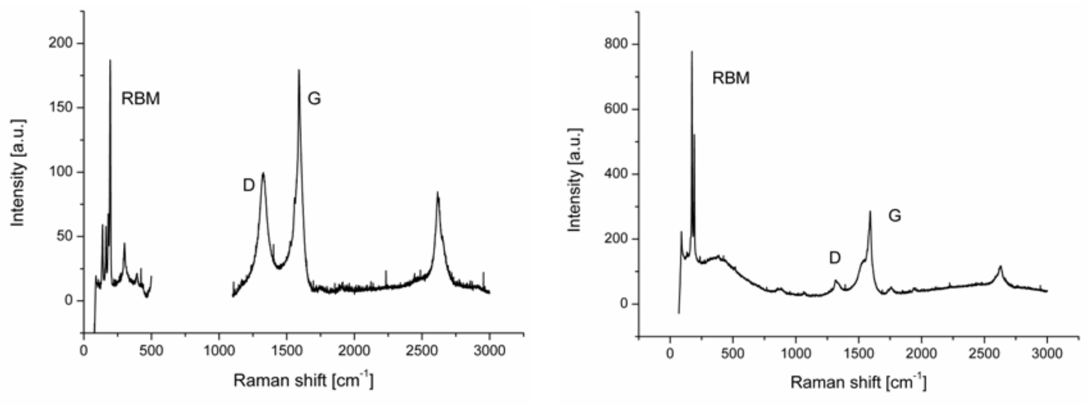


Fig.1: *Carbon nanotubes are growing between catalyst nanoparticles which allow them to bridge metal electrodes.*

3. Results

After experiments the samples were examined by Raman spectroscopy with 632.8 nm He-Ne laser and scanning electron microscopy (SEM).

With the help of Raman spectroscopy, the quality and crystallinity of carbon nanotubes might be characterized. In the upper part of Raman spectrum two strong peaks, G and 2D at position of 1 590 cm^{-1} and 2 620 cm^{-1}, respectively, and one weak peak, D at position of 1 320 cm^{-1}, can be seen. In the lower part of the spectrum we can see strong RBM peak which is characteristic for singlewalled carbon nanotubes (SWCNTs).



a) *b)*

Fig.2: *a) Measured Raman spectrum for first type of used catalyst layer b) for second type of catalyst layer (catalyst is evaporated only to the electrode surface).*

The quality of carbon nanotubes is then estimated according to the ratio of these individual peaks, I_D/I_G.

In the Fig. 2 we can see Raman spectrum measured for both cases of our experiments (different catalyst preparation). From Raman spectrum we can see that samples grown in our experiments contain singlewalled carbon nanotubes (presence of strong RBM mode). From lower I_D/I_G ratio for second case of our experiments, we can see, that carbon nantotubes grown in this experiment offer better quality and crystallinity. This is thanks to their structure – they are longer and with better crystal lattice quality. The structural morphologies of synthesized CNTs were characterized by scanning electron microscopy. For the first method of catalyst preparation we can see in the Fig. 2 that carbon nanotubes conductively connect metal electrodes, but rarely as individual nanotubes. More often they grow between catalyst particles situated in gap between metal electrodes as dense network of short carbon nanotubes. For second method we achieved better results thanks to absence of catalyst particles between electrodes. In the Fig. 3 we can see carbon nanotubes bridging metal electrodes.

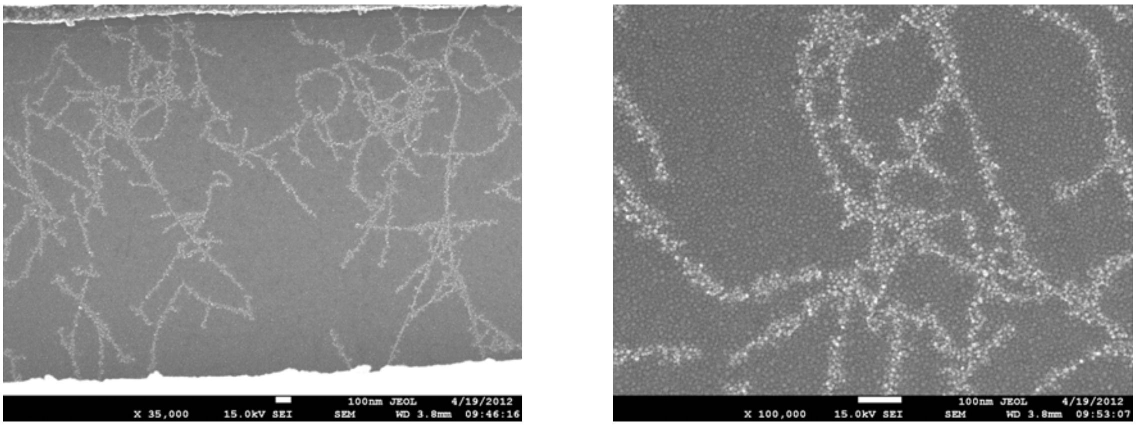


Fig.3: *Growth of carbon nanotubes between electrodes for catalyst evaporated to the electrode surface.*

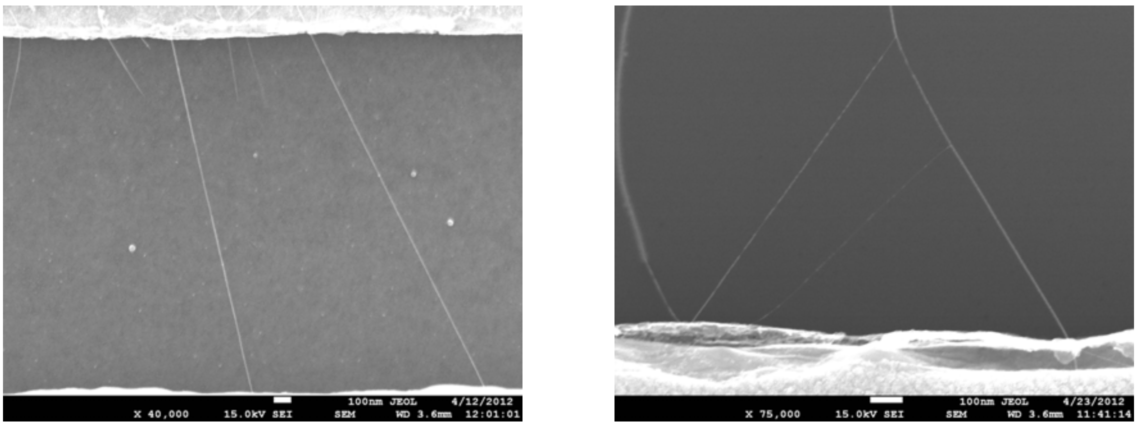


Fig.4: *Growth of carbon nanotubes between electrodes for catalyst evaporated only to the electrode surface.*

Distance between the electrodes is around 2 μm. As carbon nanotubes grow they overcome gap between electrodes and connect with catalyst particles in the opposite electrode. One of the possible explanation of this fact is that carbon nanotubes grow in random direction but thanks to high temperature vibrations they continue to grow until they reach opposite electrode. Thanks to these phenomena they are able to make conductive connection between two electrodes.

4. Conclusion

In our experiments we demonstrate growth of carbon nanotubes that can make bridge between the metal electrodes. The effect of the different methods of the catalyst preparation on the quality and morphology of the carbon nanotubes was examined. The better results we were able to achieve for catalyst evaporated only to the metal electrode surface. Carbon nanotubes are growing between electrodes and conductively connect them. This method can be used for constructing the microelectronic elements which require reliable contact between electrodes – for example gas sensors.

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