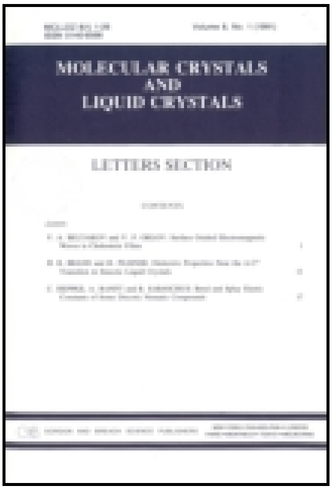


Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Measuring the Electrical Conductivity of Carbon Nanotubes Grown on Sodalime Glass Substrates using Cu as Catalyst

A. Mahmoodi[a] & M. Ghoranneviss[a]
[a] Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran
Published online: 08 Apr 2014.

Mol. Cryst. Liq. Cryst., Vol. 591: pp. 86–90, 2014

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2013.824272

Measuring the Electrical Conductivity of Carbon Nanotubes Grown on Sodalime Glass Substrates using Cu as Catalyst

A. MAHMOODI* AND M. GHORANNEVISS

Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran

We have studied the electrical resistance of carbon nanotubes (CNTs) grown on sodalime glass using Cu as catalyst at 580°C temperature. The conductivity was measured at room temperature using four point probe technique. The Cu catalyst was coated on glass substrate by using dc magnetron sputtering system and etched by hydrogen (H_2) gas in order to form nanometer sized catalytic particles. Mixture of $C_2H_2/H_2/Ar$ (20:80:100 standard centimeter cubic per minutes) gases were heated at 580°C for growth of CNTs on a glass substrate by using Thermal Chemical Vapor Deposition (TCVD). The temperature dependence of sheet resistance and current-voltage characteristics of the film were measured by a four point probes method. The morphology of the catalyst surface was probed by Atomic Force Microscopy (AFM), and the growth behavior of CNTs was investigated by scanning electron microscopy (SEM).

Keywords Carbon nanotube; four-point probe; low temperature

Introduction

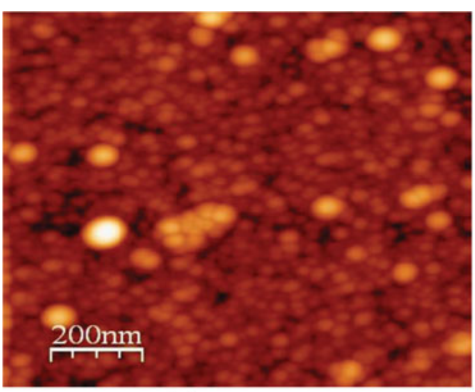
Nanomaterials based on carbon nanotubes (CNTs) have been widely studied for various applications due to their unique characteristics including small diameters, high electrical conductivity, high surface area to volume ratio, and outstanding mechanical and thermal properties [1,2]. The electrical properties of CNTs are of significant scientific interest and are relevant for many proposed and realized applications [3–6]. One of the most attractive applications of CNTs is an electron emitter for flat panel displays such as field emission display (FED) [7]. Sodalime glass is commonly used as a low-cost substrate for the display panel; it is highly desirable to grow CNTs directly on the sodalime glass substrate [8]. However, the glass substrates are covered by a thin film of a metal film (Ni, Fe, Cu) in order to catalyze the CNTs growth and to avoid bare glass inhibiting the CNTs formation [9]. For many years, copper has been used as a conventional material for interconnects of ultra-large scale integrated circuits (ULSI), due to its excellent electrical conductivity. However, with the feature size of interconnects in ULSI decreasing gradually to nanometer scale [10], it becomes difficult for Cu to work for nano-interconnects due to the effects of electron surface scattering and grain boundary scattering from Cu electrodes. CNTs can be considered as an ideal candidate to play the role of “incorporating element” in composite interconnects,

*Address correspondence to A. Mahmoodi, Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, PO Box: 14665-678, Tehran, Iran. Tel.: +982144869626; Fax: +982144869640. E-mail: na.mahmoodi@gmail.com or azammahmoudi@srbiau.ac.ir

because of its one dimensional structure, as well as unique electrical, mechanical, and thermal properties [11–16]. Therefore, we measured the electrical conductivity of Cu catalyst coated on glass substrate before and after growth of CNTs.

Experimental

A sodalime glass substrate of 20 × 30 mm^2 was used. A thin film of copper was used as a cathode electrode and was deposited on glass substrate by a cylindrical Dc magnetron sputtering system. The apparatus consists of a glass cylinder vacuum chamber with a rotary vacuum pump, an oil vapor diffusion pump and pressure gauge. This system consists of two coaxial cylinders as cathode (inner one) and anode (outer one). The diameter of the outer and the inner cylinders are 10 cm and 3 cm, respectively and the height of the inner and the outer cylinders are 20 cm. The sputtering target mounted inside the glass chamber. The deposition conditions were as follows: direct current Ar plasma, gas purity 99.995%, discharge power of 120 W, Ar flow approximately 10 sccm and a sputtering time of 3 s. The thickness of cu film is 30 nm, and It is deposition of cu film was performed under 1.1×10^{-2} torr of Ar pressure at room temperature. The TCVD (Thermal Chemical Vapor Deposition) set up in our experiment is an electric furnace composed of a horizontal quartz glass tube with an internal diameter of 75 mm and a length of 1000 mm which was operated in atmospheric pressure. Argon (Ar) Gas with a flow rate of 200 sccm was supplied into the CVD (Chemical Vapor Deposition) reactor to prevent the oxidation of catalytic metal while raising the temperature to 400°C. The sample was annealed under H_2 ambient at 580°C for 10 min. During the annealing process, cu film was found to break up into nanoparticles. Subsequently, CNTs were grown on the catalyst at 580°C using a mixture of acetylene, hydrogen, and Argon with a flow rate of 20 sccm, 80 sccm, and 100 sccm respectively for 30 min. After growth, the system was cooled down to room temperature at Ar atmosphere. The electrical properties of thin films were examined by using a micro fabricated four-point probe before and after growth of CNTs. The size and density distributions of cu catalyst was investigate using atomic force microscopy (AFM). Scanning electron microscopy (SEM) was used to characterized the morphologies and profiles of as- grown CNTs.



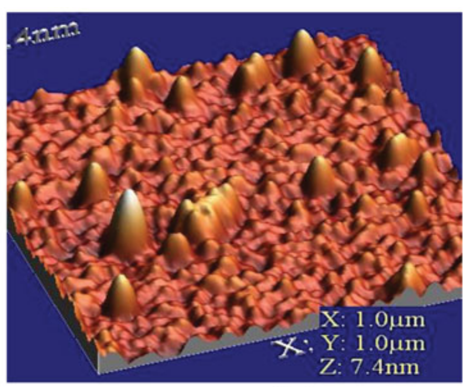
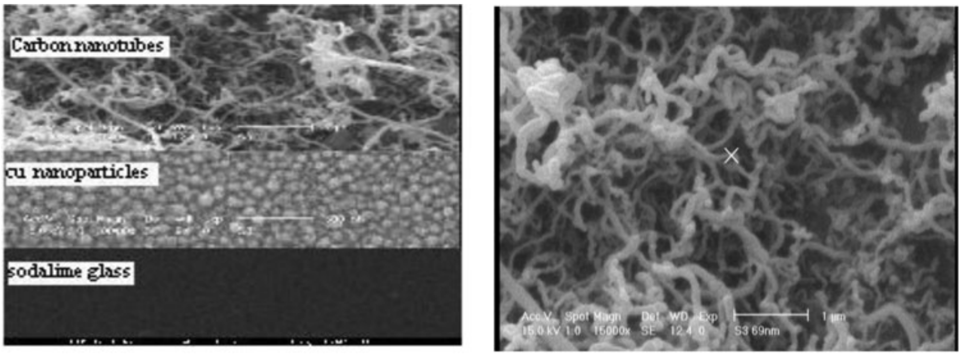


Figure 1. 2D (a) and 3D (b) AFM images of Cu nanoparticles coated on glass substrate.

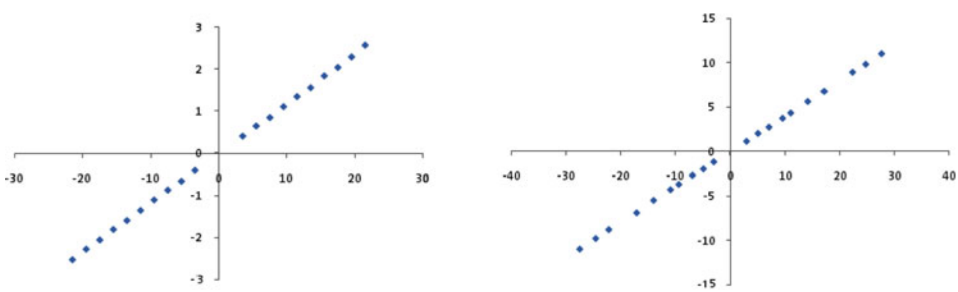


(a) (b)

Figure 2. (a) SEM micrograph of CNTs grown on Cu/sodalime glass (20×30 mm^2) at 580°C (b) magnified top view of the CNTs.

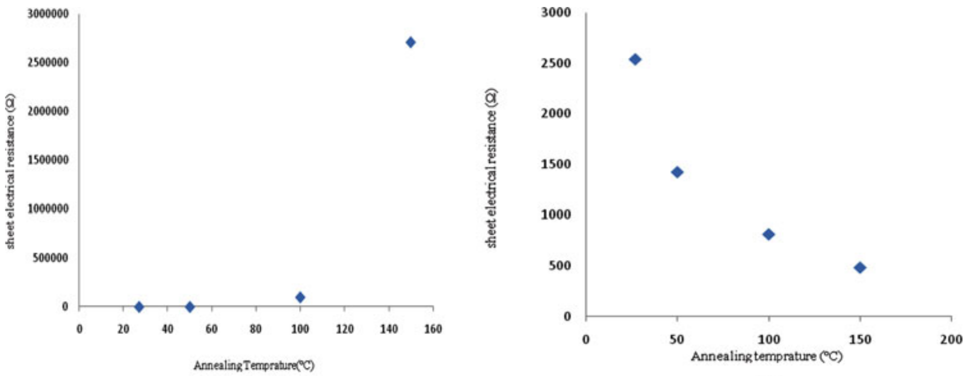
Result and Discussion

Figure 1 shows the AFM image of copper which coated on glass substrate as a catalyst. The image shows smooth surface with mean square (RMS) roughness of 5.19 Å and average roughness of 3.71 Å which support the 2D and 3D image of AFM observations. The image was loaded into J Micro Vision analysis tool (J Micro vision: Image Analysis Toolbox, www.jmicrovision.com) for measuring the size and shape of the nanoparticles in the samples. It is seen that the average size of Cu nanoparticles are 14 nm and mostly have spherical shape. Figure 2(a) is the SEM micrograph of the sample and shows that the CNTs are grown homogeneously on a large area of sodalime glass. Figure 2(b) is the high magnification of grown CNTs. The measurement of electrical sheet resistance (Rs) uses Rs $= (V/I) \times$ CF, where V is the measured DC voltage across the two voltage probes and I is the DC current passing through the two current probes. The value of CF for samples of various sizes and shapes can usually be found in a reference book. Figure 3 displays the I-V characteristics of the surface of Cu/glass and the surface of Cnt/Cu/Glass measured at room temperature [RT]. The I-V curve at RT is strictly linear so that Ohm's law is valid at low electrical field. The measurement was performed at a pressure of about 10^{-2} torr to minimize the influence of atmospheric humidity and to prevent oxidation of surface when increasing the temperature



(a) (b)

Figure 3. Current-voltage characteristic of surfaces measured at room temperature (RT) (a) Cu/Glass(V/I) (b)Cnt/Cu/Glass(V/I).



(a) (b)

Figure 4. The dependence of the electrical sheet resistance on the annealing temperature: (a) Cu/glass (b) cnt/cu/glass.

to 150°C. The annealing temperature dependence of the electrical sheet resistance for as-deposited CNTs/Cu/glass films and Cu/glass films are shown in Fig. 4. Figure 4(a) shows that the electrical sheet resistance of Cu/glass film increases as the annealing temperature increases which is similar to metallic surface and Fig. 4(b) shows that the sheet resistance of the CNTs/Cu/glass film decreases with increasing temperature to 150°C which is typical of semiconductors at this temperature range.

Conclusions

In summary, we have successfully grown CNTs on sodalime glass substrate, by using thermal CVD. The CNTs were obtained at 580°C using Cu catalyst. The electrical sheet resistance of cu/glass films increases, as the annealing temperature increases, the behavior expected for metals. Our results reveal that the surface of CNTs/Cu/glass is semiconductor due to the decrease of the sheet resistance with increasing temperature to 150°C.

References

[1] Baughman, R. H., Zakhidov, A. A., & de Heer, W. A. (2002). *Carbon Nanotubes—The Route Toward Applications Science*, *297*, 787.
[2] Jorio, A., Dresselhaus, G., & Dresselhaus, M. S. (2008). *Carbon Nanotubes: Synthesis, Structure, Properties and Applications*, Springer: Berlin.
[3] Martel, R., Schmidt, T., Shea, H. R., Hertel, T., & vouris, P. A. (1998). *Appl. Phys. Lett.*, *73*, 2447.
[4] Abraham, J. K., Philip, B., Witchurch, A., Varadan, V. K., & Reddy, C. C. (2004). *Smart Mater. Struct.*, *13*, 1045.
[5] Oratkar, N. K., Modi, A., Lass, E., & Ajayan, P. (2004). *J. Nanosci. Nanotechnol.*, *4*, 744.
[6] Mateiu, R., Davis, Z. J., Madsen, D. N., Molhave, K., Boggild, P., Rassmusen, A. M., Brorson, M., Jacobsen, C. J. H., & Boisen, A. (2004). *Microelectron. Eng.*, *73–74*, 670.
[7] Kim, J., & No, K. (2002). *Int. J. Mod. Phys. B*, *16*, 979.
[8] Lee, C. J., Park, J., Kang, S. Y., & Lee, J. H. (2000). *Chem. Phys. Lett.*, *326*, 175.
[9] Musso, S., Fanchini, G., & Tagliaferro, A. (2005). *Diamond & Related Materials*, *14*, 784.
[10] Dubin, V. M., Akolkar, R., Cheng, C. C., Chebiam, R., Fajardo, A., & Gstrein, F. (2007). *Electrochim. Acta*, *52*, 2891.

[11] Andrews, R., Jacques, D., Qian, D., & Rantell, T. (2002). *Accounts Chem. Res.*, *35*(12), 1008.
[12] Kaneto, K., Tsuruta, M., Sakai, G., Cho, W. Y., & Ando, Y. (1999). *Synthetic Metals*, *103*(1–3), 2543.
[13] Berber, S., Kwon, Y. K., & Tomanek, D. (2000). *Phys. Rev. Lett.*, *84*(20), 4613.
[14] Krishnan, A., Dujardin, E., Ebbesen, T. W., Yianilos, P. N., & Treacy, M. M. J. (1998). *Phys. Rev. B*, *58*(20), 14013.
[15] Deheer, W. A., Chatelain, A., & Ugarte, D. A. (1995). *Science*, *270*(5239), 1179.
[16] Baughman, R. H., Zakhidov, A. A., & de Heer, W. A. (2002). *Science*, *297*(5582), 787.