Study of Ni-coated Carbon Nanotubes Reinforced on Titanium Matrix Composites and Nanoelectronics of Multiwalled CNT's

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Abstract— Carbon Nanotubes (CNTs) can be described as honeycomb like lattices of carbon atoms rolled in cylinders. CNTs are well known for its extraordinary strength and stiffness overpassing even steel. CNT's are effective reinforcement to improve the mechanical properties of the matrix. The interface between Ni-coated and Ti alloy transfers load when tensile fracture takes place. The beauty of nanoelectronics of this small sized nanotubes is also discussed in the paper.
Keywords: Carbon Nanotubes, Titanium Alloy, Nanocomposite, Ultrasonic

I. Introduction

Due to number of layers Carbon Nanotubes can be divided into Single-walled Nanotubes (SWNTs) and Multi-walled Nanotubes (MWNTs). Way layers of MWNTs covering each other can be compared with Russian doll (SWNT covered with larger SWNTs).

CNTs material has unique properties:

- Its weight is only 1/6 of steel, 100 times its tensile strength
- Metallic or semiconductor's properties depending on its chirality
- Liquid trapped inside carbon tube gains properties of 4^{th} state of matter

The number of layers in MWNTs usually changing from 6 to 25. The diameter of MWNTs may be 30 nm comparing to 0.7-2.0 nm in majority of SWNTs [2].

To figure out why CNTs has such unique properties, first we will observe its mechanical characteristics. Despite the fact that each CNT's graphene sheet is symmetrical, it has different properties in axial and radial directions. By measurements made with atomic force microscopy (AFM) was proven CNTs is the strongest existing material, which tensile strength equals to 45 GPa (20 times more than steel) [3].

CNT also reveals highly conductive properties of matter. Talking about electrical properties of CNT it worth to be mentioned that it possesses either metallic or semiconductor properties depending on its wall structure (note that n and m are indices defining directions in which graphene sheet will be rolled to single-walled nanotube):

- Metallic (if n = m)
- Semiconducting with a petty band gap (if n-m is a multiple of 3)
- Moderate semiconductors (in other cases)

The thermal properties of carbon nanotubes are related to their structure and extremely small size. [5]. CNTs in composite materials providing them not only high strength, but also potentially high thermal conductivity. CNTs in room temperature expose conductivity similar to diamond (300 W/mK).

Due to the low density of the CNT's the nanocomposites are maintained at the densities similar to that of Ti. This is because of the weak bondng between Ti and C the synthesized composite reinforced with CNT's may not be strong enough. Thus an, alternate way of using CNTs as reinforcement with enhanced strength is required.

II. Experimental Procedures

Commercial Ti-6Al-4V is the alloy used as the matrix. Nanotubes with 10nm-30nm in diameter and 10μm-20μm in length were used.

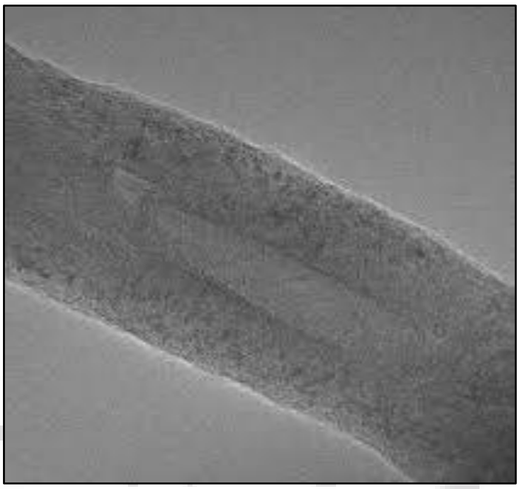

Fig. 1: TEM image of MWNT.

In order to improve the dispersion of SWNTs in the electroless bath, the SWNTs were heated at 800K for 1h. The next step in the process was to add the shorted SWNTs. Finnaly they were dispersed ultrasonically and intensively. Finnaly, the CNts were synthesizeld and activated in a solution of 0.3g/l $PdCl_2$– 0.25g/l HCl for another half hour, respectievely. Once washing is carried out with distilled water the activated CNTs were coated by Nickel for 30 mins.$PdCl_2$

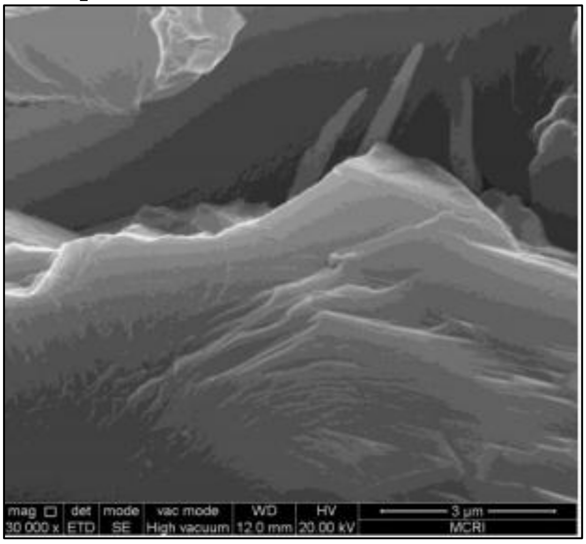

Fig. 2: SEM micrograph of tensile fracture surface of 0.5 wt % CNTS/ Ti-6Al-4V composites

The above diagram shows the tensile fracture surface of 0.5%wt%CNTs/Ti6Al4V composites. Carbon nanotube bundles are found at the cross section of the composite. And they still stay in the matrix on the other side. Better interfacial bonding between Ni coated and the Titanium alloy play an important role in bridging. The interface between Ni-coated and Ti alloy transfers load when tensile fracture takes place. Hence, it can be seen that the effect of CNT addition leads to the increase in mechanical properties of Titanium Alloy.

III. Nanoelectronics of CNTs

Due to electronics properties we discussed earlier, CNTs obtain high conductivity. As readers can see on Figure 4, way CNTs used represented by a very small, but yet high aspect-ratio conductive additive, used for all kinds of plastics. CNTs require much lower loading (concentration) to gain same conductivity comparing to other additives (such as stainless steel fiber, carbon black etc).

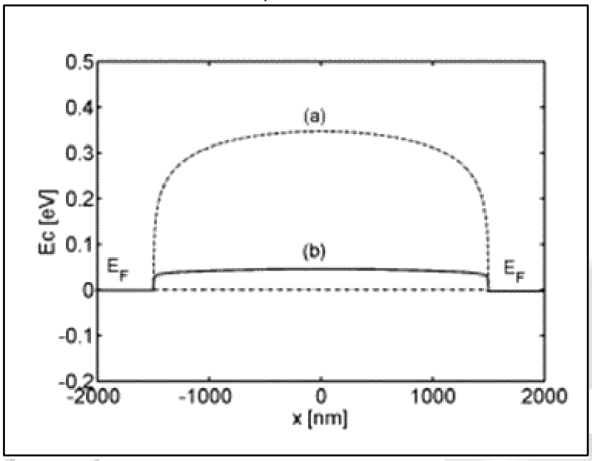

Fig. 4: Conductive Bandage

When the intrinsic nanowire is attached to 10 metal contacts as it shown on Figure 4, the charge density on nanowire depends critically on the electric environment rather than properties of metal contact. Reducing the gate oxide thickness the contact size decreases the distance over which the source / drain field penetrates into the nanowire channel. Suppressing the short channel effects helps to improve transistor performance.

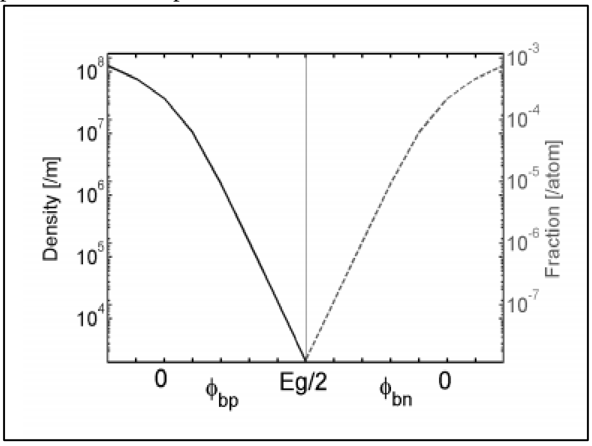

Fig. 5: Electron density and the hole density in the center

Following formula describes charge density per unit length:

$$Q_L(z) = -e\int_{-\infty}^{+\infty} dE\,\psi(E)D(E)f\big(\psi(E)[E - E_f^{\sim}(z)]\big) \qquad (1)$$

Where $Q_L(z)Q_L(z)$ - charge density per unit length;

e – electronic charge;

$E_f^{\sim}(z) = E_f - E_m(z)E_f^{\sim}(z) = E_f - E_m(z)$ – difference between Fermi energy level and middle gap energy of the carbon nanotube.

Since the source / drain electrodes are grounded – Fermi level is set to zero $E_f = 0E_f = 0$.

The electrostatic potential, V satisfies the Poisson equation:

$$\nabla^2 V(z,r) = -\frac{\rho}{\varepsilon}\nabla^2 V(z,r) = -\frac{\rho}{\varepsilon} \qquad (2)$$

Where $\rho\rho$ – charge density, $\varepsilon\varepsilon$ – dielectric constant.

If the metal contacts are grounded, and the metal/ semiconductor work function difference is $V_0 = \phi_{CNT} - \phi_m V_0 = \phi_{CNT} - \phi_m$ (where $\phi_{CNT}\phi_{CNT}$ – nanotube work function, $\phi_m\phi_m$ – work function of metal), then electron density is $\eta(z) = D^-(V_0 - V_z)\eta(z) = D^-(V_0 - V_z)$, where $V_z V_z$ – electron potential energy.

IV. Applications of CNTs

Properties of carbon nanotubes allow using them in wide range of modern and new applications. The theoretical predictions scientists make for future possible applications attracts hundreds of million dollars invested in new researches. Potential areas are aerospace, electronic devices, biotechnology and biomedicine, in which they can be used as gas adsorbents, templates, actuators, composite reinforcements, catalyst supports, hybrid protein-carbon structures, components of biosensors, scanning probe microscopy, as vesicles for DNA delivery into living cells, nano-reactors and small-scale substrates (even as substrate for neurons) [6][7].

Scientists insist on additional studies on toxicity of carbon nanotubes to provide safe using and prevent risks of working with this material.

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