Effect Of Sintering On Electrical Conductivity Of Silver-MWCNT Nanocomposite.

Vimal Sharma [1], Hemant Pal[1, 2*], Rajesh Kumar[3] and Nagesh Thakur[4]
[1]Department of Physics, National Institute of Technology, Hamirpur (H.P.) 177005 India
2Department of Physics, Govt. College Chamba (H.P.) 176310, India.
[3]Department of Physics, Jaypee University of Information and Technology, Solan, (H.P.), 173234 India.

[4]Departments of Physics, Himachal Pradesh University, Shimla (H.P.) 171005, India.

*Corresponding author: - Hemant Pal, Department of Physics, Govt. college Chamba (H.P.) 176310, India. Email:-hemantpal76@gmail.com, mob: - 94181-22414,

Abstract

Silver-MWCNT nanocomposites have been successfully synthesized by modified molecular level mixing method followed by sintering. The structural morphology was analyzed by XRD, SEM and EDS. The Electrical conductivity of the composites was measured by four probe method. The experimental results showed that the electrical conductivity increases on incorporation of CNTs and thereafter sintering. The influence of sintering on the electrical conductivity depended on the combined effects of porosity, CNTs distribution in the matrix, CNT twists and grain growth. The composites sintered at 600 ^{0}C showed the comparative more enhancements in electrical conductivity of Ag-MWCNT nanocomposite at 1.5 vol% of CNTs.

Keywords: Metal Matrix Nanocomposite, Carbon nanotubes, Sintering, Electrical Conductivity.

1. INTRODUCTION

Metal nanoparticles play important roles as interconnects and in nanoscale electronic devices. Silver nanoparticles are especially attractive due to its extremely high electric and thermal conductivities. However, pure metal nanoparticles are limited for metallic interconnection applications as their resistivity increase largely with the decrease in dimension due to its increased electron scattering. [1]

On the other hand, apart from their excellent mechanical properties carbon

Nanotubes [CNTs] are also known for having long mean free path (order of several microns), extremely high current densities (> 109 A/cm2 at 25°C), and high aspect ratio. [2] The electrical conductivity of individual multiwall carbon nanotube is of the order of 10^7 to10^9 s/m which is about 100 times greater than the metals.[3] The idea of using carbon nanotubes as highly conductive filler in metal matrix has drawn great attention. The use of carbon nanotubes (CNTs) as filler in metals is so far a challenge due to non-straight and entangled structured .[4]

On the basis of simulation it has been proposed that a composite based on aligned, ballistic conducting carbon nanotubes embedded in a metal matrix might work as an ultra-low-resistive material with the potential of having a room-temperature resistivity far below than metals. [5]

The present work aims to study the variation of electrical conductivity of Ag-MWCNT nanocomposite with CNT volume percentage and sintering thereof.

2. EXPERIMENTAL DETAILS.

In the synthesis of nanocomposite commercially available MWCNTs (purity 90-98 vol %) of diameter 4-12 nm and length 15-30 µm are used. Five samples of Ag-MWCNT nanocomposite with 0, 1.5, 3, 4.5 and 6 volume % MWCNTs were synthesized. The synthesis process is called as modified molecular level mixing method [6] as we have used noncovalently functionalized CNTs with chemical reduction process in place of covalent functionalization and thermal reduction process as a modification in the method proposed by S.I. Cha. et. al. called as molecular level mixing method.[7] Finally, Ag-MWCNT nanopowder was obtain by drying at 30-40 ^oC on hot plate and this nanopowder was further consolidated by a simple graphite molding press at a pressure of 6 tones. The microstructure of Ag-MWCNT nanocomposite powder was investigated by X-ray diffraction (XRD), Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) and for the electrical conductivity measurements four probe electrometer (Kiethly2400 source meter and nano voltmeter 6221 Kiethly) has been used.

3. RESULT AND DISCUSSION

3.1 STRUCTURAL ANALYSIS

The XRD pattern of Ag-MWCNT (3 vol %) is shown in fig.1indicating the crystalline nature of the sample with peaks corresponding to Ag nanoparticles.

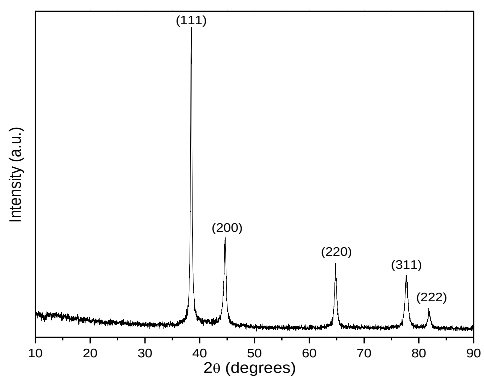

Fig1-XRD Pattern for Ag/CNT nanocomposite powder Ag/CNT(3vol%) .

The slight rise in XRD curve from baseline between 15^0-25^0 indicates the presence of CNTs. In order to determine the elemental composition of Ag-MWCNT nanocomposite elemental analysis was carried out using EDS which confirms the CNT volume in nanocomposite as shown in figure 2.

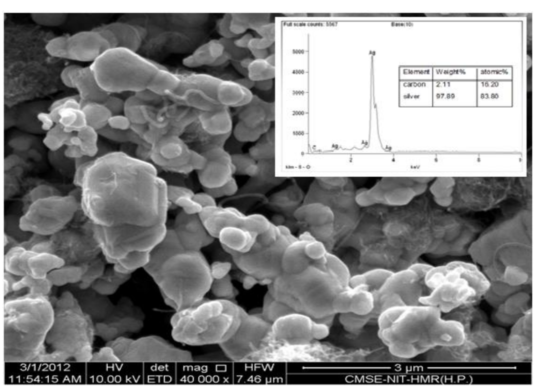

Fig.2- EDS Analysis of Ag/CNT Nanocomposite.

The morphology and distribution of carbon nanotubes in the matrix are shown in the SEM micrographs. The carbon nanotubes are embedded in the silver matrix but agglomeration of carbon nanotubes and voids in the matrix of consolidated sample are present. The reduction in the porosity and grain growth is more evident in the sintered sample.

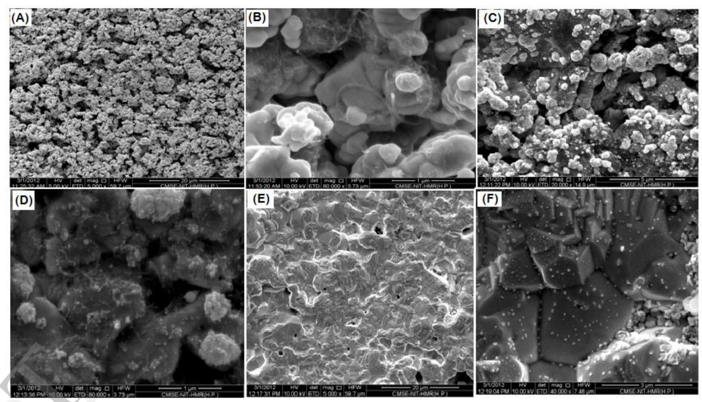

Fig 3. SEM micrographs of Ag/MWCNT nanocomposite (A) Ag-MWCNT powder (B) Ag-MWCNT(at 1.5 vol%)(C,D) consolidated Ag/MWCNT nanocomposite (1.5 VOL%) (E) Ag pellet after sintering (F) Ag-MWCNT nanocomposite pellet after sintering

3.2 ELECTRICAL CONDUCTIVITY AND SINTERING

The electrical conductivity was measured using a standard four-point probe method. All conductivity measurements were performed at room temperature and 600^0c. For each sample, conductivity data represent the average value of 10 measurements. The electrical conductivity of Ag-MWCNT nanocomposite at room temperature and 600^0c are measured as plotted in the following diagram. There is comparative enhancement in electrical conductivity of Ag-MWCNT nanocomposite after sintering at 600 ^{0}c for 12 hour at the rate of 5 deg/min in horizontal tube furnace as shown in Fig.4

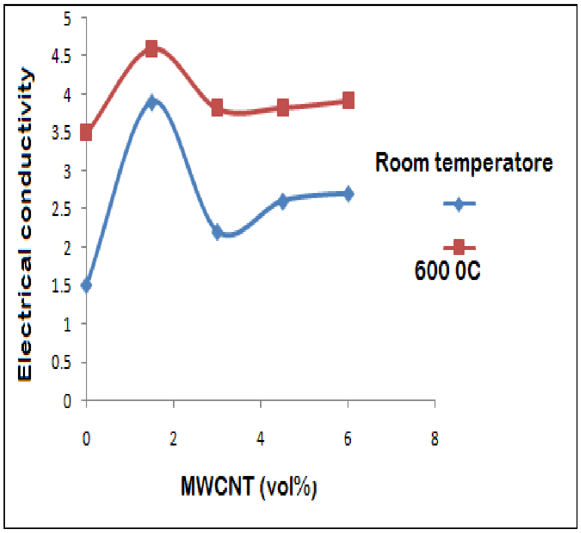

Fig.4- Variation of electrical conductivity of Ag-MWCNT nanocomposite with sintering.

4. RESULTS AND DISCUSSION.

Due to higher current carrying capacity (10^9A/cm^2) and low resistivity (1.2x10^{-4} to 5.1x10^{-6}Ωcm) of individual multiwall carbon nanotubes can be used as reinforcement for improvement of electrical conductivity in metal matrix. [3]

On the basis of free electron gas theory the Electrical conductivity of metallic conductors can be described as

$$\sigma = ne^2\lambda/mv$$

where n is the electron density of state, λ is the mean free path, m is the mass of electron and v is the Fermi velocity. The electrical conductivity is

proportional to the mean free path, i.e., the longer the mean free path, the higher the conductivity will be. [5] The metallic MWCNTs can be ballistic conductors and having mean free path equal to nanotube length and much more than silver.[8] The free electrons in the p_z orbital of CNTs can move within cloud and are no longer localized to a single carbon atom. Besides being responsible for high conductivity, the delocalized π-electrons of carbon nanotubes could be utilized to promote adsorption of various moieties on the CNT surface via π–π stacking interactions. In Ag-MWCNT nanocomposite couplings between electronic states through the charge transfer interaction from the silver nanoparticles to MWCNTs. The embedded MWCNT in a silver matrix facilitates electron transfer along with the ballistic transport from end to end, thereby prolonging the electron's mean free path of nano-composite as comparison to silver as a consequence of which electrical conductivity of Ag-MWCNT nanocomposite increases. [11]

Although CNTs possess high electrical conductivity due to long mean free path and free delocalized free electron but with the increase of CNT content in metal matrix, the high surface area of the nanotubes creates a large interfacial region between the CNTs and the silver, resulting in large scattering during electron transfer and hence leading to a decrease in conductivity. Also on the same time as the CNT vol percentage increases, the structural defects like micropores and clustering of CNTs also increases which combined with lattice strain in the

silver matrix around the nanotubes, act as barriers to electronic motion. Thus, the electrical conductivity of the composites decreases with increasing CNT volume content.

The sintering and densification processes directly affect the electrical properties because during sintering, the particles bond together and the pores shrink. Ag-MWCNT nanocomposite pellets were sintered in a muffle furnace at 600 ^{0}C at the rate of 5 ^{o}/min for 12 hours. The electrical conductivity of these samples was measured as the average value of 10 consecutive measurements is evident from the figure that the electrical conductivity of Ag-MWCNT nanocomposite increases due to sintering. Coalescence of the silver nanoparticles during the sintering process increases the density [12] and hence the conductivity of the nanocomposites.

4 CONCLUSIONS.

The Ag-MWCNT nanocomposites fabricated by modified molecular level mixing method shows homogenous and embedded distribution of the CNTs in the silver matrix connecting the grain boundaries. Consolidated Ag/CNT nanocomposites have been found to enhance electric conductivity (at 1.5 vol % loading) as compared to that of pure nanosilver. The electrical conductivity further improved on sintering at 600 0c due to reduction in porosity, grain growth and CNTS distribution.

ACKNOWLEDGEMENT

The authors thankfully acknowledge the financial support from Department of Science and Technology

[Project-SR/FTP/PS-054/2011(G)], India.

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