The Egyptian International Journal of Engineering Sciences and Technology

Vol. 24 (January 2018) 34 - 39

http://www.eijest.zu.edu.eg

Experimental Work for Using of Nanotechnology Coating to Minimize Transmission Losses by Reduction of Resistance

Amal F. Abdel Gawad[a], Mohamed Taalab[a], A. ElSebaei[a], N. S. Ali[a], Mai El-Shahidy[b]

[a] *Faculty of Engineering, Zagazig , Egypt*

[b]*Chemical Engineering Depart. , Science and Technology Center of Excellence.*

ARTICLE INFO

Article history:
Received 02 June 2017
Received in revised form 22 Nov. 2017
Accepted 26 Nov. 2017
Available online 15 June 2018

Keywords:
Nanotechnology
Nano particles
Magnetron sputtering
Power
Transmission

ABSTRACT

This article provides an impact of applying physics and engineering modern techniques for electric power transmission improvement. Since power losses is a problem in present power systems, many concerns about how to minimize it. Nanotechnology is one of these new techniques and it is also a fastest growing field in research and technology. The main interest of nanotechnology is not electrical power engineering only but there were a lot of possible applications to improve electrical, mechanical, thermal or chemical properties of electric power equipment. This paper illustrates a new application of nanotechnology in electrical power transmission that appeared in coating the transmission lines of type ACSR with a nano layer of copper to minimize the resistance of the transmission and so minimize the transmitted power losses. The substrate used in our experiment was made of aluminium with purity of 99.9 % of dimensions 3×6×0.5 cm. The coating process was done by Hybrid Physical Vapor Decomposition by using DC magnetron sputtering technique. Tested the resistance of the coated substrates is reduced and the obtained results have proven the desired goal of power loss reduction in transmission lines.

1. Introduction

The huge amount of power generated in a power station (hundreds of MW) is to be transported over a long distance (hundreds of kilometres) to load centres to cater power to consumers with the help of transmission line and transmission towers. The important consideration in the design and operation of a transmission line are the determination of voltage drop, line losses and efficiency of transmission. These values are greatly influenced by the line constants R, L, C of the transmission line. For instance, the voltage drop in the line depends upon the values of above three line constants. Similarly, the resistance of transmission line conductor is the most important cause of power loss in the line and determines the transmission efficiency. This resistance is affected by important phenomena called SKIN EFFECT in which the effective cross-section area of the conductor used by the current is reduced. So by coating the conductor with very good conductive metal such as copper, the resistance of it will be reduced and increases the current flow capacity.

ACSR (Aluminium Cored Steel Reinforced) is one of the most used conductors in transmission lines. It consists of alternate layers of stranded conductors, spiraled in opposite directions to hold the strands together, surrounding a core of steel strands. The purpose of introducing a steel core inside the stranded aluminium conductors is to obtain a high strength-to-weight ratio. A stranded conductor offers

*Nehad Salah . Tel 01004240803
E-mail address; nehadsalah@yahoo.com.

more flexibility and easier to manufacture than a solid large conductor. However, the total resistance is increased because the outside strands are larger than the inside strands on account of the spiralling.

Nanotechnology introduces promising economical solutions and products to achieve reliable sustainable environment. The term nanotechnology embraces many different fields and specialties, including engineering with bringing existing technologies down to a very small scale, measured in nanometres. Processes and functionality take place at the nanoscale, exhibiting properties not available in the bulk material. At this size, atoms and molecules work differently, and provide a variety of surprising and interesting uses.

Priya G. Deshmukh [1] mentioned a review on applications of Nanotechnology in the energy sectors including the transmission system. Many researches tried to improve the performance of transmission lines in power system with many different ideas and techniques as would be illustrated next.

Kwang-Un Jeong used Polymer nanocomposites reinforced with multi-walled carbon nanotubes (MWCNTs) for Semiconducting layers of high-voltage electrical power cables. Homogeneity of the MWCNT-reinforced polymer nano composites was achieved by solution mixing, and their mechanical, thermal and electrical properties were investigated depending on the type of polymer. Based on the criteria of tensile properties and volume resistance, a poly [ethylene-*co*-(ethyl acrylate)]/MWCNT nano composite was selected as the best candidate for the semiconducting layers of high-voltage electrical power cables [2].

Networks of CNTs were used to build planar transmission lines which functioned as stripline waveguides in the frequency range studied by Mahmoud A. EL Sabbagh [3]. He replaced conventional metallic conductors in electric circuits by CNTs, in general, and RF/microwave circuits in particular. From results, the losses of CNT networks were still high compared to copper. This was due to the low-cost CNTs used, with 1:3 metallic to dielectric composition. As fabrication techniques improved, it was anticipated that materials consisting of only metallic CNTs would be produced at low cost.

The fabrication of iodine-doped, double-walled nanotube cables having electrical resistivity reaching, 10^{-7} Ω.m was reported by Yao Zhao [4]. Due to the low density, their specific conductivity (conductivity/weight) had been higher than copper and aluminum and was only just below that of the highest specific conductivity metal, sodium. The application of such nanotube cables was demonstrated by partly replacing metal wires in a household light bulb circuit. The conductivity variation as a function of temperature for the cables was five times smaller than that for copper.

Ricardo H.R. Castro, Pilar Hidalgo, and Eric C. Diniz [5] used the Electrophoretic Deposition to create Single Walled Carbon Nanotubes (SWCNT) in nanoscale on commercial aluminum wires. They did that to improve the conductivity of these wires. The thickness of the coated film on the wire was 2-3 nanotubes (<90). The resistance of the coated wires under different temperatures was tested. The results showed that at low currents with high temperature, the resistance was high and by increasing the current, the resistance decreased. They measured the conductivity of the coated and uncoated wires. From the results, they found that the conductivity of the coated wires were higher than those of the uncoated ones but still lower than the conductivity of copper (~ 60 S μm^{-1}). The increase of conductivity in the coated wires was due to the formation of the metallic SWCNT bundles during the deposition. Finally, the use of CNTs increased the maximum current density of the wires with the conductivity also. EPD technique succeeded in deposition process on a non-planar substrate (wire).

H.M. Mahmoud [6] focused on increasing stability and maximum loadability of a system by replacing congestion conventional transmission line with new carbon nano tube (CNT) line to reduce congestion of the system and /or system losses, hence maximum loading point of the system increased and system dynamic performance improved. Based on simulation results could conclude that (CNT) line instead of congested line gave higher maximum loadability and minimized the worst case voltage deviations. Also (CNT) line improved system dynamic stability performance through time domain simulation results.

A developed CNT-reinforced aluminum composites with electrical and mechanical properties that enabled substantially greater transmission capability than traditional ACSR was studied by O. Bourne, J. Guan, M.B. Jakubinek, S. Lin, R. MacNeil, B. Simard, A. Akhtar, F. Ko, J. Lo, and R. Zhang [7]. Authors succeeded in production of aluminum and SWCNT-Al MMCs, containing up to 5 wt% raw SWCNTs, from powder. Where the formation of Al4C3 was successfully inhibited, the conductivity of the metal matrix composites was comparable to pure aluminum samples. In a preliminary test, the ultimate tensile strength also was significantly improved relative to a baseline aluminum sample prepared by the same method. Considering the electrical resistivity and strength values observed here, along with the estimated percentage improvements required to replace the steel strands in conventional ACSR cables and the potential avenues for further improvement, these initial results were encouraging in terms of the potential to produce CNT-reinforced aluminum conductor cables and merit further investigation.

Minh-Tung Le used copper as a coating metal in his work [8] scince electrical resistivity of Cu films had been a very important factor for using interconnects. Copper is an attractive interconnecting material due to its low resistivity and super resistance to electro-migration. Thin films of Cu are deposited by various techniques such as evaporation, sputtering, chemical vapour deposition electroplating, and ion beam deposition. Among these techniques, direct current (DC) magnetron sputtering is one of the best methods for practical preparation of Cu films. Since DC magnetron sputtering technique has the advantage of much better productivity than other deposition methods, it is widely used as mass production processes.

Arun Augustin [9] applied copper coated touch surface by DC magnetron sputtering on zincated and non-zincated aluminium substrate. He studied the difference between sputtering of copper on two different aluminium substrates. XRD characterization indicated that by zincating, the tendency for copper alignment could be reduced. SEM studies indicated that the copper crystallites on zincated substrate were predominantly in the range of 125-200 nm whereas in the case of non-zincated substrate, it was in the range of 40-60 nm. Contact angle studies showed that the wettability of copper coated on non-zincated Al was more compared to copper coated on zincated aluminium.

The objectives of this paper are: (i) develop new advanced planar transmission line (TL) by coating it with a very good conductive metal (copper), (ii) characterize its electrical properties. To achieve that goal, we fabricate in-laboratory an aluminum alloy that coated with a very thin layer of copper of nano scale. We use magnetron sputtering source in Hybrid Physical Vapor Deposition and plasma enhanced chemical vapor deposition (Hybrid PVD-PECVD) equipment to deposit copper coating with different parameters and reach acceptable results in minimizing the losses in transmission.

2. EXPERIMENTAL SETUP :

Evaporation of metal using MS source in Hybrid PVD - PECVD for the formation of copper coating is so far known as a high-efficiency laboratory technique. The equipments of Hybrid PVD – PECVD (protec nanoflex 400) can be seen in Fig.1.

Fig.1: magnetron sputtering (MS) device.

Aluminum alloy (Al) , as shown in Fig.(2), used for our experiment is of purity 99.5% with some other metals such as Fe (0.372%), Ti (0.021%), Si (0.064%), and others with very small ratios. This construction is done by (Spectromax- Chemical Composition of metals). The dimension of this substrate alloy is 5cm * 6cm * 0.5cm. The Al substrates are cleaned in diluted isopropanol solution for 1 minute, and are rinsed in de-ionized water prior to loading into a vacuum chamber.

Normally the first step to execute is the "vacuum and heating" phase inside the chamber filled with the substrates. The high vacuum must to be created to eliminate as much as possible the residual atmosphere. The deposition chamber is evacuated to 10-5 pa base pressure. In the deposition chamber the vacuum level for optimal coating cycle is created by a turbo molecular pump mounted above the lid of the chamber. Before the deposition of Cu films, a Cu target (99.999 % purity and 400 mm *66 mm*8 mm thickness) is pre-suttered in pure argon for 10 minute in order to remove oxide layer on the surface of the target. Cu films are deposited by MS in pure argon gas at 6*10-1 Pa. Chamber temperature is kept constant at 100 °C. The distance from the Cu target to Al substrate in the experimental is 8 cm. Different values of applied electrical power are used (1.05 kw, 1.5 kw, and 2 kw).

The thickness of copper layer for each case was illustrated by (Stylus Profilmeter model- Dektak 150). The measurements of substrate thickness are the inputs to resistance measurement device (KEYSIGHT B1500A Semiconductor Device Analyzer) in order to measure their resistance.

Fig.2: Aluminum alloy with purity 99.5%

3. RESULTS AND DISCUSSION:

The coated substrate with nano particles of copper for one case of the test cases is shown in fig. (3). Scanning Electron Micrographs(SEM) of Nano copper coatings for the sample that had been applied to 100c°, 1 hour, and 2KW power is shown the photo shown in fig.(4).

Fig.3: coated substrate

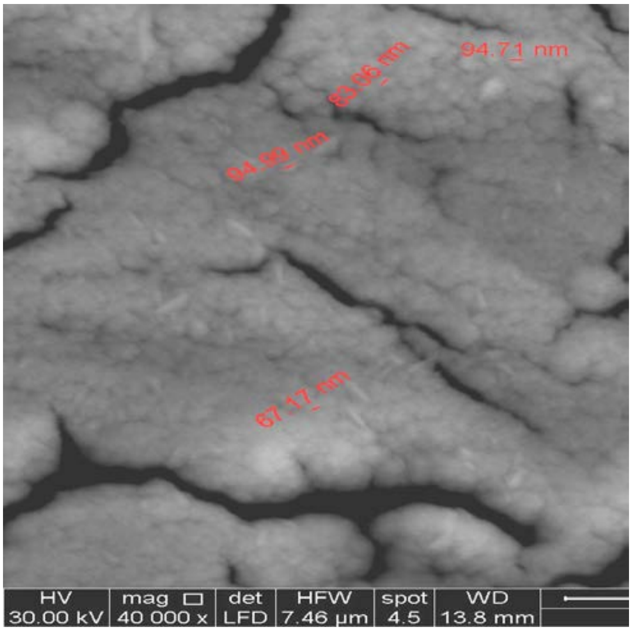

Fig.4: SEM photo for the coating layer on the substrate

Figure (4) shows scanning electron microscopic view of the top surface of the copper coating. Topographic image shows that coating is formed by very fine clusters of crystallites. The histogram for size distribution of clusters of crystallites showed indicated that major clusters are in between 83.08-94.99 nm size.

The parameters used in coating process with magnetron sputtering source, thickness of the resulted coating layers, and the resistances of the coated substrates (AL-Cu) are presented in table (1) as well as in figures (5) to (8).

Table 1. Results of the coating process

Substrate	Power (KW)	Time (hr)	Thickness	Resistance (Ω)
AL	-	-	0.5cm	0.5
AL-Cu1	1.05	1/2	569.75nm	0.43
AL-Cu2	1.05	1	1030.33nm	0.38
AL-Cu3	1.5	1/2	587.8nm	0.42
AL-Cu4	1.5	1	1101nm	0.34
AL-Cu5	2	1/2	682.02nm	0.40
AL-Cu6	2	1	1221.34nm	0.33

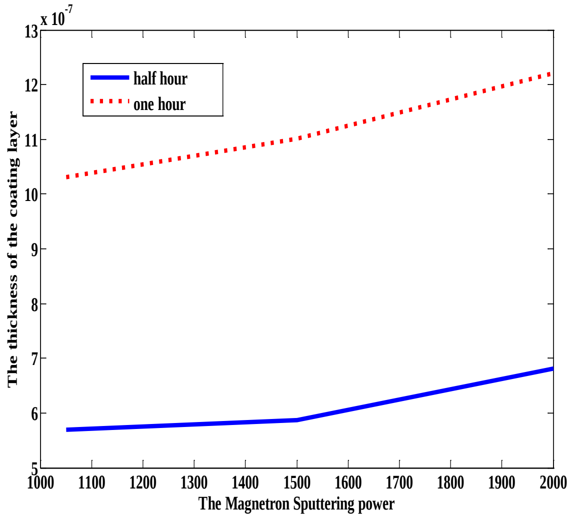

Fig.5: The effect of MS power on the thickness of the coating layer.

From the curve in fig.(5), it can be deduced that, the thickness of the coating layer increased as the applied power to the Hybrid PVD-PECVD device increases at any time. This is because the crystallite size increased with the sputtering power since the higher surface mobility caused by high adatom energy strengthens the crystallinity of the Cu films at higher sputtering power. And this makes the thickness of the coated layer increased.

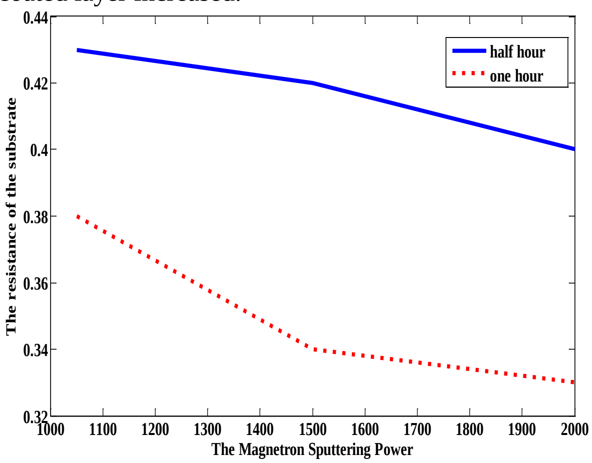

Fig.6: The effect of MS power on the resistance of substrate.

Since the thickness had been increased by increasing the applied power, the resistance to the electrical current will be decreased according to the equation;

$$R = \rho \frac{l}{A} \quad \Omega \qquad (1)$$

Where;

R : is the resistance of the material.
ρ : is the resistivity of the material.
l : is the material length.
A : is the area of the material.

This was clearly appeared in figure (6). By increasing the applied power for the coating operation from 1.05 kw to 1.5 kw, the resistance of the substrate decreases by 1% for time of half hour and by 4% for time of one hour. The increase in MS power from 1.5 KW to 2 KW makes a decrease in the substrate resistance by 2% for time of half hour and by 1% for time of one hour.

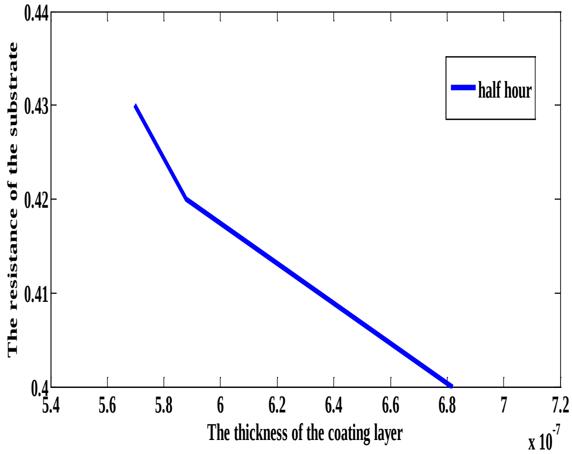

Fig.7: The effect of thickness on the resistance of substrate for time of half hour.

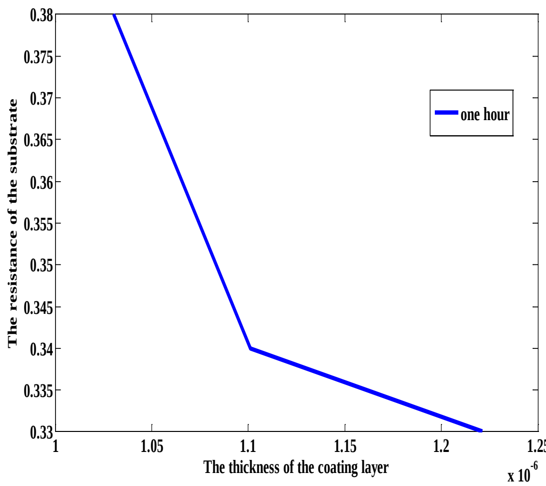

Fig.8: The effect of thickness on the resistance of substrate for time of one hour

As obvious in Figures (7), and (8), by increasing the time of coating operation, the thickness increases and the resistance decreases. This assured the equation 1.

4. Conclusion:

Cu films are deposited on AL substrates at various sputtering powers in the range from 1.05 to 2 KW using DC magnetron sputtering. These nano coated layers are applied on aluminium substrates in order to improve its current flow capacity by reducing its resistance. The effect of sputtering DC power on the electrical and structural properties is investigated. The results show that by coating the aluminum substrate with a copper layer in nano scale, the resistance of aluminum decreases. With decreasing the electrical resistance, the power transmitted in transmission system increases and losses decreases. Also, by increasing the MS applied power, the thickness of the coating layer increases and the resistance decreases.

References:

[1] Priya G. Deshmukh Prof. S.S. Katariya, "Nanotechnology Applications In The Energy Sector", International Journal of Advancements in Research & Technology, Volume 2, Issue3, March-2013 IISSN 2278-7763.

[2] Kwang-Un Jeong, Jee Young Lim, Jong-Young Lee, Seong Lak Kang and Changwoon Nah, "Polymer nanocomposites reinforced with multi-walled carbon nanotubes for semiconducting layers of high-voltage power cables", Published online in Wiley Interscience: 12 November 2009.

[3] Mahmoud A. EL Sabbagh, Samir M. El-Ghazaly and Hameed A. Naseem, "Carbon Nanotube-Based Planar Transmission Lines", IEEE, 2009, PP 353-356.

[4] Yao Zhao, Jinquan Wei1, Robert Vajtai1, Pulickel M. Ajayan1 & Enrique V. Barrera1, "Iodine doped carbon nanotube cables exceeding specific electrical conductivity of metals", SCIENTIFIC REPORTS, September 2011, PP 1-83.

[5] Ricardo H.R. Castro, Pilar Hidalgo, and Eric C. Diniz, "Enhanced electrical conduction in aluminum wires coated with carbon nanotubes", ELSEVIER Materials Letters56, 2011, pp 271-274.

[6] H.M. Mahmoud, M.A.Mehanna and S. K. Elsayed, "The Effectiveness of Carbon Nano Tube (CNT) in Voltage Stability and Power Transfer Capability", Nature and Science, 2012, 10 (4).

[7] O. Bourne, J. Guan, M.B. Jakubinek, S. Lin, R. MacNeil, B. Simard, A. Akhtar, F. Ko, J. Lo, and R. Zhang, "Carbon Nanotube (CNT)-Aluminum: Towards CNT Reinforced Aluminum Conductor Cables", The 19^{th} International Conference on Composite Materials, 2014, pp 1-8.

[8] Minh-Tung Le;, Yong-Un Sohn, Jae-Won Lim;* and Good-Sun Choi," Effect of Sputtering Power on the Nucleation and Growth of Cu Films Deposited by Magnetron Sputtering", Materials Transactions, Vol. 51, No. 1 (2010), pp. 116 to 120.

[9] Arun Augustin, K. Rajendra Udupa, Udaya Bhat K.," Effect of Pre-Zinc Coating on the Properties and Structure of DC Magnetron Sputtered Copper Thin Film on Aluminium", American Journal of Materials Science 2015, Vol. 5, No.(3C), PP 58-61.