The effect of thickness of a conductive nanocomposite ink printed on textile co-planar waveguide antenna

Nor Hadzfizah Mohd Radi[1,3], Mohd Muzafar Ismail[1], Zahriladha Zakaria[1], Jeefferie Abd Razak[2]
[1]Faculty of Electronics and Computer Technology and Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia
[2]Faculty of Industrial and Manufacturing Technology and Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia
[3]Faculty of Electrical and Electronics Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, Pekan, Malaysia

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ABSTRACT

In the area of wearable technology an enhancement of basic microstrip antenna is evolution of wearable textile antenna. A new development of wearable antenna is the incorporated of conductive plane using nanocomposite ink that embedded onto the fabric. In this paper, the performance of variety thickness of conductive Graphene-Ag-Cu ink on a drill fabric is presented. The performances include its resistivity and conductivity measurement. By performing a measurement using scanning electron microscopy, energy-dispersive X-ray spectroscopy, and four-point probe, it can obtain and measure the composition and thickness of nanocomposite layered on a fabric and resistivity respectively. Hence, it can provide detailed information about the surface morphology, roughness, and thickness of the nanocomposite coating on the fabric as well as the electrical conductivity. Finally, the electrical conductivity increased to the fifth layered from 0.1473×10^4 S/cm up to 0.5393×10^4 S/cm.

Corresponding Author:

Mohd Muzafar Ismail
Faculty of Electronics and Computer Technology and Engineering, Universiti Teknikal Malaysia Melaka
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
Email: muzafar@utem.edu.my

1. INTRODUCTION

Wearable antenna is gaining exceptional popularity nowadays due to their compactness, reconfigurability, flexibility, and durability in a variety of wireless communication applications. The potential of wearable antenna in various fields such as for medical, sports, military and many more applications [1]–[5]. For example, as for medical application, these systems are capable to monitor the performance of the body movement, monitoring the heart rate and blood pressure for medical purposes by the medical team and for general network connections. In addition, wearable antenna also known as body worn antenna that mostly comfortable and widely been studied on the usage of varies fabrics as substrate [6]–[9]. Several types of fabrics are introduced including cotton, denim, leather and felt.

The vital advantage of wearable antenna is its miniature size. Because of the miniaturization it can affect the performance of antenna in terms of radiation pattern, gain bandwidth, and radiation efficiency. The miniaturization approaches are based on either the geometry or dimension manipulation (size, shape, or design) or the manipulation of material used (using high value of dielectric material and high electrical conductivity).

A co-planar waveguide (CPW)-fed antenna contains three elements: a conductor patch or radiation patch, a dielectric or substrate plane and CPW-fed. The geometry and dimensions of CPW-fed wearable antenna on top of the drill fabric substrate is presented in Figure 1. The CPW-fed is symmetrical, having same dimensions to left and right where the optimized dimension is 28×15.5 mm without the ground plane on bottom of the substrate.

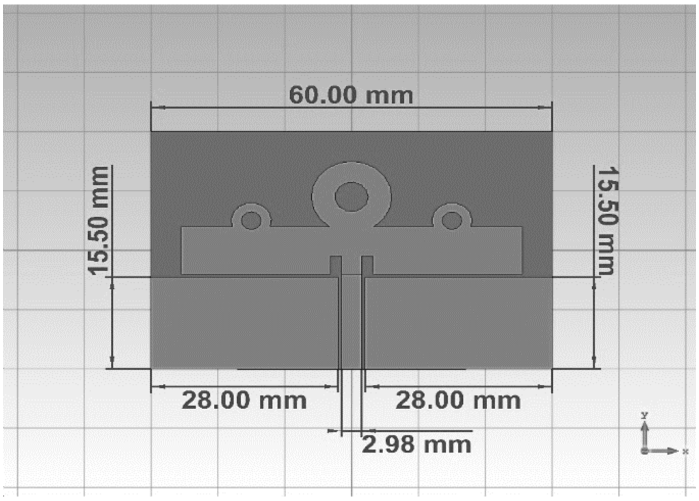

Figure 1. The dimensions of top view of CPW-fed line antenna

Silver or copper conductive ink of antennas have been reported on paper [10], [11], polyethylene terephthalate (PET) [12], and textile [13]–[15]. For the textile it was challenging due to the finite thickness of the ink layer. Chauraya *et al*. [13] reported a comprehensive review of inkjet printing that showed the efficiencies of more than 70% have been achieved. The efficiency was increased by using two layers of printing.

In this paper, the authors propose a comparison performance of variety thickness (layers) of the radiating patch (conductive ink) that printed on the drill fabric material as substrate. Since graphene has attracted interest to researchers on enhancing its properties, this research is about the hybrid of graphene with the most conductive metals silver and copper (GNP-Ag-Cu). It is due to its major potential in many applications, including electronic devices, sensors and as well as antenna [9], [16]–[20]. Wu and Drzal [21] reported a multi-layer graphene nano- platelet film with an electrical conductivity of 1.57×10^5 S/m by annealing the film that is filtered from graphite nanoplatelets suspension at high temperature. Xin *et al*. [22] used a similar method of high temperature annealing to increase the electrical conductivity to 1.83×10^5 S/m. In addition, Teng *et al*. [23] reported a multi-layered graphene film with an electrical conductivity 2.2×10^5 S/m based on ball-milling exfoliated graphene and high temperature annealing. The flexibility of multi-layer graphene film is also feasible by the reported methods and the electrical conductivity achieving a significant high electrical conductivity (around 10^4 S/cm, nearly comparable to metal) [24]. However, the conductivity of these graphene films is still much lower than that of metallic materials for silver and copper 10^7 S/m [25].

2. METHOD

This section will discuss the technique that has been implemented to the proposed topic. First the conductive ink is made by GNP-Ag-Cu. The silk screen method is used to print the conductive ink on that textile. Figure 2 shows the flowchart of technique that been used. The thickness of conductive ink is assumed based on the layering technique.

Firstly, the nanoconductive ink of GNP-Ag-Cu, the apparatus of silk screen printing (mesh frame that embedded the desired antenna design and squeegee), textile, vacuum oven, and heat press machine are prepared. The fabrication of nanocomposite ink printing process is first by placing the drill fabric substrate below the screen with a mesh count of 1,000 threads per square. Then, equally spread the small amount of ink thoroughly using 90° angle of squeegee. The printed design was cured at elevated temperatures (60 °C) for an hour to achieve the maximum conductivity of that nanocomposite ink. Next, to layering the printed textile repeat the process for the desire layers. Final process to produce the end product of wearable antenna is by hot press the printed antenna using the heat press and compress machine for setting 80 °C and 5 ton compression for 30 minutes.

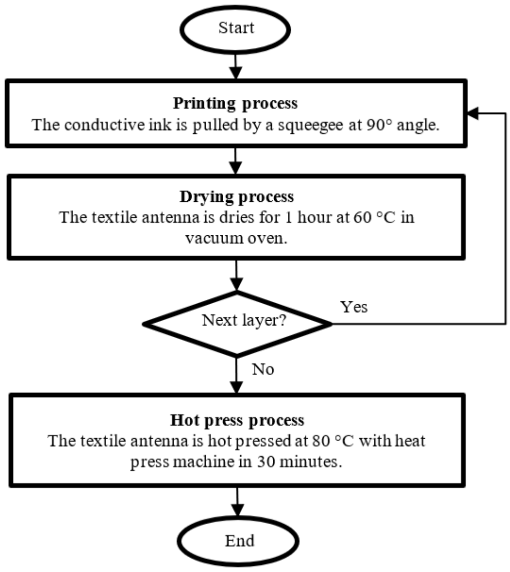

Figure 2. Flowchart of the silk screen printing process

2.1. Scanning electron microscopy and energy-dispersive X-ray spectroscopy

Scanning electron microscopy (SEM) is used to study the morphology and composition of GNP-Ag-Cu materials at the nanoscale. All the samples have been observed and analyzed by benchtop electron microscope Hitachi model TM3030 plus. In energy-dispersive X-ray spectroscopy (EDS), the sample is exposure with a beam of electrons from the SEM, causing the emission of X-rays from the atoms in the sample. The energy and intensity of these X-rays are then measured, providing information about the elements present in the sample of GNP-Ag-Cu. The images of surface morphology and the EDS spectrum presented in Figure 3. The measurements were conducted at magnifications of 1.0 kx and 5.0 kx with an accelerating voltage of 15 kV as shown in Figures 3(a) and 3(b). The presence of carbon has a highest atomic percent at 81.2 % followed with oxygen at 16.9%. Note that, this nanocomposite is a GNP-Ag-Cu, as a results signal of silver and copper also detected at 1.3% and 0.7% respectively as shown in EDS spectrum in Figure 3(c).

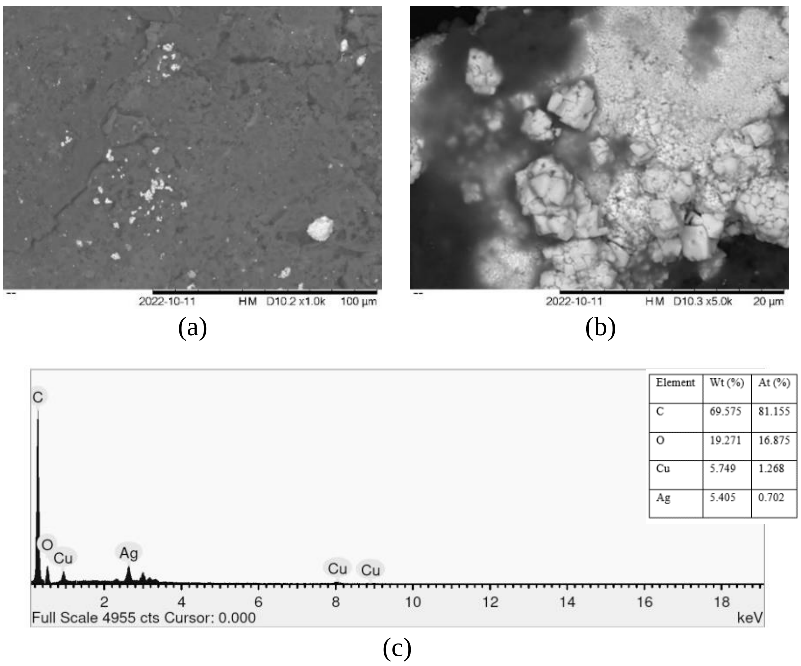

Figure 3. SEM and EDS images: (a) 1.00 kX, (b) 5.00 kX, and (c) EDS analysis of GNP-Ag-Cu

2.2. Nanocomposite electrical properties

The electrical properties of this nanocomposition are resistivity sheet, resistivity, and conductivity. The following (1) and (2) are calculated to obtain the value of resistivity and conductivity based on the resistivity sheet that tested using the four-point probe model M-3 JG square resistance tester sheet resistance meter from Suzhou Jingge Electronics Co., Ltd.

$$\rho = R_s t \quad (1)$$

Where as ρ is resistivity (Ω cm), R_s is sheet resistance (Ω/□)) and t is thickness (cm). Meanwhile for conductivity the formula as (2):

$$\sigma = \frac{1}{\rho} \quad (2)$$

Where as σ is conductivity (S/cm) and ρ is resistivity (Ω cm).

3. RESULTS AND DISCUSSION

3.1. Interface layer

The cross section and SEM images are shown in Figure 4. The sectional is divided into two (2) parts which are ink and textile. From the SEM images, it is clearly showing the segmentation of ink on the textile. For this study, the layers or thickness of the ink is based on the printed process as stated in flowchart in subsection 2. There are one (1) to five (5) layers of all samples that can be seen clearly in Figure 4. Table 1 shows the dimension and electrical properties of the conductive ink. By referring to the table, it is shown that there are increment of the thickness layer by layer from 0.135 cm up to 0.202 cm. Hence, the reduction of resistivity sheet is inversely proportional to the value of electrical conductivity where the value is from 0.1473×10^4 S/cm up to 0.5393×10^4 S/cm.

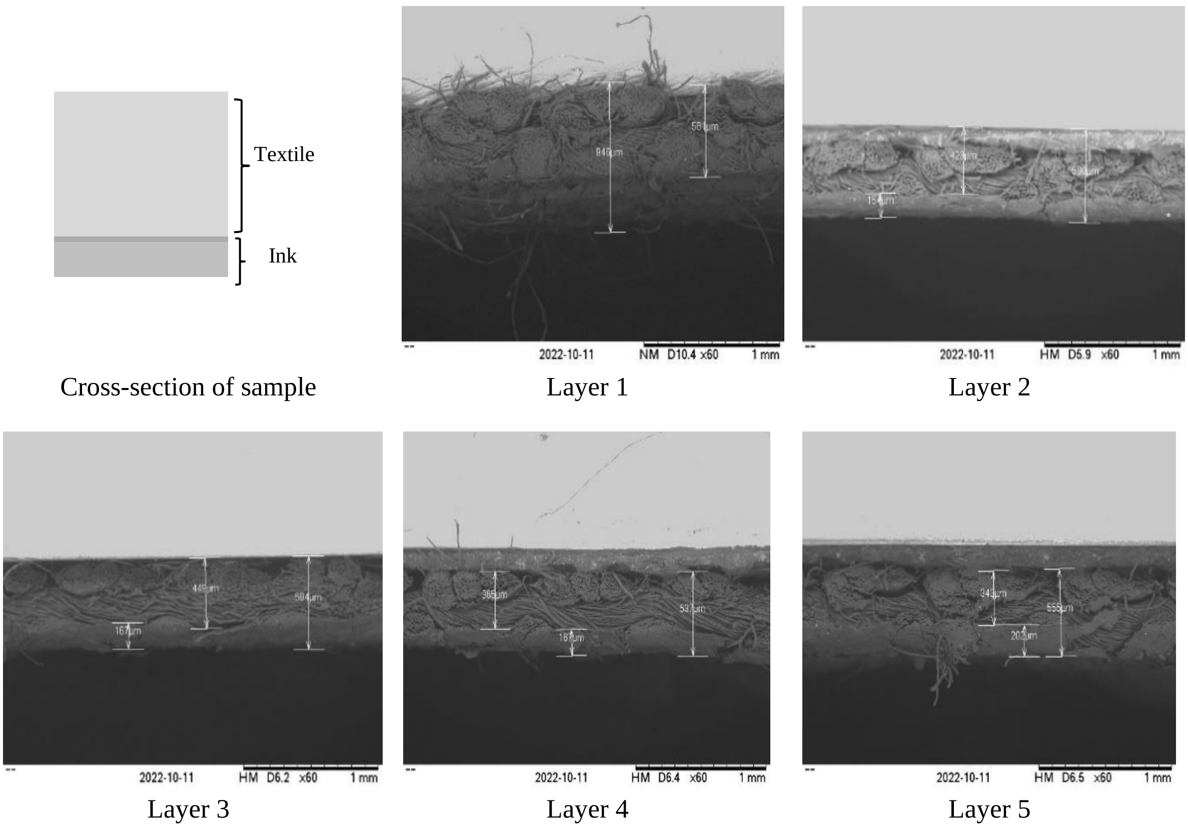

Figure 4. The cross-section and layer/s of textile by SEM

Table 1. The values of thickness and electrical properties

Sample	Thickness (cm)	Resistivity sheet (Ω/□)	Resistivity (Ω/cm)	Electrical conductivity (S/cm)
Layer 1	0.135	5.030×10^{-3}	6.79×10^{-4}	0.1473×10^{4}
Layer 2	0.154	4.320×10^{-3}	6.65×10^{-4}	0.1503×10^{4}
Layer 3	0.167	3.946×10^{-3}	6.58×10^{-4}	0.1517×10^{4}
Layer 4	0.172	2.572×10^{-3}	4.42×10^{-4}	0.2260×10^{4}
Layer 5	0.202	0.918×10^{-3}	1.85×10^{-4}	0.5393×10^{4}

3.2. Return loss antenna performance

An electromagnetic performance of the designed antenna over one (1) to five (5) layers is performed using computer simulation technology (CST) microwave studio software. The simulated return loss, S_{11} of that antenna is depicted in Figure 5. The varies radiating patch thickness is listed accordingly as stated in Table 1 and the notation of radiating patch thickness is anth (in mm). The figure implies that the antenna radiates best for 5th layer which the thickness of radiating patch is 0.202 mm at 6.943 GHz and the S_{11} magnitude of the antenna is found to be approximately -51 dB.

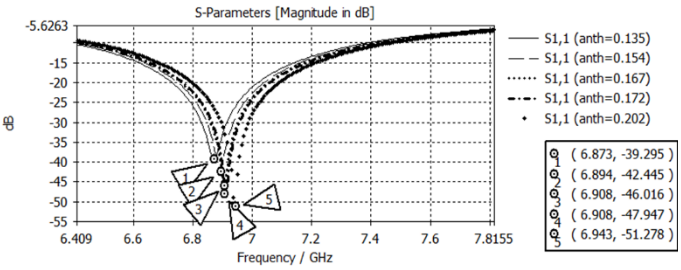

Figure 5. The antenna parameter of S_{11} for various radiating patch thickness (layer 1 to layer 5)

4. CONCLUSION

In this paper, a flexible wearable antenna for CPW-fed line on drill fabric substrate and multiple layered radiating patch using GNP-Ag-Cu conducting ink are tested and analyzed. In conclusion, increasing the thickness of the nanocomposite on a fabric can increase the electrical conductivity as stated in result from first layer up to fifth layer from 0.1473×10^4 S/cm up to 0.5393×10^4 S/cm respectively. Moreover, the antenna performance of return loss also increases due to the increases of the radiating patch thickness. For that reason, the thickness of radiating patch plays a significant parameter in designing a wearable antenna specifically for textile. On the other hand, further investigation on the antenna performance is highly recommended, to measure the effectiveness of wearable antenna including bending and its specific absorption rate (SAR). The significance of its ability to be worn, and the antenna's performance when integrated with the human body, disclosed an intriguing on-body presentation. In terms of electromagnetic properties, the human body can be considered as a lossy medium associated with high dielectric constant, which can cause frequency shifts and affects the antenna's gain and its efficiency.

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BIOGRAPHIES OF AUTHORS

Nor Hadzfizah Mohd Radi earned her diploma in Electrical Engineering Communication from Universiti Teknologi Malaysia (UTM) in 2005 and received her degree in Electrical Engineering majoring in Telecommunication in 2008 from the same university. Then, she pursued her master's in Biomedical and Artificial Intelligent (AI) areas at Control and Automation Engineering, Universiti Putra Malaysia (UPM). She is currently pursuing her Ph.D. in Electrical Telecommunication Engineering at Univeristi Teknikal Melaka (UTeM). She is also appointed as a lecturer at Universiti Malaysia Pahang Al-Sultan Abdullah (UMPSA). Her current research is on antenna design for wearable antenna using nanocomposite materials. She can be contacted at email: hadzfizah@ump.edu.my.

Mohd Muzafar Ismail received his Ph.D. in Atmospheric Discharges from Uppsala University in Sweden under the supervision of Prof. Vernon Cooray. His present research interest focuses on atmospheric discharges and specifically lightning safety. He is graduate member and professional engineer with the Board of Engineers of Malaysia. Presently, he is active in teaching, consulting and research in the field of lightning and electronics. He can be contacted at email: muzafar@utem.edu.my.

Zahriladha Zakaria is currently a professor at Universiti Teknikal Malaysia Melaka. He earned the bachelor's degree in Electrical and Electronic Engineering from Universiti Teknologi Malaysia (UTM) in 1998. In 2004, he persued master also in Electrical and Electronic Engineering course from the same university. Then, he received his Ph.D. in the field of Microwave Engineering from The University of Leeds in 2010. His research areas include RF/microwave, antenna and propagation, energy harvesting, sensors, photonics, and wireless communications. He can be contacted at email: zahriladha@utem.edu.my.

Jeefferie Bin Abd Razak received his Ph.D. in Materials Science from National University of Malaysia. His research interests are on polymer and rubber blends, diethe diploma lectric and conductive polymeric composites and polymer-based nanocomposites. He is a chartered engineer with engineering council (EC), UK and appointed as professional technologist in nanotechnology. Presently, he serves as Sr. lecturer at the Faculty of Manufacturing Engineering and is active in consultation and research in engineering materials design, testing, and optimization. He can be contacted at email: jeefferie@utem.edu.my.