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Design and Development of Textile Electrodes for EEG Measurement using Copper Plated Polyester Fabrics

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ABSTRACT

Electrically conductive polyester fabrics are investigated in this work in order to develop textile electrodes for Eelectroencephalogram (EEG) measurement. Electrically conductive polyester fabrics have been prepared by electroless copper plating method. These fabrics are then characterized by SEM and XRD. The electrical conductivity of the fabric samples is also studied. The structural studies show that the crystalline region of fabric structure is not affected by the plating. The SEM studies reveal a very uniform deposition of copper on the fabrics. The conductivity studies show that the treated fabrics have good electrical conductivity.

The developed copper plated fabric was used to develop the textile electrodes for Eelectroencephalogram (EEG) measurement. The acquired signals were compared with commercially available electrodes and the signals were found to be similar. The good measurement performance exhibited by the textile electrodes indicates that they are feasible candidates for EEG recording, opening the door for long-term EEG monitoring applications.

Keywords: Electroless copper plating, electrodes, Electroencephalogram, polyester fabric, surface resistance

I. INTRODUCTION

The developments of smart textiles guide a new direction for conventional textiles. Besides the traditional functions, people would like to enable new capabilities in textiles. Among these new developments of smart textiles, fabric-based sensors play an important role. Considering that textiles have a direct connection with the human body, the most important function of the smart textiles is focused on protecting human health, is called e-medicine or telemedicine [1]. Over the past few years, a number of wearable physiological monitoring systems have been developed for health monitoring of patients in hospitals and real life situations. The wearable sensing systems aid the daily acquisition and processing of multi-parametric health data, providing an early detection of pathological signs and improving the curative rate of disease without intervening in the patient's daily life [2].

EEG is a kind of method to measure electrical activities of the brain by using electrodes along the scalp skin. It is also a powerful noninvasive tool and can provide high temporal resolutions to reflect the dynamics of brain activities directly. It has been widely used for both medical diagnosis and neurobiological researches. Today disposable Ag-AgCl electrodes are most commonly used in EEG-measurements. As the outer layer of the skin has a dry dielectric layer, which is called stratum corneum and will cause reduction of the transfer mechanism from ions to electrons. The Ag/AgCl electrode cannot be used directly, and hence is used as a wet electrode with the help of a conduction gel that moisturizes the skin outer layer and makes it highly ion conductive. Because the few-polarizable Ag/AgCl electrode is usually used as the conventional wet electrode, conduction gel has to be applied to moisturize the skin outer layer and change it to a highly ion-conductive layer. However, this procedure is very cumbersome and also presents difficulty for the patient. Also, there is possibility that the gel may leave a residue on the skin. Further, there is a possibility of short circuit of the electrodes when they are in close proximity and when excess gel is applied. Another weak point is the short operating time of the electrode and one time use .Moreover, these aforementioned preparation procedures are time consuming, uncomfortable, and even painful for patients, since the skin preparation usually involves the abrasion of the outer skin layer. Repeated skin preparations and gel applications may also cause allergic reactions or infections. In addition the EEG signal quality may degrade over an extended time period as the skin regenerates and /or the conduction gel dries.

Textile electrodes are electrodes type, which are made from fabric. Normally, textile materials are insulators, but in the textile electrodes conductive yarn is attached to the fabric during their manufacturing process. These electrodes do not need gel to achieve connection to the skin. The textile electrodes can be made by weaving, knitting or embroidering conductive yarn to the structure. The conductive yarn can be made for example by silver coating yarn or metal filaments can be braided into yarn. The textile electrode materials are typically synthetic, for example polyester or polyamide. They endure abrasion very well, absorb moisture only a little and dry fast. The textile electrodes are good for a long time measurement, because they do not irritate skin. In addition, they are lightweight, ductile and washable.

Beckmann *et al.* (2010) have investigated the characterization of fabric electrodes with different fabric specifications for ECG measurement in detail [3]. Chin-Teng Lin *et al* developed and experimentally validated a novel dry foam –based textile electrode for long-term EEG measurement. They fabricated a novel dry foam textile electrode, using electrically conductive polymer foam covered by a conductive fabric. They reported that dry foam electrode exhibits both polarization and conductivity due to the use of conductive fabric, which provides partly polarizable electric characteristic, and can be used to measure biopotentials without skin preparation and conduction gel. In addition, the foam substrate of dry electrode allows a high geometric conformity between the electrode and irregular scalp surface to maintain low skin–electrode interface impedance, even under motion [4 & 5].

Conductive textiles, which are coated with aluminum, copper, silver and nickel, are important types of material. Currently, developed metal coating techniques are metal foil and laminates, conductive paints and lacquers, sputter coating, vacuum deposition, flame and arc spraying, and electroless plating. Among them, electroless plating is probably a preferred way to produce metal-coated textiles. The electroless deposition method uses a catalytic redox reaction between metal ions and dissolved reduction agent. With its remarkable advantages, such as low cost, easy formation of a continuous and uniform coating on the surface of substrate with complex shapes, it can be performed at any step of the textile production, such as yarn, stock, fabric or clothing [6]. With regards to the high conductivity of copper, electroless copper plating is currently used to manufacture conductive fabrics.

The objective of this study is to apply the electroless copper plating to the preparation of conductive PET fabrics and investigate properties of deposits such as the crystal structure, surface morphology and electrical resistance. Then to develop the textile electrode for EEG measurement using the copper plated fabric. Our goal with this paper is to show that the weak EEG signal can be captured using soft textile electrodes, with sufficient quality for quantitative analysis. We made simple tests, investigating if conductive textile electrodes of the same size as the standard electrodes, applied without any skin preparation can be used to confidently record EEG signals.

II. EXPERIMENTAL

A. MATERIALS

Polyethylene terephthalate (PET) fabric (GSM 117) was used as substrate. The surface area of each specimen is 100 cm^2. The chemicals used for the electroless copper plating included Stannous Chloride (anhydrous min. 99.9%), Hydrochloric Acid (37%), Silver Nitrate (99.9%), Sodium Hydroxide (99.3%), Ammonium Solution (28%), Copper Sulfate, Formaldehyde and Potassium Sodium Tartrate . All reagents were of analytical grade.

B. METHODS

I. ELECTROLESS COPPER PLATING

Electroless copper plating was carried out through multistep processes, including pre-treatment, sensitization, activation, electroless copper plating, post-treatment for stopping copper reduction, rinsing and drying.

All fabric samples were subsequently rinsed with 5% detergent at room temperature for 20 min. The samples were then rinsed in deionized water. Surface sensitization was conducted by immersing the samples into an aqueous solution containing 10 g/L $SnCl_2$ and 40 mL/L 38% HCl acid at 25 °C for 10 min. The specimens were subsequently rinsed in deionized water and activated by immersing them into a solution containing $AgNO_3$ (10 g/L) and 28% NH_4OH (10 mL/L) at 25 °C for 20 min. Afterwards, the specimens were rinsed in a large volume of deionized water for more than 5 min to prevent contamination of the plating bath. The specimens were consequently immersed in the electroless copper plating bath at 30 °C for 20 min. The bath was composed of 15 g/L $CuSO_4$ $5H_2O$, 20 mL/L HCHO (37% aqueous solution), 40 g/L $NaC_4H_4O_6$ $4H_2O$, 10 g/L NaOH. In the post-treatment stage, the samples were rinsed with deionized water at 40 °C for 20 min and dried in an oven at 60 °C. All the copper-plated fabrics were conditioned in accordance to the ASTM D1776-04 before measurement [6, 7 & 8].

II. CHARACTERIZATION

The XRD patterns were recorded by Shimadzu XRD- 6000 X-ray diffractometer unit. The SEM images were recorded by JEOL SEM (model JSM- 6360) to study the surface morphology of the control and copper plated samples in the longitudinal view.

Electrical resistance measurements were performed on all samples after conditioning the samples in a standard atmosphere. The resistance was measured ten times on each side of the sample and the average values were taken. The American Association of Textile Chemists and Colorists (AATCC) test method 76-1995 was used to measure the resistance of the samples and the surface resistivity of the fabric was calculated as follows:

$$R = R_s (l / w)$$

where R is the resistance in ohms; R_s, the sheet resistance or surface resistivity in ohms/square; l, the distance between the electrodes; and w, the width of each electrode [1,12].

III. TEXTILE ELECTRODE DESIGN

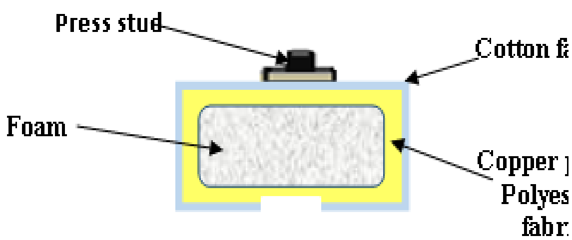


Figure 1. Design of textile electrode

The textile electrode has been designed using a layered structure with conductive and non-conductive fabrics as shown in Figure 1. A layer of foam has been placed between the folded layers of conductive fabric to ensure that a conductive layer of fabric is pressed against the skin on the front side of the electrode. Another reason to include the foam is to avoid any mechanical influence from the press-stud placed on the backside of the electrode. A non-conductive fabric, made of cotton, with a centered hole with diameter of 2 cm on the front side has been placed above the conductive fabric to make the conductive surface of the electrode in contact with the skin of similar size as the surface of the commercial silver electrodes [11].

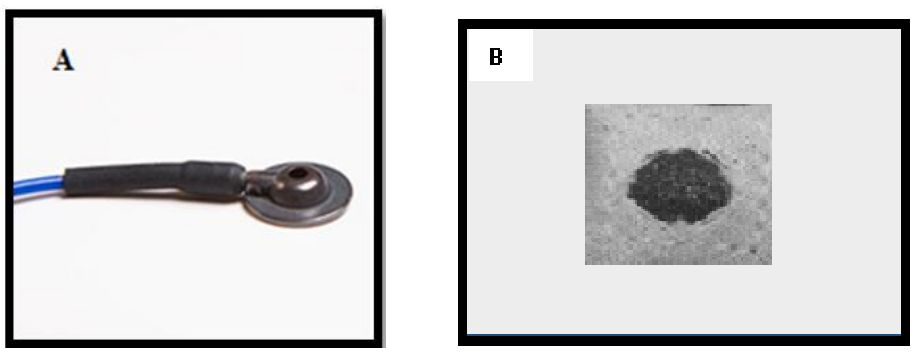


Figure 2. (a) Standard electrode. (b) Textile electrode

IV. EEG ELECTRODE PLACEMENT

A method called the 10-20 system has been developed for placement of electrodes on the scalp during EEG recordings. The 10 and 20 in the name refer to the percent distances that the electrodes are from each other in proportion to the size of the head. The 10-20 system relates the locations on the scalp to the locations of the cerebral cortex. The electrode locations used in the 10-20 system are indicated with a letter followed by a number. The letters that are used include F, T, C, P, and O. These letters correspond to frontal, temporal, central, parietal, and occipital, respectively. These are all lobes of the brain except for the central location. The number in the indicated position corresponds to the left or right side of the head. Even numbers are located on the right hemisphere while odd numbers are on the left. Some letters are followed by a Z instead of a number. The Z indicates the midline of the head. The following diagram illustrates these standard electrode positions:

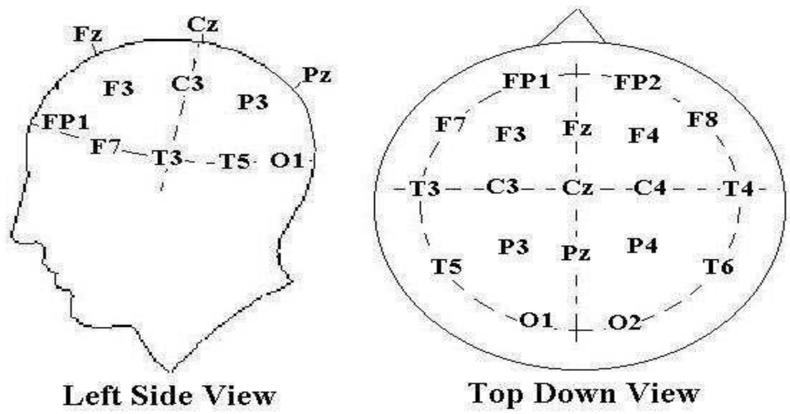


Figure 3. The 10-20 system of electrode placement

V. EEG MEASUREMENT

ECG wave forms were recorded using RMS EEG monitoring equipment with 30 mm / sec. speed. A tight-fitting headband was used to hold the electrodes in the forehead sites and FP1, and FP3 according to the international 10–20 system. The electrodes were padded in order to ensure a smooth surface and a soft pressure. They were connected using cables with crocodile clips and snap buttons. Standard electrodes were used for other positions. The setup can be seen in Figure 4.

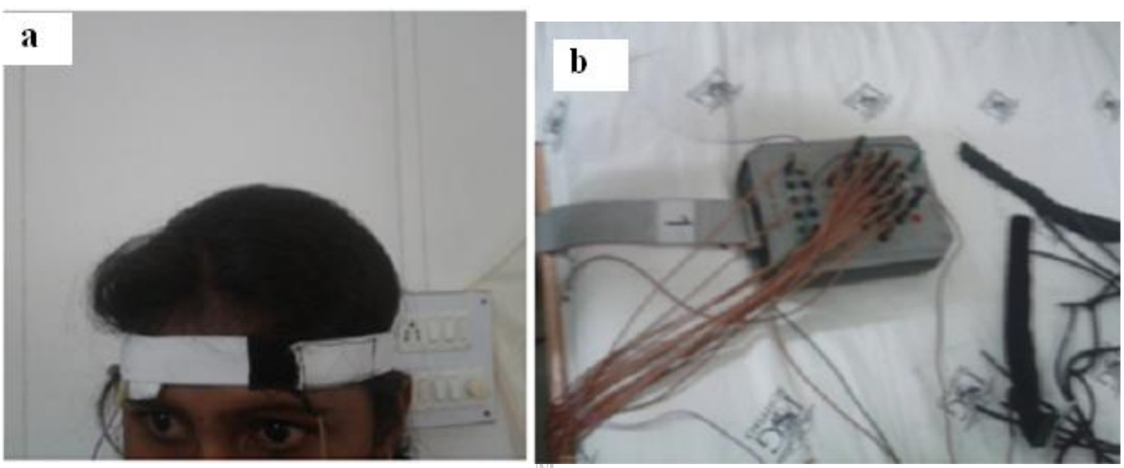


Figure 4. Experimental setup. (a) The subject with EEG electrode head band. (b) RMS EEG monitoring equipment

III. RESULTS AND DISCUSSION

A. SEM STUDIES

The surface views of SEM micrographs of the control and copper plated polyester fabrics are shown in Figure 5. In comparison with Figure.5 a, it was obvious that after copper plating, the surface of polyester fibers had significantly changed as shown in Figure.5 b. Polyester fibers were covered with copper particles which were clearly visible and the copper particles were well dispersed on fiber surfaces with the present electroless plating method. The coating was also evident at the macroscopic level in terms of the increased thickness of fabric from 0.20 mm to 0.22 mm and increased weight of the fabric from 1.17 Gms to 1.24 Gms after coating [9&10].

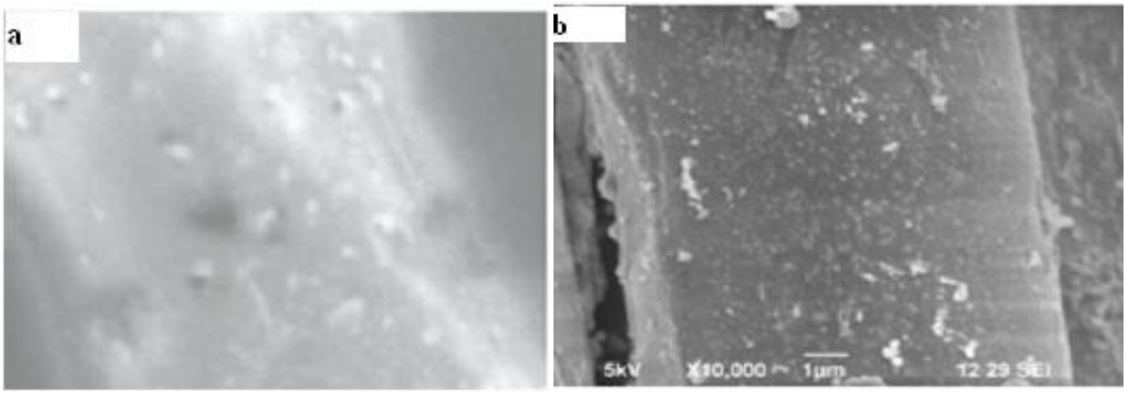
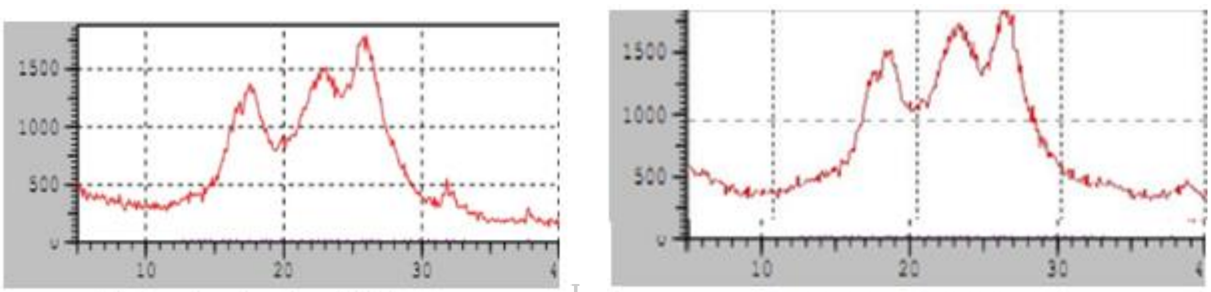


Figure 5. SEM image of control and copper plated polyester fabrics

B. WAXD ANALYSIS

Figure 6 shows the X-ray diffraction patterns of copper plated polyester samples. The X-ray diffraction pattern of the control polyester fabric shows peak maxima at 2θ values of 17.5, 23 and 25.7. The peak maxima of copper plated fabrics are found to be located at 2θ =17.7, 22.8 and 26.0, and the values are slightly shifted. The above changes in characteristic peaks indicate the deposition of copper over the polyester.



Control polyester fabric

Copper plated polyester fabric

Figure 6. XRD pattern of control and copper plated polyester

C. ELECTRICAL PROPERTIES

Surface resistivity is a material property that is normally considered constant and ideally independent of measurement technique. Surface resistivity measurement is often used to characterize fabric resistivity and is typically reported as ohm/square. We studied the electrical resistivity of the copper plated fabrics by two probe resistivity measurement in a normal environment at 65% RH. The copper plated fabrics have good electrical conductivity with the resistance value of 300 K ohm/sq.

D. EEG MEASUREMENT

Figure 7 shows the EEG signals acquired using the developed textile electrode in FP1 and FP2 positions and standard medical electrodes with conduction gel in other positions. In the graph, the waves FP2-F4, FP2-F8, FP1-F3 and FP1-F7 are obtained from the textile electrodes. The EEG wave patterns acquired by using our dry textile electrode are almost identical to that of the conventional wet electrode. Based on this comparison, results showed that the proposed dry electrode presents the quite different but effective way to acquire biopotentials than wet one. Evidently, our dry textile electrode is soft enough to contact the skin properly, and the fabric layer is very stable [10, 11&12].

Our dry textile electrode obviously provides lower skin–electrode interface impedance because the softness of the textile substrate can help to adapt to the scalp effectively when the suitable force is applied. By attaching the dry textile electrode with a little pressure, its elasticity will stabilize the contact both horizontally and vertically. The major merits of our developed textile electrode include the following: 1) without skin preparation and conduction gel, it can be applied for long-term EEG measurement; 2) it is able to adapt to irregular scalp surface and even the hairy sites to maintain low skin–electrode interface impedance; and 3) the fabrication process is of low cost.

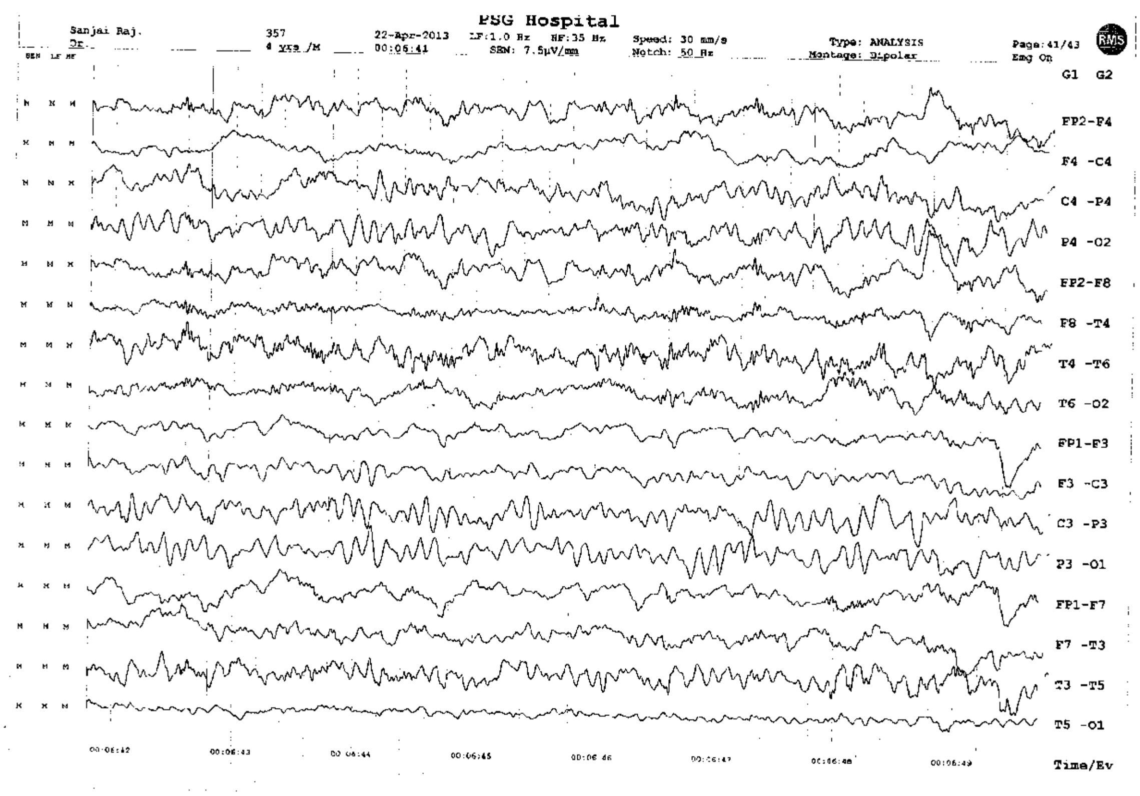


Figure 7. The real time trace of EEG measurement

IV. CONCLUSIONS

Copper was found to be successfully deposited on polyester fabrics by means of electroless plating. The deposited copper was systematically characterized by SEM and XRD.

A novel dry textile EEG electrode is developed and fabricated using the developed copper plated fabric.

Our results show that soft textile materials can be used for high quality recordings of EEG signals, at least for subjects without very thick hair. We believe that this kind of electrodes could greatly improve a neonatal monitoring system. It might also be useful for e.g., ambulating monitoring of adult subjects, brain-computer interfaces or detection of drowsiness in drivers by making it more convenient and comfortable for the wearer, this way facilitating its acceptance.

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