Design of Electroencephalogram Sensor for Long-Term Bio-signal Measurement

Prajith R. P.
PG Scholar, Department of Electronics and Instrumentation
Noorul Islam University, Kumaracoil, Tamilnadu, India

Ganesan R.
Professor, Department. of Electronics and Instrumentation
Noorul Islam University, Kumaracoil, Tamilnadu, India

Gobalakrishnan S.
Assistant Professor, Department of Nano Technology
Noorul Islam University, Kumaracoil, Tamilnadu, India

Abstract- The Electroencephalography (EEG) is a medical recording technique that neurologists use to investigate neurological disorders. EEG analysis is particularly useful for the diagnosis of neurological disorders like epilepsy. Dry active electrodes have been analysed as an alternative to the silver/silver chloride electrodes as they can be applied without any skin preparation or gel application, a dry electrode for long-term EEG measurement is proposed in this thesis. In general, the conventional wet electrodes are most frequently used for EEG measurement. However, they require skin preparation and conduction gels to reduce the skin–electrode contact impedance. When these procedures with wet electrodes used, it usually makes trouble to patients easily. In order to overcome the issues, a CNT/PDMS composite flexible dry electrode is proposed and can be used to measure bio-potentials without skin preparation and conduction gel. Electrode properties are the key to the quality of measured bio-potential signals. So it is very important to identify the nature of the CNT and PDMS materials separately. Transmission Electron Microscopy is done for analysing multiwalled carbon nanotube. The impedance measurement is done using the LCR meter and compares it with the conventional Ag/AgCl electrode and came to the conclusion that the CNT/PDMS composite electrode has the impedance very less than that of the conventional one. The EEG electrode is fabricated using CNT/PDMS composite of diameter 40 mm and thickness 3mm. EEG acquisition is done by placing two electrodes at the frontal lobe Fp1 and Fp2 for Alpha and Beta wave. This electrode may be used for the long-term measurement of other biosignals for ubiquitous health monitoring.

Keywords - Bio-composite, CNT/PDMS, Biomedical sensor, EEG sensor.

I. INTRODUCTION

The electroencephalogram is a record of the electric signals generated as the result of brain activity. Typical signal bandwidth ranges from 1Hz to 100 Hz and amplitudes varies from 1mV to 100 mV. The silver/silver chloride (Ag/AgCl) electrodes have been the main choice of physicians for a long time to monitor such signals due to their low skin hypersensitivity, good stability and signal reproducibility. When the exam requires long-term monitoring (epilepsy monitoring or eye tracking for surgery) the electrodes have to be periodically refilled with the gel, skin re-growth degrades the signal quality and allergic reactions to the gel have been reported. Also the electromagnetic interference during electrode-to-recorder signal transmission can be an important noise source, due to the low amplitudes of the signals involved. Alternatives to these electrodes are the dry active electrodes. They have an impedance converting device at the sensing site that increases the signal power just after its detection. The improved sensitivity of the dry active electrodes allows them to be used without any skin preparation or gel application. The sensor material can be either an inert metal, like platinum, gold or stainless steel or an insulator. In both cases there is a capacitive coupling between the skin and the electrode, meaning that the signal is transferred to the sensor by a capacitive-like conduction process. Some problems related with degradation of the sensor materials in contact with skin sweat, leading to biosignals degradation. The choice of the sensor material is very important in the dry electrode design.

Recent progress in technology has enabled the continuous monitoring of personal health regardless of a patient's location. The rapid improvement of smart phone technology is predicted to enhance the quality of ubiquitous (U)-health care by providing high levels of patient autonomy. To achieve convenient health monitoring, the development of a long-term wearable bio-electrode is critical. Electroencephalography is a key bio-signal that requires constant monitoring, and the bio-electrode most commonly used to monitor EEG is a gel-type silver/silver chloride (Ag/AgCl) electrode. Although such electrodes have been widely used, they are limited in their long term use because they can irritate the skin. The gel also dries over time, causing a dramatic decrease

in the signal quality. As replacements of conventional Ag/AgCl electrodes for long-term monitoring applications, dry surface electrodes have been considered because they do not require an electrolyte layer [1]-[5]. Several dry electrodes have been developed using metallic materials, they have been limited in their practical use due to high electrode-to-skin impedance, poor biocompatibility, and variations in the contact area during motion. The fabrication of soft polymer-based EEG dry electrodes for long-term wearability has previously been proposed [6]-[9]. Our previous electrodes were patterned on the polydimethylsiloxane (PDMS) substrate using metal deposition and patterning based on silicon processes, and they were packaged with a wristband to facilitate easy wearing. Although previous researches overcome several problems associated with dry electrodes, the fabrication process was complicated and required a clean room and metal deposition facilities. In addition, the incompatibility between PDMS and the metal tended to cause failures in stable bonding of the thin metal layers and motion artifact was higher than commercial Ag/AgCl electrodes. Fernandes proposed fabrication of an EEG electrode encapsulated in a nickel-PDMS composite substrate to enable the inductive measuring of EEG signals. The signals were stably measured, but the fabrication process required skilled manual and the EEG signal did not clearly capture the waves. In addition, the biocompatibility of the nickel composite was not fully proved. In this paper, we propose a CNT/PDMS composite-based EEG electrode that can be readily connected to the conventional EEG device.

PDMS has good elastic properties, is flexible, and is optically transparent [10]. PDMS has become a popular choice for biomedical applications for its nontoxicity, high gas, and water permeability [11],[12] and is amenable to a variety of fabrication methods. CNTs have excellent mechanical, electrical, and thermal properties and are good in the biomedical applications. For these reasons, CNTs have been widely used in industrial and biomedical applications. Therefore, CNT/PDMS composites, which combine the characteristics of both materials,[13],[14] may have great potential in the biomedical field.

II.METHODOLOGY

A. PDMS Mold Preparation Procedures

PDMS mold preparation is carried out by using the Sylgard 184 Silicone Elastomer Kit. The preparation techniques involved various steps, those are elaborately discussed below.

Step 1 Pre-heat oven to approximately 100 degrees.

a. To cure the PDMS, the oven was set at 100^{o}C and maintained the same.
b. We use a small hot air oven with a precise temperature scale

Step 2 Make the arrangement for the mold preparation

a. A piece of acrylic sheet was taken and made it into the desired circular shape as equal to the electrode size. We used 40 mm Dia as electrode material.
b. Taken a petri dish of diameter 50mm.
c. Place the circular acrylic of at the center of the petri dish.
d. Place the steel snap at the top of the acrylic sheet to make the contact for the electrode.

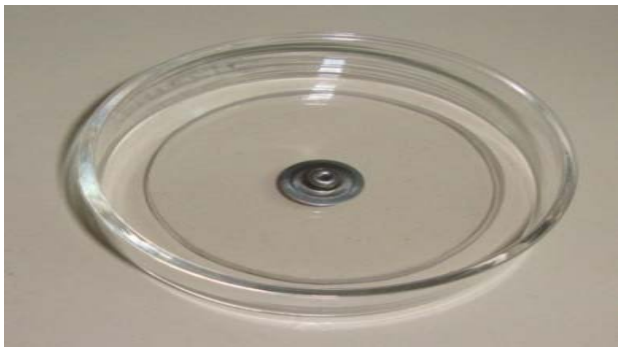

Figure 2.1 Acrylic Disc and Steel snap placed in a petri disc

Step 3 Mix the elastomer with the curing agent**.**

a. Pour a desired amount of elastomer and the curing agent into a clean container.
b. The elastomer and curing agent will be mixed at a 10 parts to 1 part ratio (10:1).

Figure.2.2. Mixing PDMS and Curing agent

c. Thoroughly mix the elastomer with the curing agent for a few minutes using mechanical force only. Here we are using mechanical stirrer for the mixing process. Keep the solution for some time until almost all the bubbles disappear from the solution.

Step 4 Pour PDMS to the Petri dish.

a. Once almost all the bubbles have cleared from the mixture pour it to the petri dish that already prepared.
b. Fill to the top of the steel snap so that there is an even surface.

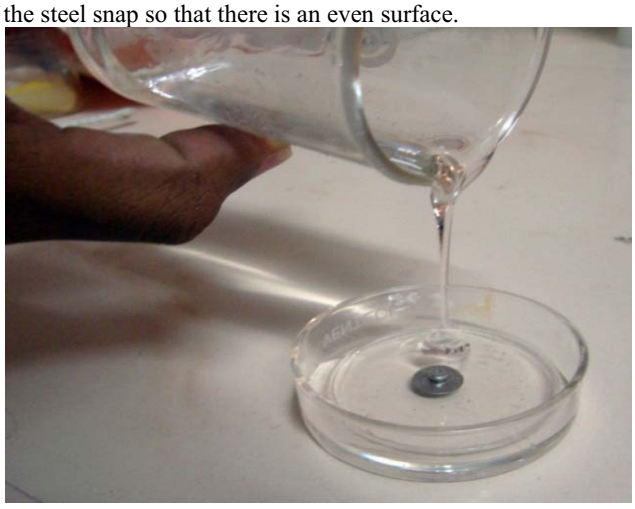

Figure 2.3.Pouring PDMS to the petri dish

Step 5 Bake PDMS in the oven.

a. Carefully place the PDMS mold into the oven. A flat paper or aluminum foil layer placed underneath the molds is a good idea just in case the PDMS overflows and sticks to the oven surface.
b. Let the samples bake for approximately 10-15 minutes, then check on the test mold by poking it with a toothpick. If it is solid then take sample out, but if it is still slightly liquid the leave in for a few more minutes.
Heat Cure 45 Minutes @ 100 Deg C

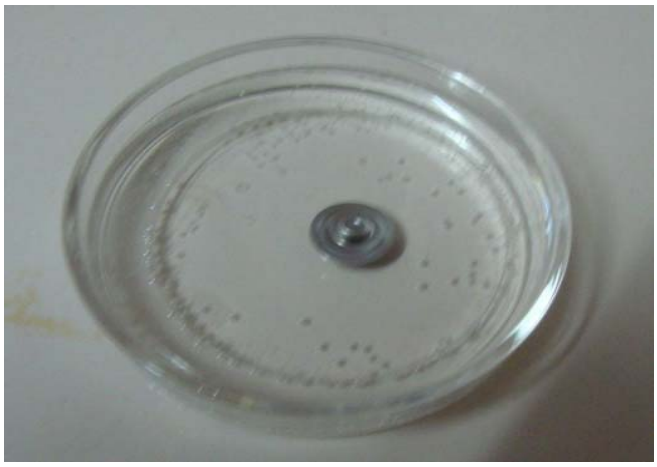

Figure 2.4. Cured PDMS mold

c. Remove fully cured PDMS samples from the oven and put them in room temperature for a few minutes. This will shrink the PDMS slightly and will help when peeling the samples delicately out of their molds.

d. Careful use of a scalpel blade can separate the PDMS from a side of the mold wall so that the rest can be pulled gently from the mold.

B. CNT Dispersion in PDMS

Step 1 Weighing the PDMS
a. Place a clean glass container on the electronic weighing machine.
b. Make the readings into zero by pressing tare switch.
c. Pour the PDMS and the curing agent into the beaker.
d. Measure up to the desired level. Here we are taking 5mg of PDMS.

Step 2 Weighing the CNT
a. Place a butter paper on the electronic weighing machine.
b. Make the reading into zero by pressing tare switch.
c. Adding the CNT to the weighing machine using steel...
d. Measure up to the desired level. Here we are taking 0.2 mg of CNT that means 4wt%.

Step 3 CNT Dispersion
a. Place the beaker that containing the PDMS under the stirrer.
b. Switch ON the stirrer and make it in a very slow speed.
c. Adding the CNT slowly while the mixture is stirring.
d. Make the stirring for some time, at least 15 to 20 minutes, so that the CNT dispersed in the PDMS completely.

Figure 2.5. CNT Dispersion in PDMS

C. CNT/PDMS Composite Electrode Preparation

Step 1 Pouring the Mixture into the mold

a. Pouring the CNT dispersed PDMS mixture into the PDMS mold that we have already prepared.

Figure 2.6 Filling mold with mixture

b. Keep the solution for some time until almost all the bubbles disappear from the solution.

Step 2 Bake it in the Oven

a. Carefully place it into the oven. A flat paper or aluminum foil layer placed underneath the molds is a good idea just in case the PDMS overflows and sticks to the oven surface.

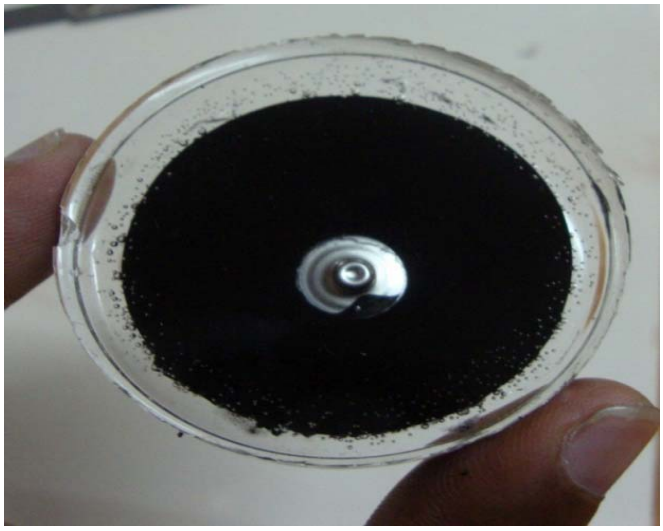

Figure 2.7 Cured mold with Electrode

b. Let the samples bake for approximately 10-15 minutes, then check on the test mold by poking it with a toothpick. If it is solid then take sample out, but if it is still slightly liquid the leave in for a few more minutes.
Heat Cure 45 Minutes @ 100 Deg C
c. Remove fully cured PDMS samples from the oven and put them in room temperature for a few minutes. This will shrink the PDMS slightly and will help when peeling the samples delicately out of their molds.

D. Separation of the Electrode from the Mold

a. When the mold is cooled down then we can make the separation easier.
b. Careful use of a scalpel blade can separate the electrode from a side of the mold wall so that the rest can be pulled gently from the mold.

Figure 2.8. Composite Electrode

III.RESULTS AND DISCUSSION

A. TEM Analysis of CNT

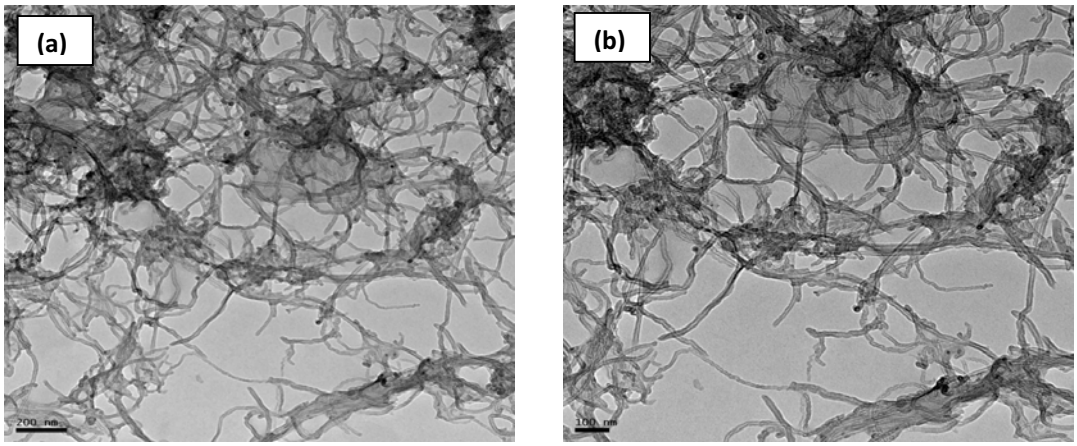

Figure 3.1 TEM image of CNT

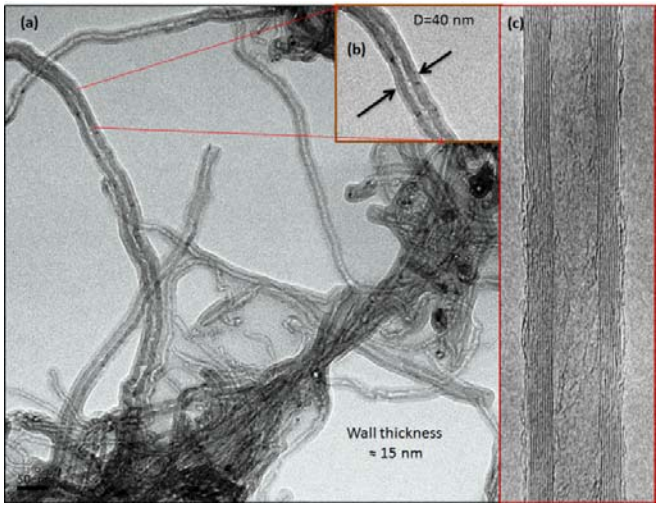

Figure 3.2 Detailed investigation of Multiwall Carbon Nanotube

The Transmission electron microscope confirms that the uniform tubular structure of carbon nanotube. The image was taken with different resolution. The Fig 3.1 (a) & (b) showed 200 nm and 100 nm resolution images respectively. It is observed that the CNT has approximately 10 micrometer long with 40 nm diameter.

The Figure 3.2 viewed at highest resolution at 50 nm; obviously it shows the diameter of the CNT and multiwall structures. The insight image Fig 3.2(a) showed the tubular structure very clearly, wall thickness was calculated approximately 15 nm and assumed that the multiwall contains eight to twelve single wall CNT as coaxial.

B. Impedance Measurement

The impedance measurement is done using the LCM meter and the graphs are plotted in Figure 3.3 From the graph it can be seen that the impedance of the CNT/PDMS electrode decreases with the decrease in the frequency. The Figure 3.10 shows the impedance graph with respect to the frequency. The impedance is maximum at 100 Hz frequency and it is only 75Ω, at the same time the impedance of the Ag/AgCl electrode is more than 20 kΩ.

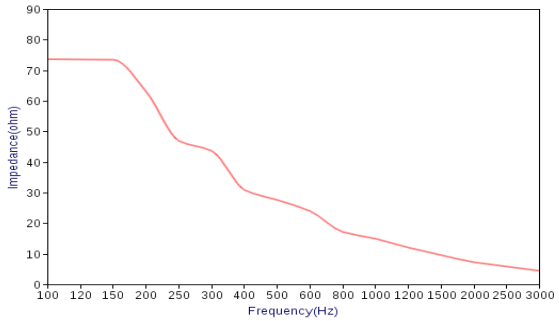

Figure 3.3 Impedance response

C. Experimental Results

The experiment is done with MADICAID-E24 EEG measuring instrument. There were two CNT/PDMS composite electrodes were placed at Fp1 and Fp2 electrode point on the skull. The Figure 3.4 is the EEG waveform recoded using CNT/PDMS EEG sensor. The conventional Ag/AgCl electrodes were used as the reference electrodes and the ground electrode.

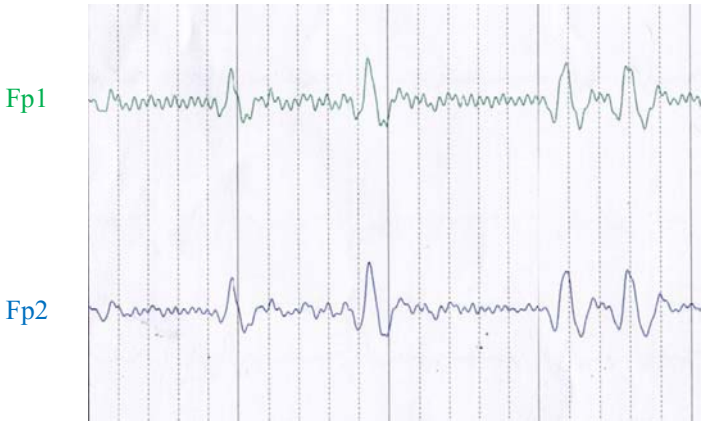

Figure 3.4 CNT/PDMS EEG Sensor Response

Figure 3.4 shows the EEG wave forms that have been taken using two electrodes placed on the Fp1 and Fp2 positions in the 10-20 electrode placement system. Alpha waves are recorded in between 7.5 and 13 Hz frequency from the Fp1 and Fp2 positions. Here the alpha wave has four peaks in both electrode outputs when the patient is in eye opened position.

IV.CONCLUSION

Fabrication of the CNT/PDMS composite electrode has been done. The TEM analysis of the CNT has also done. Possible measurement of the EEG signal has also done. The electrode did not generate any noticeable side effects, such as itching or irritation. The impedance measurement is done using the LCR meter and compares it with the conventional Ag/AgCl electrode and came to the conclusion that the CNT/PDMS composite electrode has the impedance very less than that of the conventional one. It is expected that the fabricated CNT/PDMS composite electrodes can be used in daily life to enable ubiquitous mobile health care technology. The reusability of the electrode will contribute to preserving the environment by reducing the waste of used electrodes.

V.ACKNOWLEDGEMENT

The authors would like to thank the Noorul Islam University, the department of Electronics and Instrumentation and the department of Nano technology for their support and facilities provided.

REFERENCES

[1] A. Karilainen, S. Hansen, and J. Muller, "Dry and capacitive electrodes for long-term ECG monitoring," in *Proc. 8th Annu. Workshop Semicond. Adv. Future Electron.*, Nov. 26, 2005, pp. 155–161.

[2] S. Mason. (2005). Dry electrode technology: What exists and what is under development? [Online]. Available: http://www.bci-info.tugraz.at/ Research_Info/research_forums/signals/0002/

[3] G. Ruffini, S. Dunne, E. Farres, J. Marco-Pallares, C. Ray, E. Mendoza, R. Silva, and C. Grau, "A dry electrophysiology electrode using CNT arrays," *Sens. Actuators A, Phys.*, vol. 132, no. 1, pp. 34–41, 2006.

[4] G. Ruffini, S.Dunne, L. Fuentemilla, C. Grau, E. Farres, J. Marco Pallares, P. C. P. Watts, and S. R. P. Silva, "First human trials of a dry electrophysiology sensor using a carbon nanotube array interface," *Sens. Actuators A, Phys.*, vol. 144, no. 2, pp. 275–279, 2008.

[5] J. Muhlsteff and O. Such, "Dry electrodes for monitoring of vital signs in functional textiles," in *Proc. 26th Annu. Int. Conf. IEEE Eng. Med. Biol. Soc.*, 2004, pp. 2212–2215.

[6] J. Y. Baek, J. H. An, J.-M. Choi, K.-S. Park, and S.-H. Lee, "Flexible polymeric dry electrodes for the long-term monitoring of ECG," *Sens.Actuators A, Phys.*, vol. 143, no. 2, pp. 423–429, 2008.

[7] M. S. Fernandes, K. S. Lee, R. J. Ram, J. H. Correia, and P. M. Mendes, "Flexible PDMS-based dry electrodes for electro-optic acquisition of ECG signals in wearable devices," in *Proc. Annu. Int. Conf. IEEE Eng. Med. Biol. Soc.*, 2010, vol. 2010, pp. 3503–3506.

[8] L. Geddes and M. Valentinuzzi, "Temporal changes in electrode impedance while recording the electrocardiogram with 'dry' electrodes," *Ann. Biomed. Eng.*, vol. 1, no. 3, pp. 356–367, 1973.

[9] P. Griss, P. Enoksson, H. K. Tolvanen-Laakso, H. K. Merilainen, S. Ollmar, and G. Stemme, "Micromachined electrodes for biopotential measurements," *Microelectromech. Syst., J.*, vol. 10, no. 1, pp. 10–16, 2001.

[10] H. Cong and T. Pan, "Photopatternable conductive PDMS materials for microfabrication," *Adv. Functional Mater.*, vol. 18, no. 13, pp. 1912–1921, 2008.

[11] S. Charati and S. Stern, "Diffusion of gases in silicone polymers: molecular dynamics simulations," *Macromolecules*, vol. 31, no. 16, pp. 5529–5535, 1998.

[12] A. Folch and M. Toner, "Cellular micropatterns on biocompatible materials," *Biotechnol. Prog.*, vol. 14, no. 3, pp. 388–392, 1998.

[13] L. Ci, J. Suhr, V. Pushparaj, X. Zhang, and P. M. Ajayan, "Continuous carbon nanotube reinforced composites," *Nano Lett.*, vol. 8, no. 9, pp. 2762–2766, 2008.

[14] W. Xu, M. Kranz, S. Kim, and M. G. Allen, "Micropatternable elastic electrets based on a PDMS/carbon nanotube composite," *J. Micromech. Microeng.*, vol. 20, pp. 104003-1–104003-7, 2010.