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# Design and Development of MWCNTS/PDMS Composite Flexible Dry Electrode and Smart Electronics for Mobile Electrocardiogram Application

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***Abstract— In this work, we have designed and developed MWCNTs based ECG electrodes that are versatile, skin friendly, flexible and waterproof thus helpful in better acquisition of ECG signals compared with the traditional electrodes available in the market. Thick film fabrication technology has been employed in developing the electrodes. Due to advancement in nanotechnology, we have reduced the dimensions, cost, and power requirement of the electrodes. We have used multiwalled-carbonnanotubes(MWCNTs) / Polydimethylsiloxane (PDMS) composite material for developing the electrodes. These electrodes will provide higher performance over typical electrodes and yet another important factor is that these electrodes are waterproof. We have also developed smart electronics circuit for interfacing the proposed MWCNTs/PDMS composite ECG electrode with android phones for mobile ECG application.***

***Keywords: ECG Electrode, Carbon Nanotube, Polydimethylsiloxane(PDMS).***

## I. INTRODUCTION

With the advancement of science and technology; smart, wearable and compact devices have conquered the medical world. In a world that looks forward to cost effectiveness and longevity in any device or thing, designing medical equipment that can endure extensive use is of prime interest. Continuous monitoring of vital parameters of a patient such as blood pressure, heart rate, temperature and $SpO_2$ is very essential for the well being of a patient. We know that electrical signals generated by our heart gives an array of information regarding our physical well-being.

Electrical activities of the heart are measured by a process called Electrocardiography. It requires constant monitoring in order to keep track of a patient's health. The electrode that is used for acquiring heart signals is gel type Ag/AgCl electrode. They are extensively used in medical practices but they do not have a long life and sometimes causes skin irritation. Due to prolonged use the gel dries up and degrades the signal quality.

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Noise is a major problem for this kind of electrode and sweat also causes disturbance in signal acquisition.

Dry electrodes are an alternative to the Ag/AgCl electrodes. They eliminate several drawback caused by wet electrodes [1].

With the advancement of nanomaterials and fabrication technology [2], nano-fabrication has helped in designing dry electrodes. With such advancements, nano circuits and nano components are designed nowadays. The most commonly used for fabrication is CNT and PDMS. The electrodes are very stretchable and flexible and highly efficient. They can reduce the cost of electrode manufacturing resulting in decreasing the cost of ECG examination.

A carbon nanotube (CNT)/ polydimethylsiloxane (PDMS) composite- based dry ECG electrode was fabricated that could be readily used. On testing for over seven days continuously, the electrode didn't show any degradation in output [3]. In the work of Chlaihawia et al. silver (Ag) flake ink was screen printed on a flexible polyethylene terephthalate (PET) substrate to fabricate the dry ECG electrode. Multi-walled carbon nanotube (MWCNTs)/polydimethylsiloxane composite, as a conductive polymer, was then deposited on the printed Ag electrode by using a bar coating technique. The performance of the printed electrodes was investigated by testing the MWCNT/PDMS composite conductivity and measuring the electrode-skin impedance for electrode radii varying from 8mm to 16 mm [4] but it is yet to commercialized and their electrodes are can't communicate the ECG signals to the android phones. Wearable ECG (electrocardiogram) system with smartphones for real-time monitoring, self-diagnosis, and remote- diagnosis for chronic heart disease patients before sudden outbreaks was designed and fabricated. The shirt attached with ECG electrode can be worn by patients either outdoor or indoor and monitored in real-time [5]. By considering the need for developing an advanced ECG monitoring system with wireless communication technology by merging the novel MWCNTs/PDMS ECG electrode with android smart phone communication electronics circuits, we have proposed this novel system.

## II. MATERIALS AND METHODS

### A. Carbon Nano Tubes (CNTs)

CNTs are basically curved graphene sheets. Graphene sheets are cylinders (seamless) obtained from honeycomb lattice, it represents a singular atomic layer of crystalline graphite.

CNTs nowadays comes in various length, diameter and functional group. Single walled carbon nanotube (SWNT) discovered by Iljima et al [6] attracted much attention due to its extradinary properties. After the discovery of carbon nanotubes in 1991 by Ijima et al an extensive research work was carried out to explore their unique electrical, physical, mechanical and chemical properties for developing high performance devices [7]. The unique properties of carbon nanotubes made them attractive for novel applications in the field of biomedical engineering [3,4].

The CNTs can operate even at room temperature which is optimal for developing ultra low power, wearable, battery operated devices [8,9]. The MWCNTs are made up of multiple layers unlike SWCNTs which further increases the surface to volume ratio and leads to high sensitivity towards gas sensing [10,11].

In our work, we have used multiwalled CNTs. The electrical and thermal property, density and lattice structure of the CNT depends on the structure of the CNT. CNTs have high conductivity and high aspect ratio which help them to frame a system of conductive cylinders. Remarkable mechanical properties of CNTs are derived from a blend of firmness, quality, and tenacity. When incorporated inside a polymer, CNTs exchange their mechanical burden to the polymer grid at a much lower weight rate than carbon dark or carbon filaments, prompting progressively productive applications. Depending on how the CNT is rolled they show metallic or semiconductor properties [12].

- **Characterization of MWCNTs**

The MWCNT dispersion of 0.5wt% in water was bought form Iolitech Ionic GmbH, Germany. MWCNT is characterized by FESEM, FTIR and Raman spectra. FESEM image (figure.1) confirms the presence of MWNT with average diameter of about 40 nm.

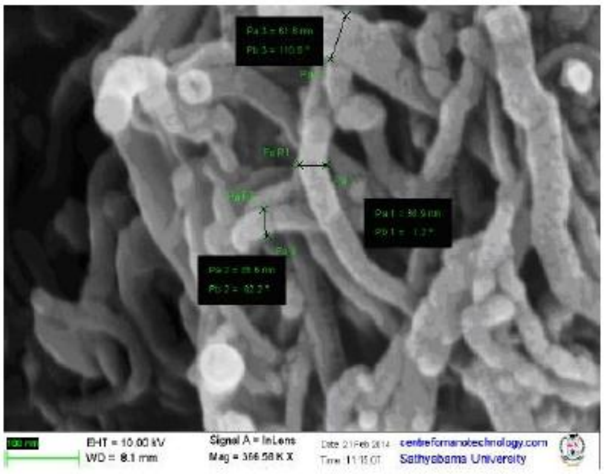


**Figure 1. FESEM image of MWCNTs**

**B. Polydimethylsiloxane:**

Polydimethylsiloxane is the most preferred of all the siloxane elastomers. It is a biocompatible synthetic polymer used in biomedical applications. It has ideal properties like non-toxic, biocompatible, elastic, durable and transparent. The flexibility of the backbone of PDMS exposes the methyl group at various interfaces, these are low interacting, thus makes the surface almost inert. The inertness reduces microbial growth and makes a good substrate for biomedical uses [13]. PDMS possesses good flexibility, flow properties and film forming capability. It is thermally stable and does not change viscosity upon temperature change between -40˚C and 150 ˚C. The open molecular structure helps to make PDMS very permeable to oxygen, nitrogen and water vapour [14].

- **Formation of PDMS base**

20 ml PDMS was cured with 2ml curing agent in 10:1 ratio. The PDMS and curing agent mixture was degassed for 5 min. The degassed mixture was poured on an acryl plate (20mm in diameter and 2mm thickness) and set for baking at 400 ˚C for 15min. After cooling the PDMS layer was removed from the acryl plate as shown in figure 2.

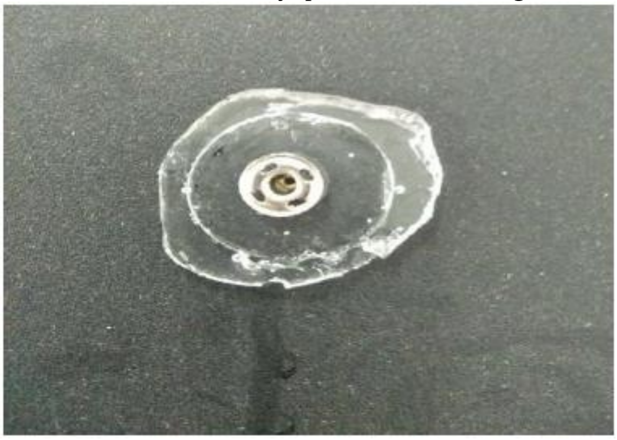

**Figure 2. PDMS base**

**C.Formation of CNT layer**

MWCNT layer was formed in two ways:-

A. MWCNTs dispersion were poured on the PDMS mould and heated for 10 minutes at 400˚C temperature.

B. Liquid MWCNTs were dispersed in PDMS along with curing agent. The mixture was degassed and heated for 20 minutes at 400˚C temperature.

The electrode fabricated by the first method exhibited a resistance of 386 kΩ (figure 3) which is comparatively much better than the second method, so we have chosen the electrode prepared by the second method as shown in figure 4.


**Figure 3. Resistance of the proposed electrode**

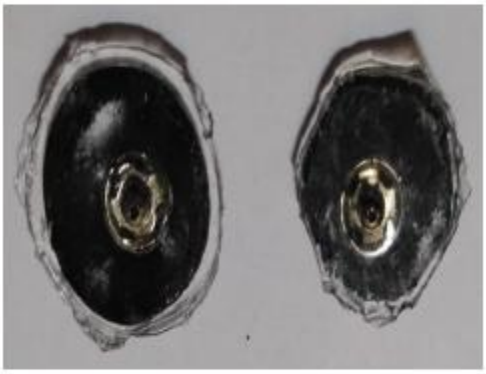

**Figure 4. MWCNTs/PDMS composite ECG electrode**

**D. Signal acquisition:**

The ECG signal was acquired using the custom built electronic circuit and the signals were generated by ECG Simulator. The electrode was attached to connectors and placed on the ECG simulator as shown in figure 5 and 6.

The signal was processed using electronic circuit and the signal was showed on mobile application.

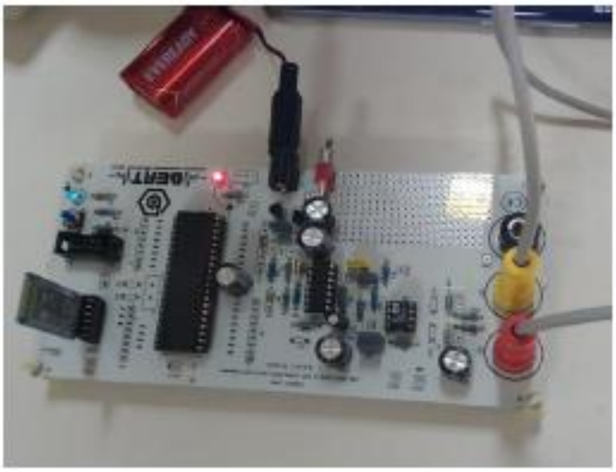

**Figure 5. Signal acquisition circuit for ECG electrode**

**Figure 6. CARDIOSIM ECG Simulator**

**Figure 7. Prototype setup for ECG signal Acquisition from the MWNCTs/PDMS composite electrode.**

## III. RESULTS AND DISCUSSIONS

**Figure 8. Acquired ECG signal**

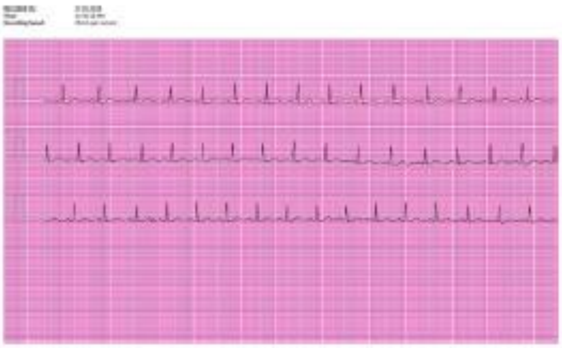

**Figure 9. Acquired ECG report from the proposed system**

The prototype setup of the proposed system is shown in figure 7. The prototype system has got a ECG simulator, custom built electronic circuit for acquiring, processing and communicating the ECG signal captured by the proposed composite dry, flexible and water proof electrodes. The acquired ECG signal on the android smart phone and the report generated is shown in figure 8 and 9. The proposed system is very much capable of mobile electrocardiogram application. In the work of Chlaihawia et al., they have proposed the similar kind of electrodes but not with the data acquisition and communication capability and where as in the work of Byungkook Jeonet al., they have proposed a novel system for wearable remote ECG system for health monitoring with printed electrode on the cloth which has got the capability of transmitting the ECG signals but not based on the MWCNTs/PDMS composite electrode which is considered to be most sensitive, flexible, dry and waterproof type.

## IV. CONCLUSION

The electrode made of MWCNTs/PDMS has captured the ECG signal on connection with CARDIOSIM ECG Simulator. The proposed prototype system is capable of capturing the ECG signal and transmitting to the android based smart phones. This system is considered to be cost effective and become the wearable medical electronic gadget for mobile electrocardiogram application. The electrode is a dry electrode and requires no conductive gel for conduction of biosignals. It produces noise free signal in comparison to traditional wet electrodes and also it is waterproof.

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