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Micro-Electro-Mechanical System (MEMS) Breath Sensor for Polysomnography Study

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Abstract: Sleep disorder study by means of Poly Somno Graphy (PSG) is the most well adopted and reliable procedure in medical practice. The present-day sleep monitoring devices for the PSG procedure is equipped with relatively expensive apparatus and technically complex modus operandi. This study is about development of a fast response Micro-Electro-Mechanical system (MEMs) breath sensor on the final design of the sleep monitoring device for sleep disorder study or personal therapy. This solid state breath sensor is constructed with micro tungsten Inter-Digitated Electrode (IDE) platform that covered with Multi-Walled Carbon Nano Tubes (MWCNT) as sensing material. The MWCNT is grown on a thin oxide layer on top of the tungsten IDE using Plasma Enhance Chemical Vapour Deposition (PECVD) technique. These MWCNT structures are capable of sensing and capturing breathing behaviour thus a fast response capacitive sensor is developed. A customized test jig imitating a human like breathing pulse was fabricated to test the sensor's performance in relation to sensitivity and response time. The research reveals that this newly developed breath sensor device is highly sensitive and shows remarkably fast response within sub-second.

Key words: Breath sensor, MWCNT, inter-digitated electrode capacitve-typed sensor, sleep disorder monitoring device, technically complex modus

INTRODUCTION

The increasing demand for very light, miniature size, fast response, accurate, robust, non-invasive, embedded Data Acquisition System (DAQS) and easy to use diagnostic sensing devices for medical applications has driven global researchers from various disciplines to keep pace with the latest needs. Humidity sensor nevertheless offers vast applications in many fields such as healthcare, automotive, heating, ventilation, industry and agriculture (Fenner and Zdankiewicz, 2001). Decision on which sensing technology is more suitable, either capacitive or resistive type in micro size sensor design, very much depending on the choice of sensing elements and the overall structure of the sensor platform design (Liu *et al*., 2013; Tang *et al*., 2011).

The exploration on nano-sensing material in MEMs sensor devices design has marked a new era in the MEMs sensor technology (Gojny *et al*., 2003; Ounaies *et al*., 2003). Carbon Nano Tubes (CNT) is one of the earliest nano material's research frontier discovered by Iijima backed in 1991. Typically the CNT structures need to be synthesized from carbon feedstock such as Methane (CH_4) acetylene (C_2H_2) and Methane (C_2H_4) (Cao *et al*., 2011; Nieto *et al*., 2000). Prior to that it needs a metal catalyst as a seed layer to initiate the CNT structure precipitation process.

Sleep disorder is a poor sleep behavior that is recognized as a medical illness from which resulting to poor quality sleep. Sleep apnea is a sleep disorder characterized by abnormal pauses in breathing or instances of abnormally low breathing during sleep. Each pause in breathing, called an apnea can last from at least ten seconds to minutes and may occur 5-30 times or more in an hour. According to a study, roughly one in every 15 Americans is affected by at least moderate sleep apnea and in Malaysia, the situation is even worse; one in every 7 Malaysian is affected. Sleep apnea patient is diagnosed with an overnight sleep test called a Poly Somno Gram (PSG) or "sleep study" (Kelly *et al*., 2012; Liu *et al*., 2013; Wei *et al*., 2010).

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MATERIALS AND METHODS

In this research, a brief fabrication process and experimental procedure of the breath sensor device are presented. The functionality of the breath sensor device is tested using a customized breath sensor response test jig and verified via. the actual human subject.

Sensor fabrication process: The breath sensor fabrication process can be divided into two stages. Stage one was fabricating the micro Inter-Digitated Electrodes (IDEs) then stage two was in-situ growing of MWCNT onto the IDE platform. The IDE structure is made of Tungsten W. A seed layer of cobalt catalyst was sputtered onto the IDE structure prior to the MWCNT growing process. The MWCNT structure was then synthesized *in situ*, using PECVD machine.

Figure 1 shows a schematic diagram of the breath sensor structure. The tungsten IDEs are lies on the silicon substrate and the MWCNTs are on top of them. The size of this IDE platform is approximately 3000×4000 μm. MWCNTs are the sensing part of the sensor and cover the overall surface of IDE fingers. The final process was attaching this platform or normally refers as "die", onto the Printed Circuit Board (PCB) and at this stage it calls Chip on Board (COB).

Experimental setup: Figure 2 shows a schematic diagram of a customized integrated testing jig for investigating the breath sensor's response time and recovery time pattern. The testing setup is equipped with air-flow regulator that imitating the human-like breathing pulse.

A mist generator was installed to generate water vapor and collected in mist chamber. The function of this water vapour is to create a humid air condition that emulating human's breath bulk matrix during exhalation mode of which is almost 100% moist. The humid air is then sucked out from the mist chamber using an air pump and channeled onto the breath sensor.

The air pump transfer timing is controlled by a relay function that regulates the output air-flow steadily, mimicking the human-like breathing pulse pattern. A normal human breathing pulse pattern is 5 sec timeframe or 7-12 breaths per minute (Andre *et al*., 2010; Benkstein *et al*., 2010). The data acquisition system is used to detect the output response from the breath sensor. Figure 3 shows the breath sensor functionality test via. human subject. This testing procedure is to verify the sensor performance under the actual application.

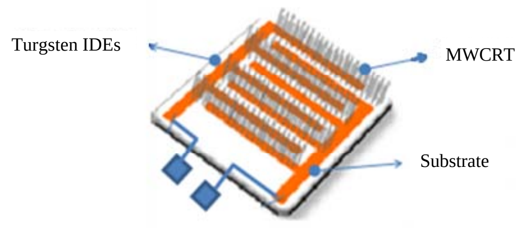

Fig. 1: Schematic diagram of capacitive-type breath sensor structure

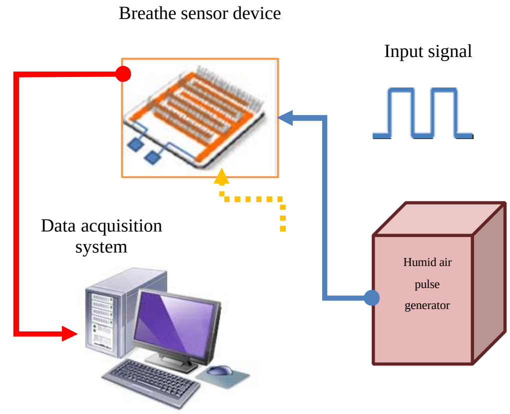

Fig. 2: Example of an unacceptable low-resolution image

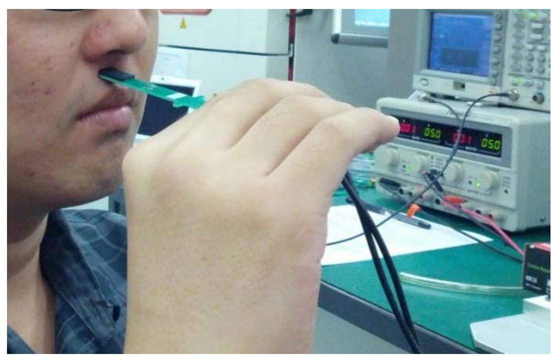

Fig. 3: Response test via. human subject

RESULTS AND DISCUSSION

Functional test via. response test outfit: The breath sensor exhibited promising performance when tested via. response test outfit. The results revealed that the breath sensor can be effectively employed to monitor normal human breathing pattern.

Figure 4 shows the results of breath sensor response measured against the time. The input signal pulse; the red line is set at 5 sec timeframe. The breath sensor output signal pulse is in blue line exhibits a steady performance

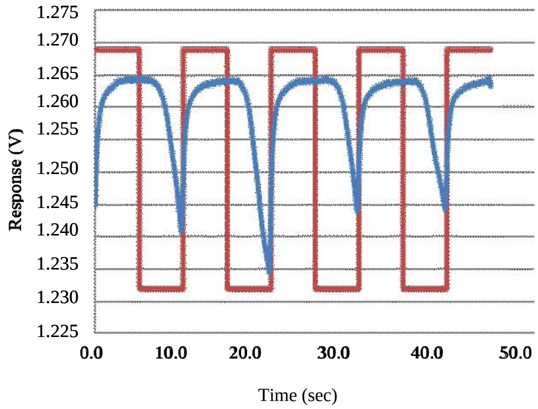

Fig. 4: Response time measurement via. testing jig

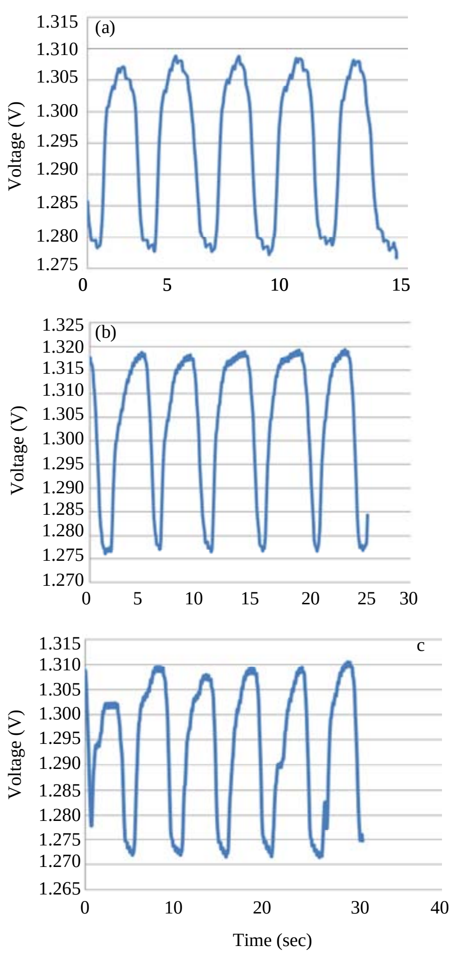

Fig. 5: a-c) Image actual response time measurement via. human subjects

with in the stipulated measured time with the average response Time (Tr) of approximately 645 mili-sec. The average fall Time (Tf) is approximately at 2 sec. The experimental results using the customized testing jig show that the breath sensor effectively response within sub-seconds with repeatable pulse pattern.

Functional test via. human subject: Figure 5a-c display the response time measurement of three healthy male subjects using the same breath sensor unit. These voluntary subjects were adult age-group of 23-24 years.

The test results show a similar-like pattern among the three male subjects with the average Tr of 957 mili-seconds and average Tf of 733 mili-seconds, respectively. This preliminary data proved that the breath sensor device is able to measure and response to the actual human breathing pulse within sub second and this finding strengthened the earlier experimental testing results via. the customized testing outfit.

CONCLUSION

The breath sensor device exhibits an average response time of 0.6 sec and average fall time of <2 sec. The functionality of the breath sensor was verified using the actual human breathing mode and the result was even more promising with both response time and fall time of >1 sec, respectively.

The breath sensor device repeatability and capability in performing according to the normal human breathing pulse pattern of 5 sec per timeframe is evidence. However, a delay in settling time that was observed during the experiment using the testing outfit is believed due to the moisture saturation condition in the MWCNTs structure.

Theoretically desorption time will improve in the presence of dry air flow at higher temperature and this behavior is in agreement with the results obtained during the experiment via. actual human subjects.

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