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DESIGN OF EXPERIMENT USING MINITAB FOR SCREENING BREATH SENSOR WORKABILITY PERFORMANCE

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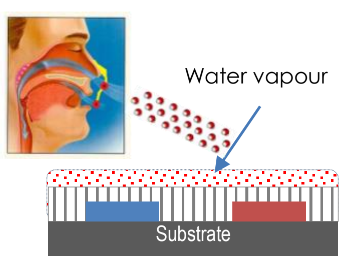
Graphical abstract



Breath Sensor

Abstract

The breath sensor device is fabricated using a capacitive Inter-Digitated-Electrode (IDE) platform sensor that is designed to detect moisture in human breath. The sensing material that is used to detect the presence of the moisture is Carbon-Nanotube (CNT). There are four main factors that were understudied in determining the workability performance of the sensor device such as the CNT structure, temperature, relative humidity and IDE platform design. Using Design of Experiment (DOE) approach an experimental study was conducted to investigate the effect of each factor to the performance that is aimed for the breath sensor device in relation to its response factor; capacitance (pF). It is essential to identify which factors or variables that give the significant effect to the workability performance of the breath sensor device and its functionality performance eventually. This useful insight is needed before optimization of the process can be done to further enhanced the breath sensor overall performance.

Keywords: Breath sensor, CNT, Inter-digitated- Electrode (IDE), Design of Experiment (DOE)

1.0 INTRODUCTION

The exploration on nano-sensing material in Micro-electro-mechanical Systems or MEMS sensor devices design has marked a new era in the MEMS sensor technology [1-2]. CNT generally can be synthesized using these three main techniques i) arc-discharged technique, ii) laser ablation technique and iii) chemical deposition technique (CVD); the plasma enhanced chemical vapor deposition (PECVD) is the enhanced version of CVD technique [3-9]. The latter is known to synthesize high quality CNTs with no defects [10]. However, the consistency of the breath sensor workability performance is not only depending on its sensing material but also other variables such as the surrounding temperature and relative humidity as well as the IDE platform design.

DOE is a systematic statistical approach that offers a variety of options in meeting the objective of any study [11]. It gives the options to reducing the number of experimental run through fractional factorial while maintaining the high level of confidence of the analyzed result. Screening is a specific type of fractional DOE that normally used in the initial stages of experimentation. Screening design helps to minimize the number of runs required in an experiment. Also, it is more economical and assists in determining the relative significance of many main effects.

Generally, human's breath bulk matrix during exhalation mode is almost 100% moist and at atmospheric level during inhalation mode. Theoretically, the breath sensor's response and recovery behavior is corresponding to the water molecule adsorption and desorption phenomena with respect to the CNT hydrophilic-hydrophobic trait [12]. In this work the workability performance or sensitivity of the breath sensor device is tested inside controlled environment of Climatic Chamber C7-1500, Votsch. The breath sensor device is tested in various relative humidity (RH) and temperature in relation to the CNT structure and its IDE platform design. In theory, the capacitance value increased as the CNT structure is exposed to environment of higher moisture and temperature.

2.0 METHODOLOGY

2.1 DOE Plan

Minitab Statistical Software is used for developing the DOE plan for the workability test experimental run. There are four main factors that were already identified for this experiment as presented in Table 1. For the purpose of this screening activity, a full factorial design was selected and the DOE plan was generated as tabulated in Table 2.

Table 1 Factors (variables) and setting levels of the DOE plan

Factors	**Levels (UoM)**
IDE Design	DP3; DP5
CNT Synthesis	45; 600 (sec)
Relative Humidity	50; 70; 90 (RH)
Temperature	25; 35; 45 (°C)

2.2 Workability Test

The workability test is important in confirming the sensitivity of the breath sensor's sensing mechanism of which includes the CNT structure and the electrical circuit working as designed. This test validates the sensor's ability in detecting the presence of moisture. The in-situ grown CNT structure is synthesized via plasma enhanced chemical deposition process as reported in [13]. The CNT structure is in nano-size and ultra sensitive to any changes at its surrounding. For this reason, an enclosed and controlled environment is necessary in examining the breath sensor performance.

2.2 Experimental Setup

The apparatus used in this experiment are (i) Climatic Chamber, (ii) LCR Meter, (iii) Breath Sensor device, (iv) Connecting wires and (v) Commercial Humidity Sensor (as a reference). Figure 1 shows the sensor devices are placed inside the climatic chamber. The temperature and the relative humidity (RH) inside the chamber are set according to the DOE plan as exhibited in Table 2; to test the sensor device sensitivity in the extended set time. The capacitance value (pF) of the sensor electrical property output response is then recorded and analysed.

Figure 1 Workability test using humidity climatic chamber

3.0 RESULTS AND DISCUSSION

The experimental plan used in this study was generated using Minitab statistical software. Full factorial DOE plan was generated that consists of 36 runs with different combination of variables as tabulated in Table 2. The response factor of this DOE is the capacitance value (pF).

The experimental data from Table 2 were then analysed using the Analysis of Variance (ANOVA) that is available in the Minitab. The main effect plot and interaction plot are selected in this analysis. The response factor is set as the capacitance value and the other factors are set as Design, Temperature, Humidity and CNT. These factors setting were then used to generate the 'Main Effect Plot for Capacitance' and 'Interaction Plot for Capacitance'; refer to Figure 2 and 3 respectively. The main effect plot shows that the Design and CNT are the most significance factors in affecting the capacitance value. This finding was further confirmed via interaction plot.

Table 2 Design of experimental plans and results

Run Order	IDE Design	CNT	Humidity	Temperature	Capacitance (pF)
1	DP3	600	90	25	292.02
2	DP3	45	90	25	373.71
3	DP5	45	50	35	250.72
4	DP3	600	90	35	291.37
5	DP3	45	70	45	371.04
6	DP5	600	90	45	201.15
7	DP5	600	90	35	201.63
8	DP3	45	90	35	375.21
9	DP3	45	50	25	366.88
10	DP3	45	50	35	367.23
11	DP5	45	70	25	252.90
12	DP5	600	70	45	194.53
13	DP5	600	50	25	191.91
14	DP5	600	90	25	193.25
15	DP3	45	90	45	376.60
16	DP3	600	50	25	274.60
17	DP3	600	70	35	280.25
18	DP5	600	50	45	191.84
19	DP5	45	50	45	250.71
20	DP5	45	90	25	256.18
21	DP3	600	90	45	290.36
22	DP5	45	50	25	250.77
23	DP3	45	50	45	367.01
24	DP5	45	70	45	253.18
25	DP3	45	70	25	369.62
26	DP5	600	50	35	192.03
27	DP3	600	50	45	274.91
28	DP3	600	50	35	274.93
29	DP5	600	70	25	201.79
30	DP5	600	70	35	194.94
31	DP5	45	70	35	253.15
32	DP5	45	90	45	256.24
33	DP5	45	90	35	255.75
34	DP3	45	70	35	370.55
35	DP3	600	70	25	280.42
36	DP3	600	70	45	279.89

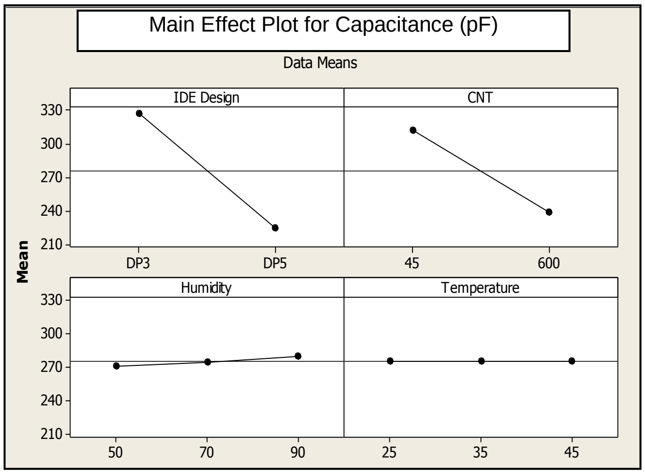


Figure 2 Main Effect Plot for Capacitance (pF)

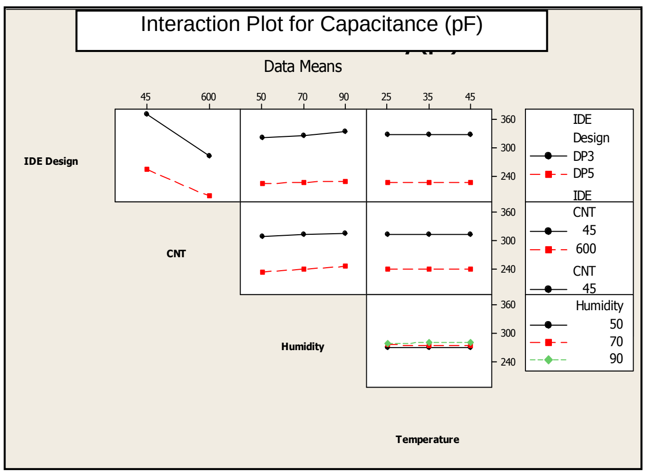


Figure 3 Interaction Plot for Capacitance (pF)

Figure 3; the interaction plot narrow down the findings by highlighting that the IDE Design is the most significance factor in determining the character performance of the breath sensor device as compared to the CNT synthesization time. However, the CNT factor also needs special attention as it does contribute to the overall performance package of the sensor device.

4.0 CONCLUSION

In overall, the CNT synthesization time and the IDE design show significant effect to the capacitance response performance, regardless of the humidity and temperature set throughout the experiment. Also, it is observed that the CNT synthesization time of 45 sec with the IDE design of DP3 exhibits higher capacitance reading. Thus this screening experimental study has successfully led the researcher to focus on the 45 sec CNT synthesization with the DP3 design in the next experimental run. Nevertheless another important findings here is that the breath sensor device exhibits exceptional performance in the higher humidity environment and this is the plus trait that the sensor supposedly to behave of which in agreement with the human breath bulk matrix condition; almost 100% moist.

In conclusion, the DOE approach used in this study provides important insight and structured investigation in identifying the most significance factors influencing the breath sensor workability performance. However, the experiment needs to be replicated in ensuring the consistency of the results and eventually validate the correlation found from this study.

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References

[1] C.-L. Wei, C.-F. Lin, and I.-T. Tseng. 2010. A Novel MEMS Respiratory Flow Sensor. *IEEE Sensors Journal*. 10(1):16-18.

[2] X. Chen, Y. Wang, Y. Wang, Z. Hou, D. Xu, Z. Yang, and Y. Zhang. 2010. Physical A Breath Sensor Using Carbon Nanotubes Operated by Field Effects of Polarization and Ionization. *Sensors and Actuators (A) Journal of Physics.* 158(2): 328-334.

[3] M. Tanemura, K. Iwata, K. Takahashi, Y. Fujimoto, F. Okuyama, H. Sugie, and V. Filip. 2001. Growth of Aligned Carbon Nanotubes by Plasma-Enhanced Chemical Vapor Deposition: Optimization of Growth Parameters. *Journal of Applied Physics.* 90(3):15-29.

[4] H.-C. Liu, Y.-J. Chen, Y.-C. Lu, C.-L. Wu, W.C. Huang, and J.-T. Huang. 2013. Monitoring Apnea in the Elderly by an Electromechanical System with a Carbon Nanotube-Based Sensor. *International Journal of Gerontology*. 1-5.

[5] F. H. Gojny, J. Nastalczyk, Z. Roslaniec, and K. Schulte. 2003. Surface Modified Multi-walled Carbon Nanotubes in CNT/Epoxy-Composites. *Chemical Physics Letters.* 370(5-6): 820-824.

[6] X. Chen, Y. Wang, Y. Wang, Z. Hou, D. Xu, Z. Yang, and Y. Zhang. 2010. Physical A Breath Sensor Using Carbon Nanotubes Operated by Field Effects of Polarization and Ionization. *Sensors and Actuators (A) Journal of Physics.* 158(2): 328-334.

[7] P. Janik, M. a. Janik, and Z. Wróbel. 2012. Micro-condensation Sensor for Monitoring Respiratory Rate and Breath Strength. *Sensors and Actuators (A) Journal of Physics*. 185: 160-67.

[8] K. D. Benkstein, B. Raman, C. B. Montgomery, C. J. Martinez, and S. Semancik. 2010. Microsensors in Dynamic Backgrounds: Toward Real-Time Breath Monitoring. *IEEE Sensors Journal.* 10(1):137-144.

[9] N. André, S. Druart, P. Gérard, R. Pampin, L. Moreno-hagelsieb, T. Kezai, L. A. Francis, D. Flandre, J. Raskin, and S. Member. 2010. Miniaturized Wireless Sensing System for Real-Time Breath Activity Recording. *IEEE Sensors Journal.* 10(1): 178-184.

[10] M. Meyyappan, L. Delzeit, A. Cassell, and D. Hash. 2003. Carbon Nanotube Growth by PECVD : A Review. *IOP*

Sciences Journals; Plasma Sources Science and Technology. 12: 205-216.

[11] A. A. Rashid, N. H. Saad, D. B. C. Sheng, K. Y. Lee, W. Y. Lee, and Noriah Yusoff. 2014. Study on Hydrothermal Process Variables Correlation to WO_3 Nanostructure through Design of Experiments (DOE) Approach. *Applied Mechanics and Materials Journals.* 607: 47-50.

[12] X. Liu, Z. Zhao, T. Li, and X. Wang. 2011. Novel Capacitance-type Humidity Sensor Based on Multi-Wall Carbon Nanotube/SiO 2 Composite Films. *Journal of Semiconductors.* 32(3): 0340061-5.

[13] Noriah Yusoff, N. H. Saad, M. Nabipoor, S. Sulaiman, D. Bien, and C. Sheng. 2014. Plasma Enhanced Chemical Vapor Deposition time effect on Multi-Wall Carbon Nanotube growth using C 2 H 2 and H 2 as Precursors. *Advanced Materials Research Journals.* 938: 58-62.