A SWNT-Based Sensor for Detecting Human Blood Alcohol Concentration

H. Leng and Y. Lin*

Department of Mechanical and Industrial Engineering , Northeastern University
Boston, MA 02115 USA
yilin@coe.neu.edu

Abstract. Alcohol intake may impair human abilities, degrade human performance, and result in serious diseases. Alcohol sensors are needed to manage the risk and effect of alcohol use to human health and performance. This paper was focused on the theoretical models and design of carbon nanotube based alcohol sensors. The experiments verified that single-walled carbon nanotubes can be used to detect alcohol vapor, and need metal pads to achieve higher sensitivity.

Keywords: Sensor, blood alcohol concentration, carbon nanotube, human-machine system, driver-vehicle system.

1 Introduction and Motivations

Alcoholic beverages are popular in modern society. However, alcohol intake impairs human abilities and degrades human performance [1]. Excessive consumption of alcoholic beverages may result in serious diseases [2]. In order to manage the risk and effect of alcohol use to human health and performance, it is worthy to monitor human blood alcohol concentration (BAC). A widely acceptable method is measuring the alcohol concentration of human exhalation.

Most technologies of measuring alcohol concentration can be classified into three methods, *(1) metal oxide based methods* in which the sensing element is metal oxides such as SnO_2 [3], *(2) optical methods* in which the absorption bands of alcohol are used [4], and *(3) carbon nanotubes (CNT) based methods* in which the resistance of CNTs changes with the ambient alcohol concentration [5]. Compared to the other two methods based alcohol sensors, CNT based alcohol sensors have the potential to achieve ultra-high sensitivity, quick response, large measurement range, compact size, and low energy consumption. These features are essential to monitor human BAC for human health and performance.

This paper is focused on developing a CNT based alcohol sensor which can be used to monitor the alcohol concentration of human exhalation, and then detect human blood alcohol concentration (BAC).

M. Cheng (Ed.): NanoNet 2008, LNICST 3, pp. 69–73, 2009.

2 Theoretical Models of CNT Based Alcohol Sensors

Theoretically, there are three models to use CNTs to measure the alcohol concentration of alcohol vapor: *(1) Pure-CNT model* is to monitor the resistance of pure CNTs. Pure-CNT based alcohol sensors can be recovered using dry nitrogen gas or by heating [5], [6]; *(2) Special-CNT model* is to monitor the resistance of the CNTs that are deposited special chemical molecules (e.g. COOH). Special-CNT based alcohol sensors are recovered by heating [7]; *(3) Mixed-CNT model* is to monitor the resistance of the CNTs that are combined with enzymes. The enzymes are used to convert the alcohol into other substances which change the resistance of CNTs [8].

Pure-CNT based alcohol sensors are the simplest. Special-CNT based alcohol sensors have higher sensitivity and better gas selection than pure-CNT based alcohol sensors. Mixed-CNT model based alcohol sensors which have good gas selection require severe operating conditions. Hence, special-CNT model based alcohol sensors are more suitable for monitoring human BAC for human health and performance.

3 Design of a CNT Based Alcohol Sensor

A CNT based alcohol sensor consists of at least five parts, a substrate, a CNT sensing element, metal pads, bonding wires, and heating wires (Fig. 1). The substrate is a piece of insulating material with a central opening. The CNT sensing element is placed in the central opening, and is bonded to the pads ① and ② using bonding wires. The heating wires cover the sensing element, and build a series circuit between the pads ③ and ④. The sensing element is heated and recovered by applying a voltage between the pads ③ and ④. The recovery time from heating start to full recovery of resistance hinders the sensor to quickly and continuously respond. A feasible solution is integrating multiple sensing elements (e.g. two), a controller, a timer, and a heater into one alcohol sensor (Fig. 2). The controller, following the timer signal, can connect the signal terminals with one sensing element and recover the other sensing elements using the heater. The complexity and expense of alcohol sensor should be increased.

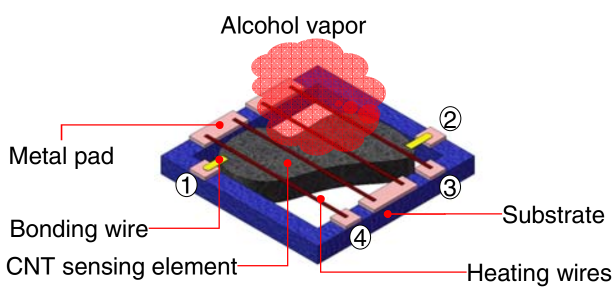

Fig. 1. A CNT based alcohol sensor

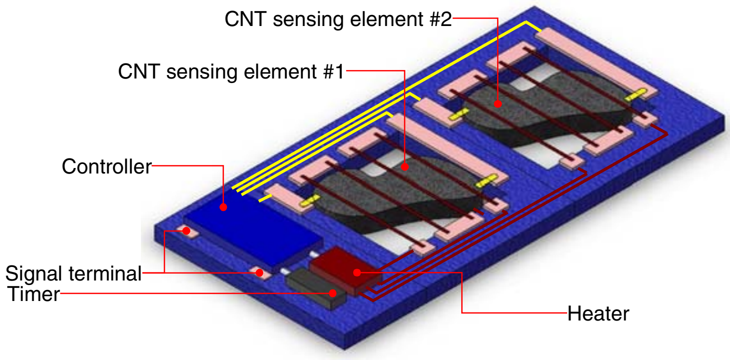

Fig. 2. A CNT based alcohol sensor combining two sensing elements

4 Experiments of CNT Sensing Elements

The functional part of the CNT based alcohol sensor in Fig.2 is still the CNT sensing element. However, it seems that researchers have not compared the performance of different CNT sensing elements in measuring alcohol vapor. Thus, this study designed two experiment groups, #1 and #2, to do the comparison.

4.1 Experiment Group #1

Experiment group #1 was carried out to verify that the resistance of CNT sensing element changes with two ambient alcohol concentrations, no alcohol and having alcohol. A multi-walled carbon nanotube (MWNT) sensing element without pads and a single-walled carbon nanotube (SWNT) sensing element without pads were prepared for the experiment group #1 using the methods of [9-10] (Fig. 3).

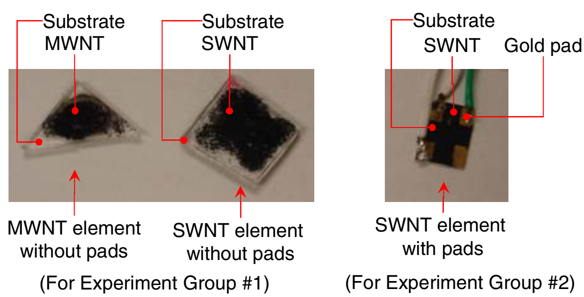

Fig. 3. CNT sensing elements for experiment group #1 and #2

Experiment apparatus and procedures. Experiment group #1 utilized ethyl alcohol (70% by volume), a precision ohmmeter, and a plastic cup with lid. The precision ohmmeter was used to measure the resistance of sensing elements. The plastic cup was utilized to establish a close space full of alcohol vapor.

When a sensing element was tested, it was fixed in the plastic cup whose lid opens, and then was connected with the ohmmeter using alligator clips. The resistance of the sensing element was recorded when the reading was stable. After placing an alcohol cotton swab in the plastic cup and closing its lid, the resistance of sensing element was recorded again when the reading was stable. Then, the resistance of the sensing element was fully recovered by removing the lid of plastic cup and the alcoholic swab. Totally, both measurements were repeated 10 times for each sensing element.

Experiment result. Experiment group #1 produced 40 records. The records of each sensing element before adding alcohol were compared with its records after adding alcohol using the analysis of variance (ANOVA) (Table 1). The result verified that the resistance of the SWNT sensing element without pads is sensitive to the ambient alcohol concentration (α=0.05, P=0.0025). The resistance of the MWNT sensing element without pads does not significantly change with the ambient alcohol concentration (α=0.05, P=0.7700). It is feasible to use SWNT sensing elements to measure an alcohol vapor.

Table 1. ANOVA (α=0.05) result of experiment groups #1 and #2

Experiment Group	Sample	Source of Variation	F	P-value
#1	MWNT element without pads	no Alcohol	0.088027	0.770096
	SWNT element without pads	VS	12.36055	0.002469
#2	SWNT element with pads	having alcohol	37.47929	8.79E-06

4.2 Experiment Group #2

Experiment group #2 was performed to verify that a CNT sensing element with pads can produce more significant resistive change when the ambient alcohol concentration changes between two levels, no alcohol and having alcohol. Considering that SWNT sensing elements respond to alcohol vapor, this study prepared a SWNT sensing element with metal pads for experiment group #2 using the methods of [9-10] (Fig. 3). This sensing element was tested using the same apparatus and procedures of experiment group #1.

Experiment group #2 produced 20 records of which the ANOVA result is showed in Table 1. The P-value of the SWNT sensing element without pads (α=0.05, P=0.0025) is much larger than the P-value of the SWNT sensing element with pads (α=0.05, P=8.79E-06). It implies that the SWNT sensing element with pads can achieve higher sensitivity in measuring an alcohol vapor.

5 Conclusions and Future Work

When human blood alcohol concentration is measured to decrease the effect of alcohol use to human health and performance, the severe technical requirements can be satisfied using carbon nanotube based alcohol sensors. Among their three theoretical models, the special carbon nanotube based alcohol sensor is more suitable for this measurement. The recovery time of carbon nanotube based alcohol sensor can be eliminated by integrating multiple sensing elements into one sensor. The experiments verified that single-walled carbon nanotubes can be used to detect an alcohol vapor, whereas multi-walled carbon nanotubes can not. The single-walled carbon nanotubes with metal pads have higher sensitivity than those without pads.

The future work is to produce a SWNT based alcohol sensor involving two sensing elements and test its performance.

Acknowledgments. The carbon nanotube samples used in this study was provided by Dr. Yung Joon Jung and Laila Jaberansari.

This project is supported by National Science Foundation (NSF) the Sensor Innovation and Systems program (Award Number 0825864). The authors would like to thank Dr. Shih-Chi Liu for his kind support to this research.

References

1. Kim, H., Yang, C., Lee, B., Yang, Y., Hong, S.: Alcohol effects on navigational ability using ship handling simulator. International Journal of Industrial Ergonomics 37(9-10), 733–743 (2007)
2. National Institute on Alcohol abuse and Alcoholism (NIAAA), 2006, Report to the extramural advisory board (2006), http://pubs.niaaa.nih.gov/publications%5CDEPRStrategicPlan%5CBriefingBook2.htm#D._CHRONIC_DISEASES
3. Promsong, L., Sriyudthsak, M.: Thin tin-oxide film alcohol-gas sensor. Sensors and Actuators B (Chemical) B25(1-3), 504–506 (1995)
4. Azzazy, M., Chau, T., Wu, M., Tanbun-Ek, T.: Remote sensor to detect alcohol impaired drivers. IEEE Lasers and Electro-Optics Society 1995 Annual Meeting. In: 8th Annual Meeting. Conference Proceedings, vol. 2, pp. 320–321 (1995) (Cat. No.95CH35739)
5. Someya, T., Small, J., Kim, P., Nuckolls, C., Yardley, J.: Alcohol Vapor Sensors Based on Single-Walled Carbon Nanotube Field Effect Transistors. Nano letters 3(7), 877–881 (2003)
6. Kong, J., Franklin, N.R., Zhou, C., Chapline, M.G., Peng, S., Cho, K., Dai, H.: Nanotube molecular wires as chemical sensors. Science 287(5453), 622–625 (2000)
7. Sin, M., Chow, G., Wong, G., Li, W., Leong, P., Wong, K.: Ultralow-power alcohol vapor sensors using chemically functionalized multiwalled carbon nanotubes. IEEE Transactions on Nanotechnology 6(5), 571–577 (2007)
8. Tsai, Y., Huang, J., Chiu, C.: Amperometric ethanol biosensor based on poly(vinyl alcohol)-multiwalled carbon nanotube-alcohol dehydrogenase biocomposite. Biosensors & Bioelectronics 22(12), 3051–3056 (2007)
9. Jung, Y.: Controlled Synthesis of Carbon Nanotubes using Chemical Vapor Deposition Methods. In: Nanomanufacturing Handbook, ch. 4. CRC, Boca Raton (2006)
10. Xiong, X., Jaberansari, L., Hahm, M., Busnaina, A., Jung, Y.: Building Highly Organized Snigle-Walled Carbon Nanotube Networks Using Template Guided Fluidic Assembly. Small 3(12), 2006–2010 (2007)