Vertically aligned carbon nanotubes based micro-sensor for alcohol detection

U Dhawan, R Kumar, O P Sinha, A Mathur

***Abstract*— We have demonstrated vertically aligned, multi-walled carbon nanotube (MWCNTs) based alcohol sensor with good selectivity and sensitivity up to 50 ppth (ppth=parts per thousand). Vertically aligned CNTs were synthesized onto silicon substrates using chemical vapor deposition (CVD) system. The sensor was exposed to different alcohols and the impedance was measured using HIOKI LCR Hi tester – 3522-50 system. The results indicates that the sensor is capable of sensing different types of alcohols in various concentration ranges. It exhibits fast, reversible, selective response for different alcohol samples. We have tested the response of the sensor with alcohol concentrations from 50ppth to 100ppth. The impedance of bare sensor was 2.9896 MΏ which was changed to 12.7 MΏ for isopropanol, 33.8 MΏ for butanol, and 48.2 MΏ for ethanol. The sensor can easily reset to its original value by applying small amount of heat using micro-heater fabricated on a PCB board for this application. Based on our prototype of the sensor. We demonstrated the feasibility of using vertically aligned carbon nanotubes based miniaturized alcohol sensor and turning it into an economical, commercialized product in near future.**

***Keywords*— Sensor, Carbon nanotubes, Impedance Spectroscopy.**

I. Introduction

Recent development of nanotechnology has created huge potential to build highly sensitive, low cost, portable sensors with low power consumption. The extremely high surface-to-volume ratio and hollow structure of nanomaterials is ideal for gas molecules adsorption and storage. Therefore, gas sensors based on nanomaterials, such as carbon nanotubes (CNTs), nanowires, nanofibers, and nanoparticles, have been investigated widely [1-3].

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Upon exposure to certain gases, the change in the properties of CNTs or CNTs-based composites can be detected by various methods. As a result, CNTs-based gas sensing systems and the theoretical analyses of gas adsorption and collision effects on the nanotubes have been the subjects of intense research. CNTs are allotropes of carbon that have a cylindrical nanostructure. There is no other material in the world that has a size that is close to these nanotubes; they are larger than all other materials. Their properties are very important in nanotechnology which involves manipulating and dealing with atoms and molecules.

The nanotube structure is obtained by grouping cylindrical allotropes of carbon. Carbon Nanotubes have started to exist as a very important element in the sensor industry. A paper by Dr. Katherine A. Mirica et al [15] describes structural and functional principle to carbon nanotubes for their application in the detection of harmful gases.

Carbon nanotubes possess very unique characteristics due to their hollow centre, nanometre size and large surface area, and are able to change their electrical resistance drastically when exposed to alkalis, halogens and other gases at room temperature. Hence, carbon nanotubes have the potential to be a better chemical sensor.

Structurally, carbon nanotubes are long, thin sheets of carbon atoms that can then be shaped into cylindrical forms. Carbon Nanotubes have a remarkable ability to conduct electricity and transmit this energy across their structure which makes them an excellent sensing elements. Carbon Nanotubes also have high tensile strength and elastic modulus due to which they can be used in a wide variety of applications in multiple industries.

In this work, we fabricated a sensor using vertically aligned MWCNTs for sensing alcohol. The vertically aligned CNTs were grown on silicon substrates using thermal chemical vapour deposition system using a mixture of ferrocene and toluene [4]. These as-grown CNTs were exposed to different type of alcohols such as butanol, Isopropanol and ethanol etc, in a custom based setup. The impedance measurements were performed using HIOWKI impedance analyzer. The different concentrations of alcohol to which the sensor was subjected were 100%, 90%, 80%, 75%, 50%. The change in the impedance of the sensor shows that different alcohol concentrations as well as different samples are well distinguished by it.

II. Materials and Methods

Figure 1: *Thermal Chemical Vapor deposition chamber.*

Carbon Nanotubes were synthesized using a 2% mixture of ferrocene and toluene, where toluene acts as a carbon source and ferrocene acts as a catalyst on silicon as the substrate, in the Chemical Vapour Deposition chamber. The electrical characterization was carried out using Electrical Impedance spectroscopy using LCR-HIOWKI TESRTER 3522-50.

III. Results and Discussions

The as-grown vertically aligned Carbon Nanotubes were characterized using scanning electron microscope. Fig. 2, shows a forest of Carbon Nanotubes which is aligned on silicon substrate.

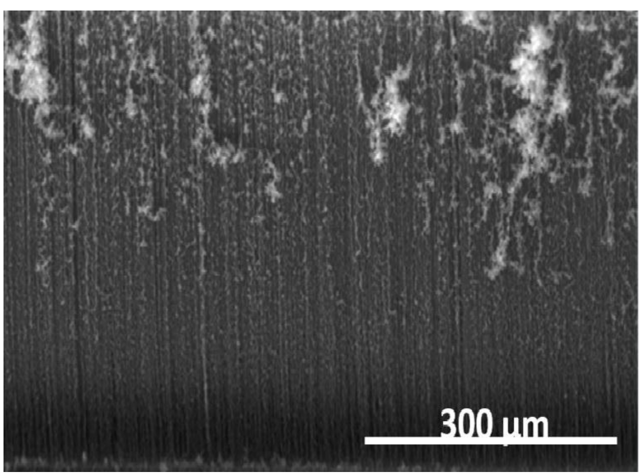

Figure 2: Vertically *aligned Carbon Nanotubes on Silicon substrate*

As shown in Fig. 3. the frequency was swept from 50Hz to 5000Hz, the maximum gain was observed at 3000Hz. It was observed that impedance gradually decreased with the decrease in concentration of the alcohol sample when the amount of water vapour is around 50%, the impedance increases sharply suggesting the signals being dominated by water vapours. The possible reason for this is due to the high impedance caused due to water vapours in the measurement, as the alcohol solutions were made using serial dilutions with water and respective alcohol.

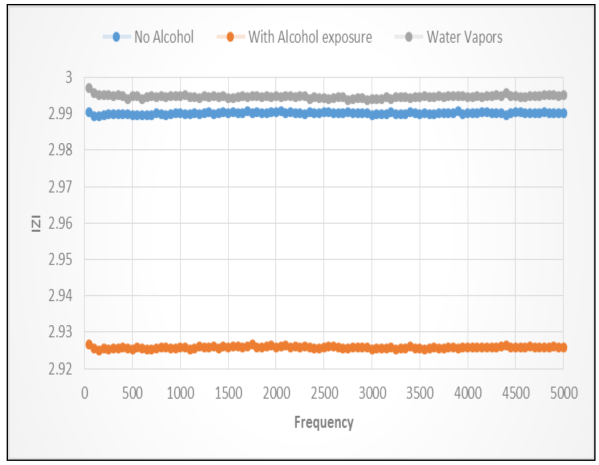

Figure 3: *Showing Frequency Response with Different Analyte*

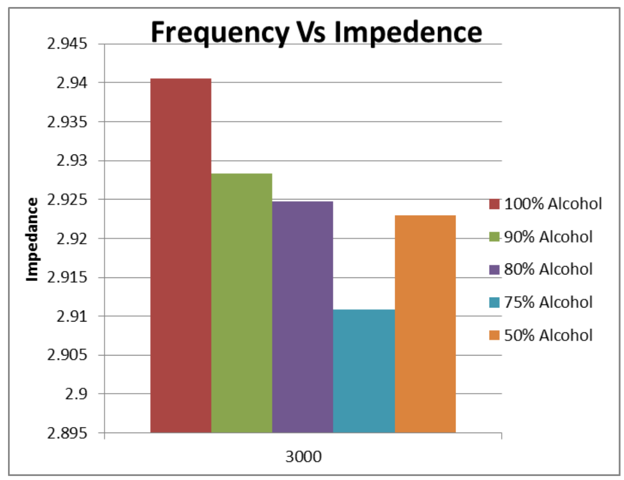

Figure 4: *Showing sensor response at a fixed frequency*

An almost linear relationship was obtained when a graph of different alcohol concentrations was plotted against change in resistance.

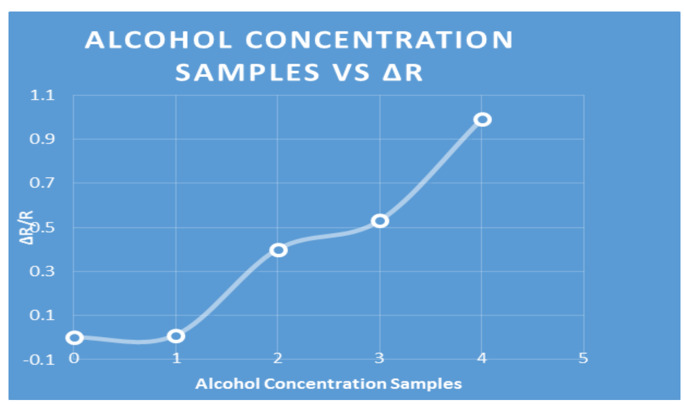

Figure 5: *Showing change in resistance at different concentration of IPA*

When the graph of Time Vs Impedance for different alcohol samples were plotted, the results obtained were as shown in the Fig. 6. It has been observed that Impedance of different alcohol concentrations continuously decreased. Water had the highest impedance, followed by Isopropanol, Butanol, and Ethanol. This analysis was performed by continuous exposure of various alcohols after re-setting the sensor using micro-heater attached with the silicon substrate.

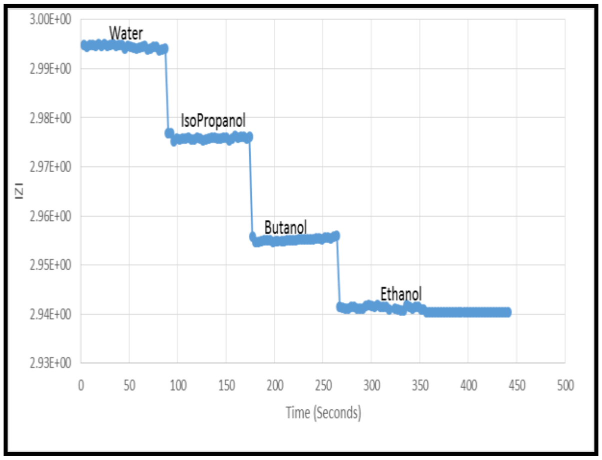

Figure 6: *Showing impedance for different samples of alcohol at fixed frequency (3kHz).*

Finally, the graph of different alcohol samples was plotted against the impedance values obtained (Fig 7). Various alcohol samples like Ethanol, Butanol, and Propanol were tested and it was noted that the impedance linearly decreased from Propanol to Ethanol.

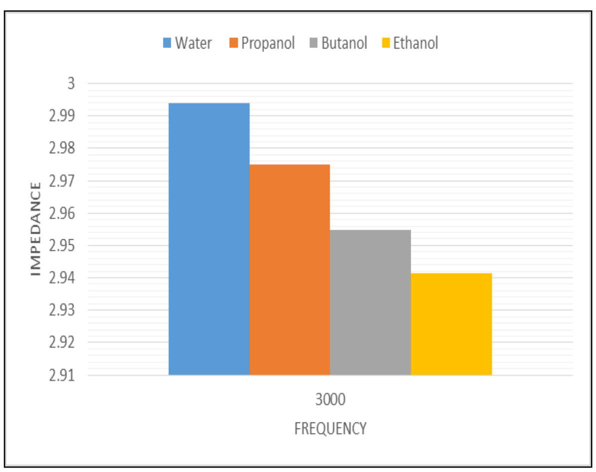

Figure 7: *Showing Different Alcohol samples Vs Impedence.*

IV. Conclusions

In this work, vertically aligned Carbon Nanotubes were grown on the silicon substrate. Initially, a frequency sweep was performed from 50Hz to 5000Hz, it was observed that the maximum gain occurred at 3000Hz.Various alcohol samples (Ethanol, propanol, butanol) of different concentrations were tested and it was found that the sensor is capable of detecting the change in the concentration with respect to the sample by showing a change in the impedance values. The sensor was also capable of differentiating between different concentrations of alcohol by showing a change in the impedance value. It can also distinguish between water vapours and alcohol samples by showing a hike in the impedance value. Hence, a vertically aligned CNT alcohol sensor was developed.

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