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A CNT-based artificial nose for food spoilage detection

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Abstract - *The proposed paper is regarding an artificial nose in the shape of a box, in which food can be stored. The box determines whether the food stored in it can safely be eaten, or if the food should be thrown away because it is spoiled. The box uses a carbon nano tubes (CNTs) based nano-sensor to detect the waste gas produced by food-bacteria and quantify its concentration. The CNTs will be deployed on the box-cover substrate via spray technique. The detection will take place via conductometric measurements of the resistance of the CNTs before and after the exposure to the waste gas. In this way the box can indicate to the user if it is no longer safe to consume the food in the box, and thus it might prevent the user from getting stomach-related sickness.*

Key Words: **Biosensors, Chemiresistor, Carbon Nano Tubes, Bacteria**

1.INTRODUCTION

In the last decade, the field of bio sensing was thoroughly revolutionized by the introduction of Nano-materials, able to function as Nano-sensors. Bio sensing revolves around using variety of methods, mostly analytical devices, to diagnose, analyze and quantify the existence of biological entities, such as enzymes, proteins and bacteria in a specific system. It has been proved before that using Nano-sensors in this field yield high quality results in terms of accuracy, quickness and efficiency.

This paper will focus on the subject of food freshness, And bacteria growth detection. Food wasting is an ever growing issue, especially in developing countries. Around the world, 35% of the produced food is never consumed, and eventually gets thrown away. A big portion of this number is cause by perishable food, which gets spoiled mostly by bacteria growth. Easy and quick detection of spoiled perishable food may reduce this number and also prevent illness from unaware consumers of perishable food.

In most households there are some boxes of food laying for a few days in the refrigerator. When those boxes are opened, we have a special sense which alerts us if the food we want to eat is spoiled – it is olfaction, the sense of smell. Nevertheless, sometimes this sense is failing us and as a result, we get a tummy ache or even get sick. In order to improve the abilities of that sense we came up with a tool that mimics that sense with more sensitivity to the signals we get from the spoiled food. This tool might prevent us from second guessing whether we should eat non-fresh food or not, lowering the risk of tummy aches and sickness.

2. Literature Review

2.1 Biosensors

A biosensor is an analytical device capable of converting a chemical response to interaction with a biological entity to a measurable and quantifiable signal, such as an electrical current or heat expulsion. The general process includes a bio-receptor which bind to the desired chemical, causing a chemical reaction and change in electrical or thermal properties of the structure. The change is recorded and converted to a proportional signal for further analysis. Bio-sensors are able to interact and detect a variety of chemicals, mostly in gas form.

2.2 Chemiresistor

Chemiresistor is a material which responds to changes in the chemical environment by changing its electrical resistance. Direct chemical interaction between the samples, gases for example, and the chemiresistor results in a change of charge distribution in the material compared to its equilibrium state. The change in resistance is proportional to the amount of the chemical reaction, so it is possible to quantify the concentration of the sample in the nearby environment. The architecture of a classic chemiresistor is composed of the sensing material and two electrodes which cover it from both sides. The electrodes measure the electrical resistance of the material.

2.3 Carbon Nano Tubes

Carbon Nano-tube is a Nano-structure of carbon atoms in the form of a cylinder, composed of six sided carbon rings. It is in a Nano scale range in two dimensions, with extremely high length-to-diameter ratio. Carbon Nano tubes are functional in low temperature environments, hence, can operate in room temperature. Low energy consumption and sub-ppb concentration level detection makes the Nano-tubes the perfect candidate for gas detection expelled from bacteria. The Nano-tubes are P-type conduction, so interaction with an electron-donating sample result an increase of the electron-hole recombination and a decrease in conductance. Interacting with an electron-withdrawing sample result the opposite effect. Forming a structure of Nano-tubes net will enable us to detect the presence and concentration of a required element over a large area.

2.4 Bacteria And Food Spoilage

The most common cause of food spoilage is the growth of bacteria. Either found naturally in the food or added by some external source, the presence of harmful bacteria in consumed food may cause variety of illnesses. Most bacteria consume the oxygen in the surrounding, the sugars, fats and proteins present in the food source in order to grow and reproduce. Amidst the growth and reproduction process, the bacteria expel waste in the forms of harmful acids and proteins, and variety of gases such as CO_2, H_2S and NH_3. High concentration of these gases in the sample's surrounding suggests a possible process of spoiling. In general, the process of food spoilage is a long process, taking between few hours and few days, so it is slow enough to enable easy detection and prevention using appropriate manners. Beside the need for consumables, most of the bacteria types require "convenient" temperature for them to grow and reproduce. Because of that, proper refrigerating may prevent spoilage. Common types of relevant bacteria are: E Coli, Salmonella, Brochothrix and others.

3 Design

The sensing system for the detection of spoiled food will be designed as a regular food storage box. The sensor itself will be placed on the cover of the box. The box will be made of glass or a polymer like PET. The cover will be used as a substrate plate for the fabrication of the sensor on it, and from the other side of the cover, the external side, will be a device connected to the sensor via wiring. The device will analyze the signal that is coming through the sensor. on the external side of the cover there will be a small red

LED that will turn on once the signal from the sensor indicates food spoilage.

4 Fabrication

For creating the sensor layer on the glass/polymer substrate a deposition by spray technique will be used. The deposition will be by air atomizing nozzle which will spray the CNT films on the cover of the box which is the substrate. The operation will be using a wet spraying regime and the substrate will be heated so the drying of wet droplets arriving at the substrate will be faster (fig 1). For the formation of the wet spraying regime the CNTs will be dispersed in an aqueous solution by using a surfactant. Finally, in order to change the film's behavior from insulating to conductive, chemical post deposition treatment is necessary to remove the CMC-matrix embedding the CNTs.

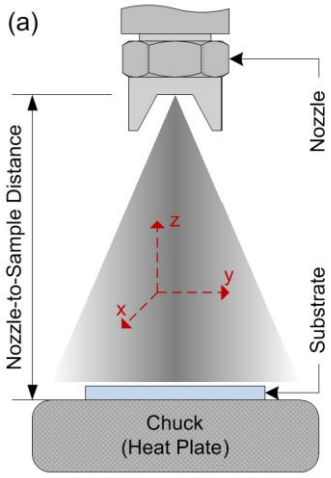

Fig. 1. Schematic drawing of the spray setup

5 Detection

As we previously explained, a biosensor is an analytical device which converts a biological response into a quantifiable signal. Due to the shape and to the surface to volume ratio of CNTs, the influence of binding with a molecule will be big enough to be detected.

Typically, in (bio-)electrochemistry, the reaction under investigation would either generate a measurable current (*amperometric*), a measurable potential or charge accumulation (*potentiometric*) or measurably alter the conductive properties of a medium (*conductometric*) between electrodes. These different phenomena need specific devices to allow them to detect the signal and compute it. Our method of choice is the conductometric method, which means we will measure the conductance of the CNTs sprayed on our box-cover substrate. By analyzing the changes of the conductance values we will be able to determine the concentration of bacteria-associated gas.

In order to measure the conductance, we will use 3 electrodes – A working electrode, a counter electrode and a reference electrode. The reference electrode, commonly made from Ag/AgCl, is kept at a distance from the reaction site in order to maintain a known and stable potential. The working electrode serves as the transduction element in the biochemical reaction, while the counter electrode establishes a connection to the electrolytic solution (the CNTs in our case) so that a current can be applied to the working electrode. These electrodes should be both conductive and chemically stable. Therefore, platinum, gold, carbon (*e.g.* graphite) and silicon compounds are commonly used, depending on the analyte. The higher surface-to-volume ratio of nano-objects makes their electrical properties increasingly susceptible to external influences, especially as these structures continue to shrink towards the atomic limit. Since the nanometer dimensions of these objects are comparable to the size

of the target biomolecules, higher measurement sensitivity may result, and sensitivity may also increase due to higher capture efficiency which will provide us a high level of accuracy.

We also have to keep in mind that the overall device should be compatible with food (by containing non-toxic or harmful materials) and should be relatively cheap in order to make the entire process economically feasible.

As we previously explained, during food decomposition proteins, sugars and lipids are degraded by all kind of bacteria producing waste gas. Our goal is to detect them before they reach a critical level and alarm people before their consumption.

Due to their shape and to the surface to volume ratio, nanotubes will be perfect for this job. The CNTs are able to bind to the different gas molecules emitted during the food decomposition and consequently change their resistance value. This change in value is exactly what our sensor will measure and by quantifying it we will be able to determine the state of the food in question.

3. CONCLUSIONS

In conclusion, in this paper we propose the use of a special box which can determine the state of food, thus serving as an artificial nose. We think this king of solution can prevent a lot of grief in the shape of food poisoning and stomach aches. As we all use plastic or glass boxes to preserve our food in refrigerators, we can all use this kind of system to know when it is unsafe to consume the contents of the food we keep. We think this kind of box can change our lives for the better and possibly make our eating habits safer and healthier.

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