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EFFECT OF APPLIED MAGNETIC FIELD ON SURFACE MORPHOLOGY, OPTICAL AND ELECTRICAL PROPERTY OF TIN (IV) OXIDE (SnO_2) NANOMATERIAL FOR MEAT SPOILAGE DETECTION

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INTRODUCTION

The specter of *botcha* or "double dead" meat is a persistent, if not underestimated, threat in Filipino markets. In 2014, the National Meat Inspection Service (NMIS) recorded the confiscation of more than 12 metric tons of so-called hot meat, unfit for human consumption. The hazard that consuming this and other forms of spoiled meat poses to human health cannot be overstated, especially because spoiled meat can harbor dangerous pathogens or parasites such as *Salmonella, Staphylococcus, Pseudomonas Aeroginosa,* and *Trichinella.*

Currently, the consumer's first, and perhaps only, line of defense is their own manual inspection of meat products—their own knowledge of telltale signs such as discoloration and malodor. Even law enforcement must rely on en masse surveillance and sensory inspection to identify and confiscate hot meat. Needless to say, this process lends itself to unwarranted expense and the possibility of human error.

Pertinent to safeguarding consumers' rights to safety and organoleptic quality of meat products is the development of materials sensitive to the detection of meat spoilage. Such a device would greatly aid the implementation of local laws against "double dead" meat and increase efficiency and accuracy when it comes to upholding product standards. Ideally, this tool would be highly portable, extremely sensitive and selective, and operational under a versatile range of external conditions, at minimal production cost.

Gas production is typical of the bacteria or toxins involved in meat spoilage, making gas-sensing technology a viable indicator. Some of the gaseous substances produced in the involved chemical reactions of bacterial metabolism are carbon dioxide, acetone, methanol, and ethanol. High surface area, low toxicity, and low cost make nanostructured tin (IV) oxide (SnO_2) an appropriate material for a gas sensor, as it undergoes sensitive changes in resistivity upon contact with gas. Exposure to applied magnetic field (AMF) during fabrication can greatly affect the characteristics of SnO_2 nanomaterial and subsequently its potential application for gas sensing.

Existing methods for preventing microbial diseases depend on controlling different types of pathogenic bacteria by food safety management and through medical and environmental observation (Meng&Doyle, 1998). The polymerase chain reaction (PCR) is mainly used in research in food microbiology for the identification of bacteria genus and species due to its high efficacy and accuracy. Although PCR is an advanced technology, inhibitors that occur in foods or the culture media could affect the reaction. However, this technology cannot differentiate between active cells and inactive dead cells so it could lead to false result and thus fail to reflect bacterial numbers accurately.

This study investigated the effects of AMF on the surface morphology and elemental composition of SnO_2 nanomaterials. Nanostructured SnO_2 was fabricated through horizontal vapor phase growth (HVPG) deposition with variable AMF. The nanomaterials were then characterized through scanning electron microscopy (SEM) to determine surface morphology and energy dispersive x-ray (EDX) for elemental composition. Optical properties and electrical characterization were also examined through photoluminescence spectroscopy and the van der Pauw method, respectively. Finally, the gas-sensing ability of the nanomaterial with spoiling meat samples was assessed and compared against a control sample, and a prototype portable meat spoilage detector was fabricated and tested.

RESULTS

FABRICATING TIN OXIDE NANOMATERIALS WITH APPLIED MAGNETIC FIELD

The deposition, nucleation, and growth of the SnO_2 nanowires followed the vapor-solid and vapor-liquid-solid process. The nanowires were grown in a quartz tube, with varying temperatures, growth times, and with varying intensities of AMF. The presence of AMF during fabrication resulted in the formation of nanowires with higher density and more highly defined structure, as apparent in the SEM micrographs. The temperature gradient was found to have a greater influence on nanowire growth as well. The optimal morphology of the nanowire was generated farther from the furnace at section 3b, with magnetic field at 3100 G, and growth time of eight hours.

In contrast, nanomaterials fabricated without AMF showed less defined structure, more irregularities, lower density, and a direct proportionality of diameter to growth time, indicating that the synthesis of homogenized one-dimensional tin oxide nanowires was significantly more successful with the use of AMF. With regards to elemental composition, EDX spectroscopy revealed the presence of tin (Sn), oxygen (O), and silicon (Si) in the samples. The silicon is explained by the use of the quartz substrate (SiO_2) during fabrication. The varying ratios of Sn to O suggest that growth occurred via the vapor-solid process as well.

Photoluminescence spectra were obtained using Applied Spectral imaging SD-300, while direct current measurements were taken with the Keithley 2400 source meter and 2010 multimeter. The nanowires grown with AMF showed red light emission and a greater area of luminescence, giving an energy gap of 1.7-1.9 eV that decreased with longer growth time. A decrease in resistivity was also observed proportional to AMF intensity and growth time. On the other hand, nanowires grown without AMF had increasing resistivity and resistance, and blue light emission with an energy gap around 2.6-2.9 eV. It should be noted that the greater density of nanowires in the sample corresponds to the lower resistivity values. Overall, these results indicate that the use of AMF in fabricating nanomaterials is favorable for optimizing the morphological, optical, and electrical properties for gas detection.

CONSTRUCTING A PROTOTYPE GAS SENSOR FOR DETECTING MEAT SPOILAGE

To evaluate the gas-sensing capacity of the fabricated nanomaterials, the responsiveness and sensitivity to various volatile substances was compared against a control sample. Voltage measurements were carried out with a Pasco Scientific voltage sensor. The gases tested were carbon dioxide, acetone, ethanol, and methanol. Carbon dioxide is an end product of aerobic cellular respiration, while acetone is produced during fermentation by anaerobic species, as are the alcoholic compounds methanol and ethanol. To generate spoiled meat samples for testing, fresh pork and beef samples from Monterey meat shop were allowed to spoil at room temperature for three days.

The experimental sensor substrate was found to be responsive to these four gases. This response was determined by the observation of characteristic changes in the measured voltage corresponding to each gas. These gases are among the common products of the chemical reactions involved in the spoilage of meat, making them important indicators of spoilage—thus, their detection can be the basis of a device to assess meat quality. Importantly, the sensor substrate did not show significant response when the headspace gas was from fresh meat, which points to a lower probability of getting false positive results.

Following the above results, a prototype for a portable spoiled meat detector utilizing the SnO2 nanomaterial was fabricated. Initial testing of the prototype showed a characteristic response when detecting spoiled meat headspace gas. The prototype was also found to have a significantly shorter recovery time compared to the earlier tests that, along with the relatively low cost and lightweight construction, is an important feature of a portable detector.

POLICY RECOMMENDATION

One of the foremost considerations in the meat industry, especially for policymakers, is the protection of consumers' rights to high quality products that are safe to consume. To this end, the visual inspection based methods currently employed by law enforcement, which are subject to the limitations of subjectivity and human error, as well as incurring cumulative expense, present an area for improvement towards efficiency and accuracy. This study has shown that tin oxide nanomaterial fabricated with applied magnetic field has optimal characteristics for gas sensing, and is applicable when it comes to detecting spoiled meat. Therefore, the use of AMF fabricated SnO2 nanomaterial is recommended in the development of a spoiled meat detector.

Importantly, the nanomaterial is relatively cheaper to manufacture, and of lightweight construction which maximizes portability—these are important considerations for mass production and usage. The development of a portable spoiled meat detector presents a suitable alternative for agencies such as the NMIS in order to improve their capability to quickly identify and confiscate illicit meat products that are unsafe to consume, especially during peak times of demand such as during the Christmas season, with frequent *botchas* cares in the markets. As a mass-produced device would be pre-calibrated and has a digital readout, making it relatively easy to operate, it could be distributed to officials at the local level who would be trained in using and maintaining it. In addition, the possibility of obtaining empirical evidence on those who are selling hot meat makes it easier for the government to prosecute them.

The device's use is not limited to government agencies, as it would also be relevant to various food and food-related enterprises and services, such as dining establishments that want to make sure that they are purchasing quality ingredients. Aside from commercial entities, there is also likely a demand among private consumers who want to be able to guarantee their own safety with the products they buy for home. As a final note, as for recommendations for future studies, other parameters of nanomaterial fabrication such as furnace orientation, ramp time and rate, cooling rate, amount of SnO2 powder, size of the quartz tube, and variation in magnetic field intensity can also be investigated to optimize the nanowire synthesis. An important area of investigation is developing further sensitivity to various types of meat such as fish, chicken, and others, as well as correlating the specific sensor response to the stage of meat spoilage. This could be potentially achieved by utilizing an array of doped SnO2.

Reference:

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