

Coaxial Electrospinning of Tin Oxide to Improve Its Gas-Sensitive Properties

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Abstract— SnO₂ porous nanofibers doped with Cu were prepared using coaxial electrospinning technology. A solution of SnCl₄ with [(5%) Cu(ch₃coo)₂] was spun with a quantity of organic polymer PVA at a concentration of 15% (w/v), used as the core, and confined with a PVA solution at the same concentration to form the shell. The applied electric potential was 24KV. Core and shell were spooned on collector formed from glass slides on aluminum foil. The spun fibers were heat-treated at 350°C to obtain (SnO₂/Carbon) porous nanofibers. The energy band gap was calculated from the UV-VIS absorption spectrum, and it was found to be 2.86 eV. Atomic force microscopy (AFM) images were acquired to study the morphology of the (SnO₂/Cu/Carbon) porous nanofibers. and the nanofiber diameter and surface roughness were calculated. The operating temperature of the prepared sensor was measured. The sensor's sensitivity was tested for H₂S and H₂ gases.

Keywords— Coaxial electrospinning, Porous Nanofibers, Polymer, Gas Sensor.

I. INTRODUCTION

Nanofibers overcome aggregation during dispersion in an aqueous medium due to their fibrous shape. The nanoscale dimension provides a high surface-to-volume ratio, making them important in modern applications. Nanofibers differ from nanoparticles in terms of dimension ratios and are unlike nanotubes due to their crystalline properties.

Nanofibers can be prepared within the submicron to nanometer range from polymers with different physical and chemical properties.[1]

The diameters of nanofibers are mainly determined by the nature of the polymer used, the different treatments, and the method of preparation. Electrospinning is the most widely used technology due to its advantages, such as simple preparation and good fiber production. There are several types of electrospinning, including coaxial spinning.

Coaxial electrospinning is an advanced nanotechnology that offers flexibility and practicality in producing core-shell nanostructures. A concentric spindle [1] allows for the injection of one solution into the other at the needle tip, while simultaneously drawing the core solution into the outer solution to produce hollow or shell nanofibers [2]. It has been widely applied in controlling nanofiber structures, solar cells, fuel cells, and energy storage.[3]

Solutions acquire a positive electrical charge when a high electrical potential is applied to them. The positive charge accumulates on the surface (shell), which is the outer surface of the solution coming out of the axial capillaries, as in Figure 1-A. The droplet of the solution (shell) elongates and extends due to the repulsion of the charge and the like charge to form a Taylor cone, as in Figure 1-B. Once the accumulation of charge reaches the threshold value due to the increase in the applied potential, a fine jet of liquid extends from the cone, as

in Figure 1-C.

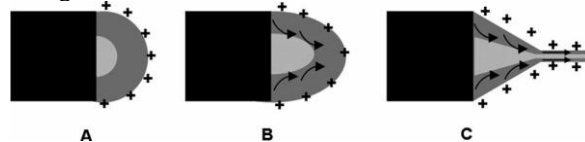


Figure (1): Schematic diagram of the formation of a compound Taylor cone.

Surface charges on a shell solution, (B): The viscous drag exerted by a deformed shell droplet on a core, (C): The (core-Shell) composite Taylor cone which is formed as a result of the continuous viscous drag.

Stable spinning relies on an outer shell solution that pulls the inner core solution through shear forces, contact forces, electrical drag forces (responsible for fluid pulling), and contact friction forces, which keep the inner solution confined within the core solution during fiber tension.[4]

Tin oxide (SnO₂) is a promising semiconductor with an energy gap of 3.6 eV. Tin oxide has gained significant importance when prepared as nanofibers using coaxial electrospinning. This technique offers unique control over the fiber structure and crystalline composition, resulting in hybrid materials with combined physical and chemical properties and high sensitivity to various gaseous compounds and volatile solutions—a capability not achievable by conventional methods.[5]

II. The importance and objectives of the research:

- Preparation of porous fibers characterized by their nanostructure and large length-to-surface ratio by the axial electrospinning method.
- Increased conductivity and reduced operating temperature of the tin oxide gas sensor

Experimental study

3-1 Method of preparing and spinning nanofibers:

Electrospun metal oxides have unique properties that are not achieved by traditional methods, and electrospun tin oxide has been chosen.

Preparation method:

To prepare nano-tin oxide, 7g of tin (IV) oxide was added to 50ml of distilled water and then mixed using a magnetic mixer with the addition of 2g of PVA and left for 4 hours until it was completely dissolved at 60°C. Copper acetate was added at a rate of 5% of the tin oxide ratio, which is the method of preparing the core. Then the resulting material was filled into a first syringe.

2g of PVA was dissolved in 50ml of distilled water and stirred at 60°C in a mixer for 4 hours until completely dissolved. This is the method for preparing the shell. The resulting solution was then placed in a second syringe, and the needle of the first syringe (0.2mm diameter) and the needle of the second syringe (0.5mm diameter) were inserted.

The fibers were placed on an electrospinning machine, and the spindle speed was adjusted to control the amount of spun liquid. The voltage was set to 24 kV, as shown in Figure 2 [6]. The fibers were heat-treated at 350°C for two hours, then gradually at a temperature C to preserve the wafer.

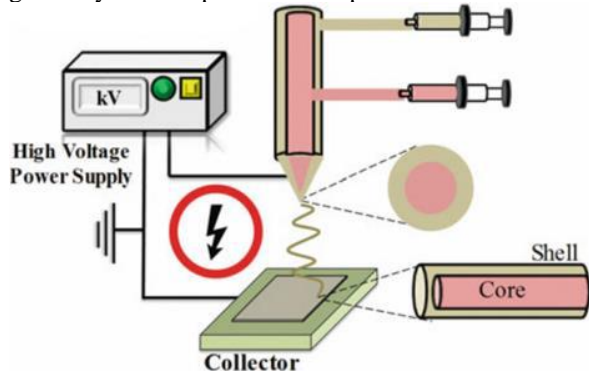


Figure (2): Schematic diagram of an axial electric spinning device

III. Measurements and discussion:

Optical measurements:

The aim is to determine the restricted field width of nanofibers prepared from (SnO₂/Cu/PVA) and coated with PVA.

The absorption spectrum of the prepared nanofibers was taken before heat treatment using a UV-VIS spectrometer, within the wavelength range (200-1100) nm, where no clear absorption peak appeared for the spun nanofibers, as shown in Figure 3a, which shows the absorption spectrum before and after heat treatment without any peak for the formation of nanofibers. The first peak is due to the π-to-π transition within the polymer used.

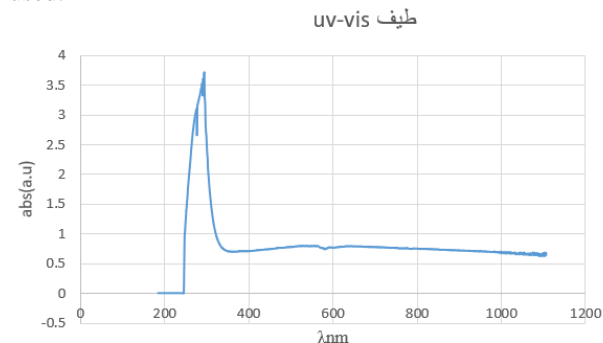


Figure (3-a) UV absorption spectrum before heat treatment

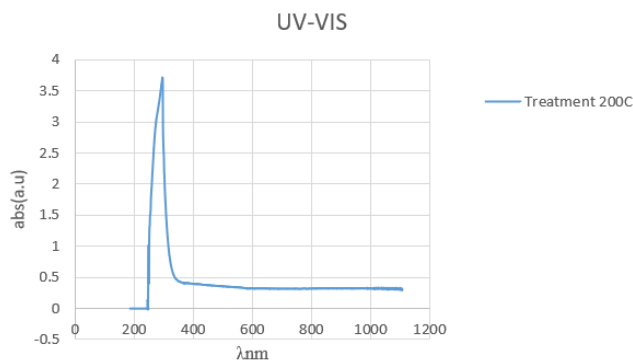


Figure (3-b) UV absorption spectrum heat treatment at 200C⁰

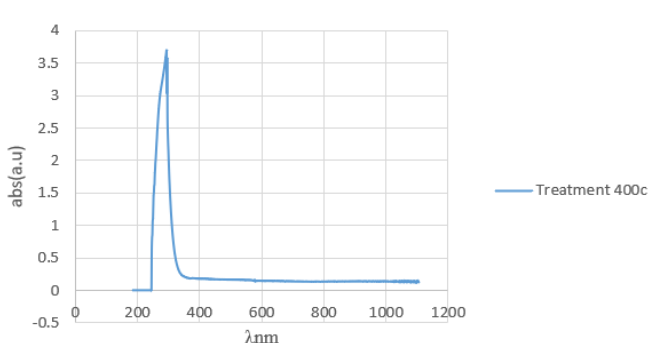


Figure (3-c) UV absorption spectrum heat treatment at 400C⁰

Surface structure:

To determine the surface structure of the spun fibers made of (SnO₂/Cu/PVA), an atomic force microscope (Naio AFM system) was used.

AFM images of the nanofibers showed them as mats of nanofibers (as illustrated in Figure 5). This indicates that the mats contain fibers with a nanostructure. The diameter of nanofibers was calculated, and their average value was 515.6 and 665.2 nm. Average surface roughness was (19.39 and 80.44) nm.

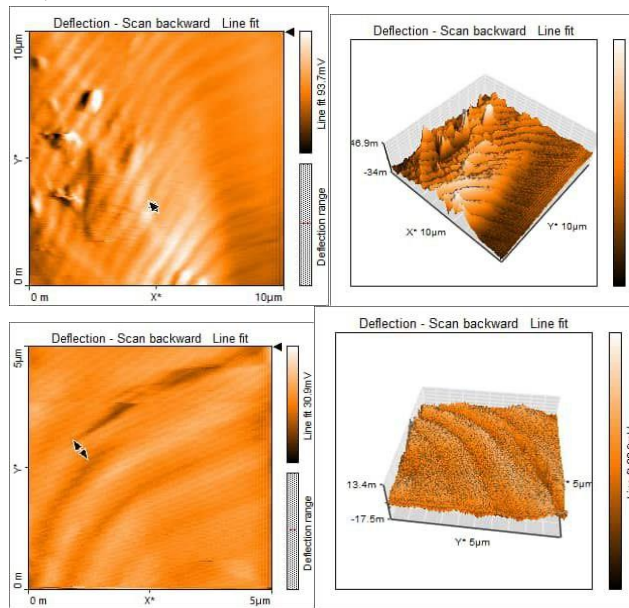


Figure (5): AFM images of the nanofibers

Determining the sensor's operating temperature:

To determine the sensor's operating temperature, the changes in sensor resistance with temperature were studied within the range of 25°C to 250°C, as shown in Figure 6.

It can be observed from Figure 6 that the sensor's resistance between 25°C and 100°C was high and on the order of

megaohms.

At 100°C, the resistance began to drop significantly to the order of kilohms. Therefore, 100°C can be considered the threshold temperature at which the resistance changes from infinite to a relatively small value, representing the operating temperature of the gas sensor.

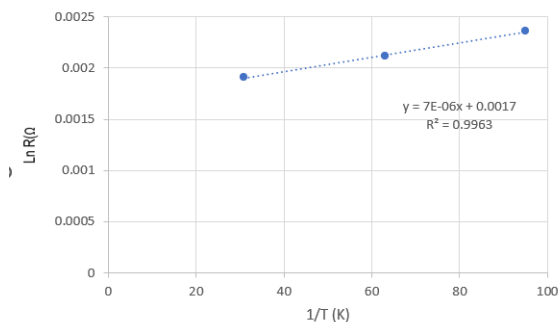


Figure (6) Changes between the logarithm of resistance and the inverse of temperature

Tin oxide nanoparticles exhibit high selectivity at low temperatures and high recovery at low times.

No other temperature values were considered because there is significant electronic and phonon scattering on the surface, resulting in low thermal conductivity due to phonon scattering and low electrical conductivity due to electronic scattering.

IV. Conclusions

- 1- Electrospinning is a simple and inexpensive technique for preparing nanofibers. The optimal processing temperature for obtaining (SnO₂/Cu/PVA) nanofibers is 400°C for two hours.
- 2- Atomic force microscopy images showed that the spun (SnO₂/Cu/PVA) nanofibers had a uniform diameter.
- 3- The ease with which polymer materials can be handled, the ability to form nanostructures from them, and their use in numerous applications are due to their suitable properties.
- 4- The addition of copper as an alloy increased the sensitivity properties, especially the change in resistance with temperature changes.
- 5- The sensor has low thermal and electrical conductivity due to phonon and electron scattering on the surface.

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This paper does not involve human participants.

Originality Note

The authors confirm that the manuscript is their original work, and if others' works are used, they are properly cited/quoted.

V. REFERENCES

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M. A. Batal is a Professor of Physics, born March 11, 1949, of Syrian Arab descent, and fluent in Arabic, English, and French. His academic training includes a Bachelor's degree in Physical and Chemical Sciences (Aleppo), an Advanced Studies Diploma from the University of Lyon (France), a PhD (Third Cycle) in Atomic and Molecular Physics (Lyon 1, France), and a State Doctorate in Plasma Physics from the National Institute of Applied Sciences (INSA), Lyon (France). He has taught university-level physics courses since 1981 and completed research work in England (University of Hull) for six months on laser applications, including plasma-enhanced laser atomization. He is the author of several books—covering topics such as electronics, atomic and molecular spectroscopy, and quantum mechanics—and has led or contributed to research

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