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## BINARY NANOHYBRID OF FLUORINATED CARBON NANOHORNS AND COPPER OXIDE FOR RESISTIVE N-PROPANOL SENSORS

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### **Introduction**

n-Propanol, a colorless and aromatic liquid, is widely used as a chemical raw material in industrial production, including the synthesis of preservatives, cosmetics, detergents, pharmaceuticals, and fuels. Concentrations of 400 ppm in air can be harmful, causing irritation to the eyes, nose, and throat. Additionally, n-propanol is a volatile organic compound often used as a biomarker for the early detection of lung cancer. Studies have shown that patients with malignant lung pathologies exhibit slightly elevated levels of n-propanol in their breath compared to healthy individuals. Semiconducting metal oxides such as WO<sub>3</sub>, SnO<sub>2</sub>, ZnO, TiO<sub>2</sub>, NiO, and Cu<sub>2</sub>O are commonly used as sensitive films in resistive n-propanol sensors due to their ease of fabrication, high sensitivity, and low cost. In this work, the sensitive film used for resistive n-propanol sensors is a binary nanohybrid of the fluorinated carbon nanohorns /Cu<sub>2</sub>O at 1/1 w/w ratio. The detection mechanism is based on the increase in resistance of the sensitive layer with rising n-propanol concentrations.

### **Materials and methods**

The process for obtaining the humidity-sensitive layer of fluorinated carbon nanohorns (CNHs-F) combined with Cu<sub>2</sub>O nanocubes involves the following steps:

#### *Synthesis of fluorinated carbon nanohorns (CNHs-F):*

Fluorinated carbon nanohorns are synthesized via plasma treatment using a mixture of F<sub>2</sub> and N<sub>2</sub> (1:8 volume ratio) at a pressure of 1 bar, in a nickel reactor, at room temperature. The injection time is 6 minutes, with an exposure time of 3–5 minutes. A dispersion of CNHs-F is prepared by dissolving 1 mg of the material in 5 mL of ethanol, followed by magnetic stirring for 5 hours at room temperature.

### Synthesis of Cu<sub>2</sub>O nanocubes:

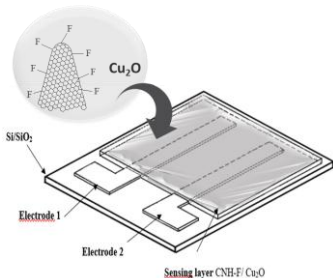
Sodium citrate dihydrate is dissolved in distilled water and stirred magnetically at a constant speed for 60 minutes. A stoichiometric amount of CuSO<sub>4</sub> solution is added to the mixture. After 10 minutes, a stoichiometric amount of NaOH solution is added. An excess of ascorbic acid (30%) is added to the suspension to precipitate Cu<sub>2</sub>O. The resulting Cu<sub>2</sub>O is washed with deionized water and dried under vacuum.

### Deposition and densification of the sensitive layer

Finally, 1 mg of Cu<sub>2</sub>O nanocubes is added to the CNHs-F dispersion. The resulting mixture is deposited onto a Si/SiO<sub>2</sub> substrate with linear or interdigitated electrodes using the "drop casting" method (after masking the contact area). The sensitive layer is densified in a nitrogen atmosphere for 60 minutes at 125°C.

### Results and conclusions

Fluorine atoms, through the electron-attracting effect, increase the number of carriers in both carbon nanohorns.

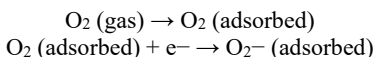


**Figure 1.** Design of the resistive sensor

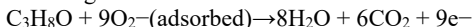
Conduction is achieved through holes (p-type carriers), so the sensitivity of the material to water molecules increases.

The monitoring capacity of n-propanol is investigated by applying a constant current between the two electrodes and measuring the voltage at different values of the n-propanol vapor concentration to which the sensitive layer of the equimassive binary nanohybrid type of fluorinated carbon nanohorns/Cu<sub>2</sub>O is exposed (Figure 1).

The residual O<sub>2</sub> molecules are adsorbed on the Cu<sub>2</sub>O surface, the electrons are attracted by the gas molecules, with the formation of anionic species, according to the reactions below:



When the sensitive film is exposed to propanol, the electrons are released into the conduction band, according to the reaction:



Thus, the whole concentration decreases, ultimately leading to an increase in the resistance of Cu<sub>2</sub>O. Additionally, the Fermi levels of Cu<sub>2</sub>O in the p-p junction made with fluorinated carbon nanohorns form a thick accumulation layer and a thin depletion layer in the sensitive film. Modulating the thickness of the accumulation layer (the carrier conducting channel) significantly influences the conduction of the sensitive layer.

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