# Formaldehyde Resistive Sensor

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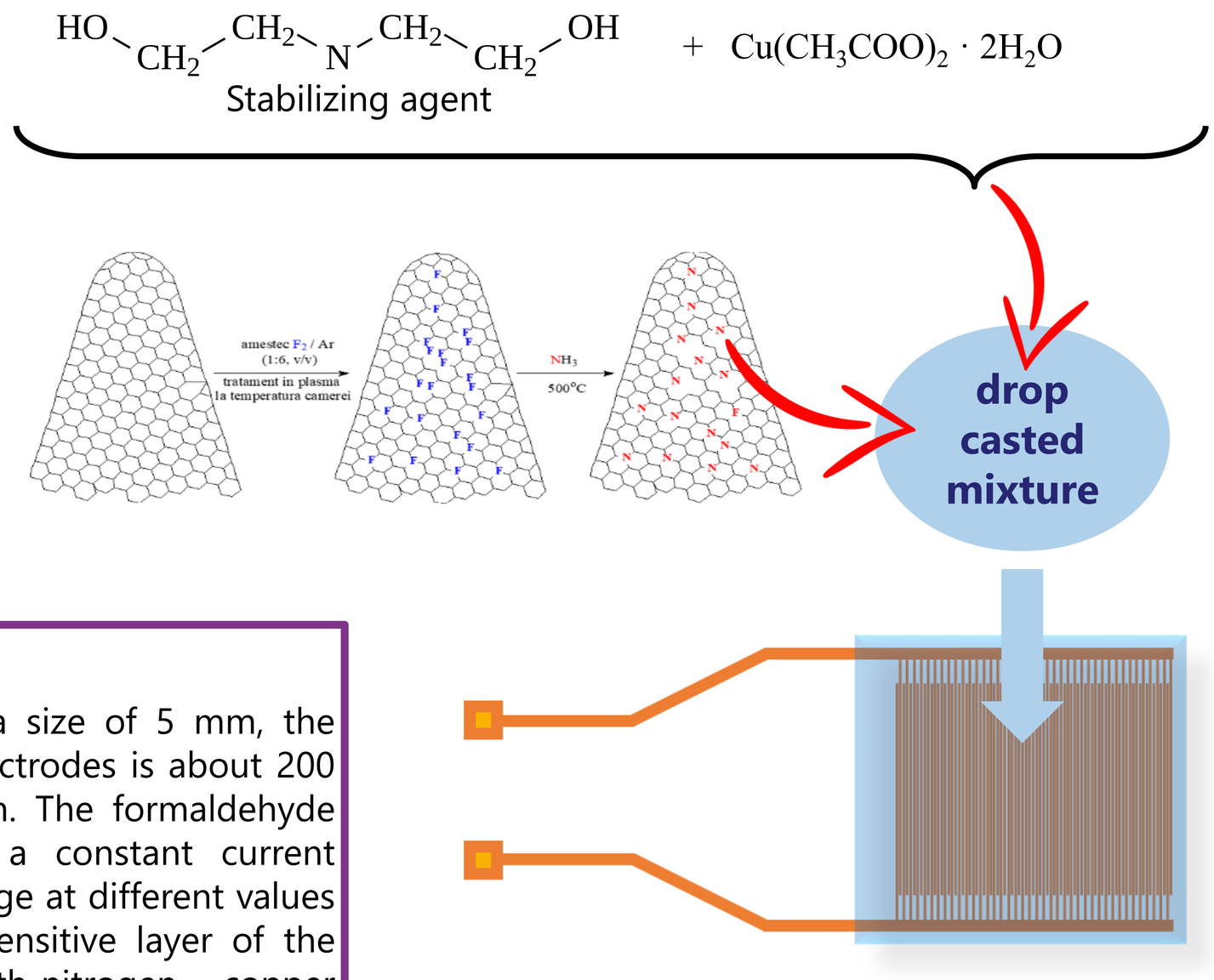
## Field of Invention

Formaldehyde is a volatile organic substance (VOC), flammable, colorless, with a strong smell, and is a valuable intermediate in the chemical industry, light industry, etc. The formaldehyde sources are forest fires, exhaust gases, and cigarette smoke. Pressed wood products, chipboards, and materials frequently used as a base in the manufacture of furniture contain urea-formaldehyde resins that, over time, emit significant amounts of formaldehyde. Formaldehyde is associated with many health risk factors (watery eyes, burning sensations in the eyes and throat, nausea, and breathing difficulties). It has been identified as a major cause of sick-building syndrome (SBS). It is worth mentioning that the International Agency for Research on Cancer (IARC) classifies formaldehyde as a human carcinogen. Considering the multitude of formaldehyde sources, as well as the high degree of toxicity, interest in the manufacture of formaldehyde sensors has grown in recent decades.

## Original approach

The sensitive film described in this invention, which is used to obtain resistive formaldehyde sensors, is a binary nanohybrid of the nitrogen-doped carbon nanohorns (N-CNHs) / copper oxide (CuO) type.
The mass percentage of nanocarbon material in the sensitive layer varies between 70 and 90%. From the point of view of the detection principle, the resistance of the sensitive layer increases with the formaldehyde concentration level.
The decrease in conductivity is explained by the fact that formaldehyde donates electrons to the sensitive layer, reducing the concentration of holes.




## Sensing structure

The sensor substrate is made of $Si/SiO_2$ and has a size of 5 mm, the electrodes being made of gold. The width of the electrodes is about 200 microns, with a separation of 6 mm between them. The formaldehyde monitoring capacity is investigated by applying a constant current between the two electrodes and measuring the voltage at different values of the formaldehyde concentration to which the sensitive layer of the binary nanohybrid type carbon nanohorns doped with nitrogen – copper oxide is exposed.



Electrodes with interdigitated configuration

## Sensor manufacturing

The raw materials required for the synthesis of the CuO / N-CNHs sensitive film are: $Cu(CH_3COO)_2 \cdot 2H_2O$, mixture of isopropanol (solvent) and diethanolamine (stabilizer), and carbon nanohorns doped with nitrogen N-CNHs.

The molar ratio $Cu(CH_3COO)_2 \cdot 2H_2O$ : isopropanol is 1:3, while the mass ratio acetate/stabilizer is 1/1.

The raw materials are mixed by magnetic stirring, which is done sequentially, in two stages: (I) at a temperature of 60 $^0$C, for 1 hour; (II) -at a temperature of 70 $^0$C, for 2 hours. Nitrogen-doped carbon nanohorns N-CNHs are added in the second stage of magnetic stirring. The obtained dispersion is subjected to magnetic stirring for three hours, at room temperature and deposited by drop casting method on a $Si/SiO_2$ substrate with linear electrodes or interdigitated electrodes.

The densification of the sensitive layer is carried out sequentially, in two stages, by thermal treatment, as follows: (I) In the nitrogen atmosphere, for 10 minutes, at a temperature of 300 $^0$C, and (II) In the nitrogen atmosphere, for 1 h, at a temperature of 400 $^0$C.

## Advantages of the proposed sensing layer

- N-CHs give a high specific surface / volume ratio, affinity for formaldehyde molecules as well as a variation in the resistance of the sensitive layer upon contact with the folmaldehyde molecules;
- copper oxide is a p-type semiconductor and has a synergistic effect with nitrogen-doped carbon nanohorns, also p-type semiconductors, when in contact with formaldehyde molecules;
- CuO changes the distribution of pores at the interface with carbon nanohorns doped with nitrogen, increasing their specific surface area;

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