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Fabrication H_2S and NO_2 Gas Sensors from Cu: GO Nano Films by Spin Coating Method

Ali Jabbar Khalaf [1] Abeer S. Alfayhan[2]

[1]Ministry of Oil, Midland Refineries Company, Najaf Refinery ,Iraq
E-mail : ali_sd1984@yahoo.com
[2]Department of Physics, College of Science, University of Babylon, Iraq,
sci.abeer.saleem@uobabylon.edu.iq

تصنيع متحسسات غاز H_2SوNO_2 من أفلام Cu : GO النانوية باستخدام الطلاء المغزلي

علي جبار خلف[1] عبير سليم الفيحان[2]
[1] وزارة النفط ,شركة مصافي الوسط , مصفى النجف , العراق
[2] جامعة بابل , كلية العلوم , قسم الفيزياء ,

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ABSTRACT

Background

· Material: Copper-doped Graphene Oxide (Cu:GO) nanocomposite thin films.
· Technique: Spin coating, chosen for its speed, simplicity, and ability to produce uniform organic thin films on flat substrates.

Materials and Method

- Process Variable: Spin speed was systematically varied at 3000, 4000, 5000, 6000, and 7000 rpm (with corresponding variations in film weight/thickness).
- Target Gases: Hydrogen sulfide (H_2S) and nitrogen dioxide (NO_2).
- Testing Conditions: Constant operating temperatures ranging from 100°C to 200°C.

Results

A clear, inverse relationship was observed between operating temperature and gas sensitivity. Sensitivity diminished as temperature rose across the tested range (100-200°C).

- Effect on Sensor Kinetics: Increased operating temperature negatively impacted the sensor's dynamic performance:
- Increased Response Time: The sensor took longer to reach its maximum response upon gas exposure

Conclusions

The prepared Cu:GO nanomaterials demonstrate strong potential as effective gas sensors for H_2S and NO_2.· The spin coating method proves to be an excellent, scalable fabrication technique for creating a uniform sensing platform.· The operating temperature is a critical parameter that requires optimization, as it presents a trade-off: higher temperatures may improve reaction kinetics but, in this case, reduce overall sensitivity and recovery. This work provides a promising platform for sensitive and selective gas detection, with potential applications

Keyword: thin film, operation temperature, sensitivity, gas sensor, spin coating.

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INTRODUCTION

Carbon nanostructures are studied in great depth because they have unique properties and can be used in many ways. There are many types of carbon, but graphene is one of the most talked-about right now because it has some really great properties [1,2]. Graphene is very good at conducting electricity, being strong, and keeping heat in. The area of graphene's surface is 2620 m$_2$. It has a strength of 130 GPa and a Young's modulus of 1 TPa. At room temperature, it has a very high electronic conductivity, and the speed at which electrons can move through it is 2.5×10^5 cm^2/Vs. About 3000 Wm/K is how much heat it moves. The special two-dimensional structure of graphene is made up of a single layer of sp$_2$ hybridized carbon atoms. Transferable graphene with a single layer A first step in making nano sheets was to mechanically peel off bulk graphite using the Scotch tape method [3]. Nanotechnology is any technology that works on a nanoscale and can be used in the real world. Nanotechnology is made up of. The construction and implementation of physical, chemical, and biological systems on submicron to atomic or molecular scales, in addition to the incorporation of the resultant nanostructures into larger systems in the early twenty-first century, nanotechnology, similar to information technology, semiconductor technology, and cellular and molecular biology, is anticipated to exert a significant influence on both society and the economy. Materials and manufacturing, Nano electronics, medicine and healthcare, energy, biotechnology, information technology, and national security all stand to benefit from nanotechnology research. The fourth industrial revolution is widely regarded as nanotechnology [4].

EXPERIMENTAL

A thin film of Cu:GO was created using the spin coating method at rotation speeds of 3000, 4000, 5000, 6000 rpm and 700 rpm and rotation times of 10 s. In 5 ml of dimethyl sulfoxide (DMSO), 0.1 g of Cu was dissolved. At room temperature, the solution was then applied to a glass slide. To summarize, cleaning the glass substrate is a good way to go. Scrub the surface of the substrate gently with a water-based cleaner to remove any oil or dust that has adhered to it. Rinse for 15 minutes in an ultrasonic unit with distilled water in a clean beaker. The second step is then repeated, but this time the distilled water is replaced with pure alcohol, which reacts with contaminants such as grease and some oxides. The slices are then blown dry and wiped with fine paper. As a research substrate, interdigitated electrodes (IDEs) are used. Detector of Gases The variation in resistivity caused by exposing the thin film surface to gas (H_2S,NO_2) is measured. Using this simple and inexpensive method of work, we obtained satisfactory results on high surface energy, high tensile energy, and high adsorption energy. The following tests were carried out: After opening the test chamber, place the sensor on the heater. When necessary, electrical connections are made between the fed pin, the spring-loaded sensor pins, and the thermocouple. When you do this, the test chamber is closed. The circulating pump is then used to evacuate the test chamber. A temperature controller is used to set the required operating temperature of the sensor. Using needle valves, the flow rate of the carrier gas flowmeters is then adjusted and tested. The gas of known concentration in the chamber is allowed to flow into the test chamber by opening the valve. The variance of the sensor resistance is measured for a known concentration of a gas ratio. Digital Mustimeter (UNI-UT81B) PC Testing The digital

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mustimeter first records the air flow bias current, then turns on the test gas for a few seconds until the current has a low contrast, and finally turns off the test gas to record the recovery time. A k-type thermocouple (XB 9208B) is employed to take the temperature. For the bias voltage, the power supply (FARNELL E350) was responsible. Resistance is determined utilizing a Fluke Digital Mustimeter (8845A or 8846A). To determine whether the sensitivity of the films varies with operating temperature, inexpensive and straightforward spin coating was used to deposit Cu-doped and un-doped thin films onto glass substrates.

RESULTS AND DISCUSSION

1- The determination of the operational temperature of the sensor.

One of the most prevalent drawbacks associated with Cu:GO gas sensors is the requirement of elevated temperatures for their optimal operation. The impact of the operating temperature on thin films is a direct consequence of this. The primary objective of the study of sensitivity is to minimize the operating temperature of the system to its lowest attainable value. The term "operating temperature" is used to describe the temperature at which the resistance of the sensor reaches a steady state. The user's text is already academic and does not require any rewriting. Resistive sensors are widely recognized as the dominant and cost-effective category of sensors. These sensors have been utilized to measure a wide variety of physical and chemical properties. Gas sensing is a phenomenon that occurs as a result of a surface reaction between chemisorbed oxygen and oxidizing gases. The user provided a numerical reference [6]. The surface of the film can undergo two distinct forms of oxygen adsorption: physisorption and chemisorption. At elevated temperatures, the chemisorption process exhibits predominance. Elevating the system's operating temperature will result in the presence of activation energy, which is necessary for the transition from physisorption to chemisorption. According to a report, there is a positive correlation between temperature and the adsorption of oxygen on the sensor's surface [7]. The sensitivity of the gas H_2S is depicted in Figure 1, illustrating its relationship with the operating temperature within the range of 100–200 °C. The Cu:GO thin films were deposited on FTO substrates, and all samples were subjected to an air mixing ratio with a bias voltage of 5 volts. The temperature range illustrated in this figure spans from 100 to 200 °C. This phenomenon can be attributed to a recent surge in the reaction rate occurring at the surface of the target gas. The user's text is already academic and does not need to be rewritten[8]. The optimal temperature for all films has been determined to be 200 degrees Celsius, as it exhibits the highest temperature values. There is a possibility that the activation energy at this temperature would be sufficient to complete the chemical reaction. Changes in sensitivity can be used as a measure of the gas absorption and desorption processes, as we have also discovered. The level of sensitivity exhibited by the NO_2 gas is visually depicted in Figure 2. A sensor was fabricated utilizing chains characterized by robust covalent bonds along the c-axis while exhibiting solely feeble van der Waals interactions between them. The sensor was designed to function effectively at ambient temperatures, specifically 26 degrees Celsius. As a consequence of this phenomenon, the energy requirements for gas adsorption and desorption are comparatively minimal, thereby conferring the advantage of operational feasibility at ambient temperatures [9]. The user has provided a numerical reference.

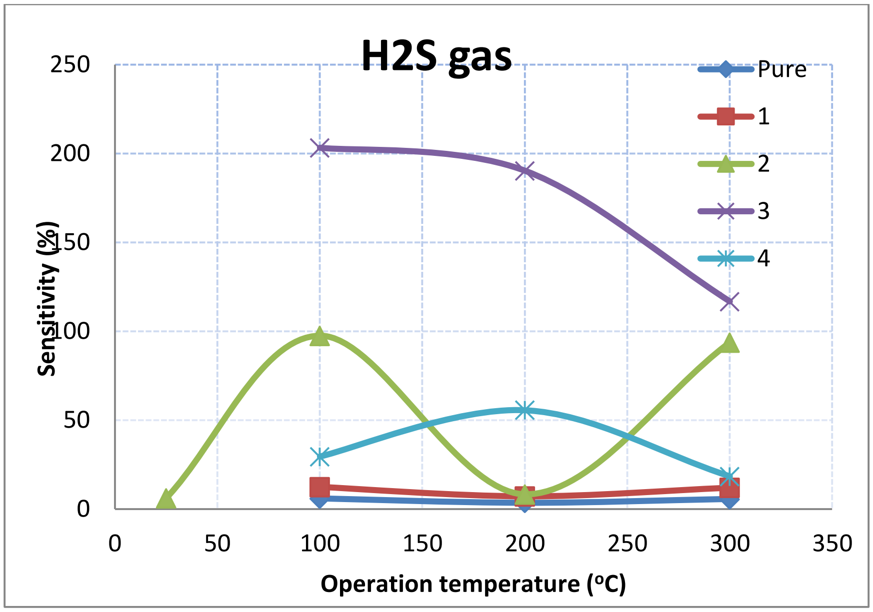

FIGURE 1. The sensitivity varies with the operating temperature of the 1- pure Cu$_{1\%}$ 2- Cu $_{9\%\ wt}$, GO $_{1\%\ wt}$ 3- Cu $_{8\%\ wt}$ GO $_{2\%\ wt}$ 4- Cu $_{7\%\ wt}$, GO $_{3\%\ wt}$ 5- Cu $_{6\%\ wt}$, GO $_{4\%\ wt}$ thin films (H_2S gas).

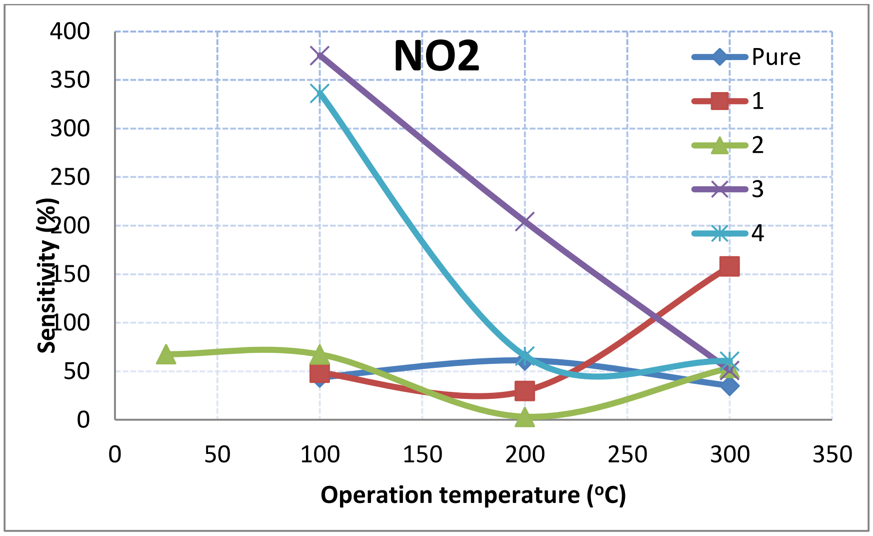

FIGURE 2. The sensitivity varies with the operating temperature of the 1- pure Cu$_{1\%}$ 2- Cu $_{9\%\ wt}$, GO $_{1\%\ wt}$ 3- Cu $_{8\%\ wt}$ GO $_{2\%\ wt}$ 4- Cu $_{7\%\ wt}$, GO $_{3\%\ wt}$ 5- Cu $_{6\%\ wt}$, GO $_{4\%\ wt}$ thin films (H_2S gas).

Table 1

Sensitivity of the Cu: GO thin films with H$_3$Sgas

Sample	Percent sensitivity at an optimal temperature (200 ^{o}C)
pure Cu$_{1\%}$	3.587115666
Cu $_{9\%\ wt}$: GO $_{1\%\ w}$	7.164948454
Cu $_{9\%\ wt}$: GO $_{1\%\ w}$	8.315098468
Cu $_{8\%\ wt}$: GO $_{2\%\ wt}$	190.3225806
Cu $_{6\%\ wt}$: GO $_{4\%\ wt}$	55.65217391

Table 2

Sensitivity of the Cu: GO thin films with NO$_2$gas

Sample	**Percent sensitivity at an optimal temperature (200 ^{o}C)**
pure Cu$_{1\%}$	61.14527287
Cu $_{9\%\ wt}$: GO $_{1\%\ w}$	29.71631206
Cu $_{9\%\ wt}$: GO $_{1\%\ w}$	3.098927294
Cu $_{8\%\ wt}$: GO $_{2\%\ wt}$	204.1990669
Cu $_{6\%\ wt}$: GO $_{4\%\ wt}$	65.85928489

2- Response Time and Recovery Time

The time interval during which the resistance of the sensor material reaches a fixed percentage (usually 90%) of its final value when exposed to full-scale gas concentration. A short response time is highly desirable in applications such as detecting flammable or combustible gases to prevent fires. [10]. Recovery Time when the target gas is removed and the sensor is placed in artificial (or reference) air, it should recover quickly and be ready for the next detection [11]. Figures (3a), (3b), (4a), and (4b) depict the relationship between response time and recovery time as a function of Cu operating temperature. GO thin films with a bias voltage of 5V for H$_3$S and NO$_2$ gas. At the optimal temperature of 200 ^{o}C, the increasing vol% of GO in Table 3 is due to an increase in recovery time and a decrease in response time. The recovery time is longer due to the lower operating temperature. The O$_2$ species is less reactive than the other oxygen species, O- and O-[12], because it adsorbs more strongly on the surface at lower temperatures. When exposed to the full-scale concentration of the gas, the sensor material's resistance reaches a fixed percentage (usually 90%) of its final value. A short response time is highly desirable in applications such as detecting flammable or combustible gases to prevent fires [13]. Recovery Time When the target gas is removed and the sensor is placed in artificial (or reference) air, it should recover quickly and be ready for the next detection [14].[15].

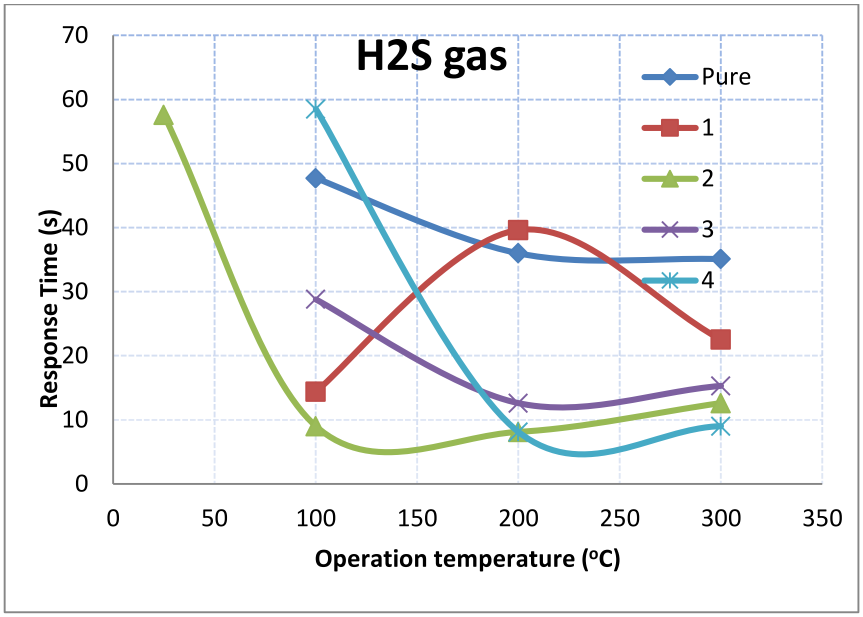

Figure 3a. The variation of Response time with 1- pure Cu1% 2- Cu 9% wt, GO 1% wt 3- Cu 8% wt GO 2% wt 4- Cu 7% wt , GO 3% wt 5- Cu 6% wt thin films (H2S gas).

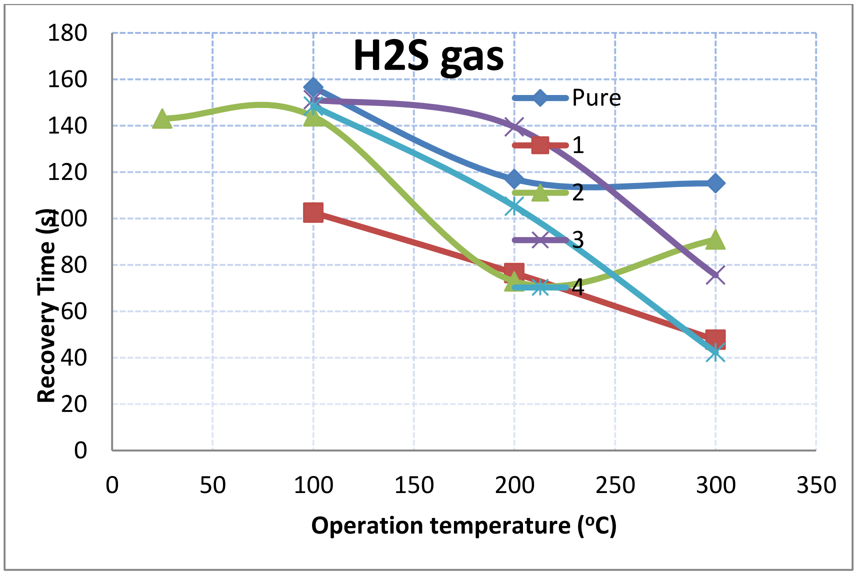

Figure 3b. The variation Recovery time with 1- pure Cu$_{1\%}$ 2- Cu $_{9\%\ \mathrm{wt}}$, GO $_{1\%\ \mathrm{wt}}$ 3- Cu $_{8\%\ \mathrm{wt}}$ GO 2% wt 4- Cu 7% wt , GO 3% wt 5- Cu 6% wt thin films (H2S gas).

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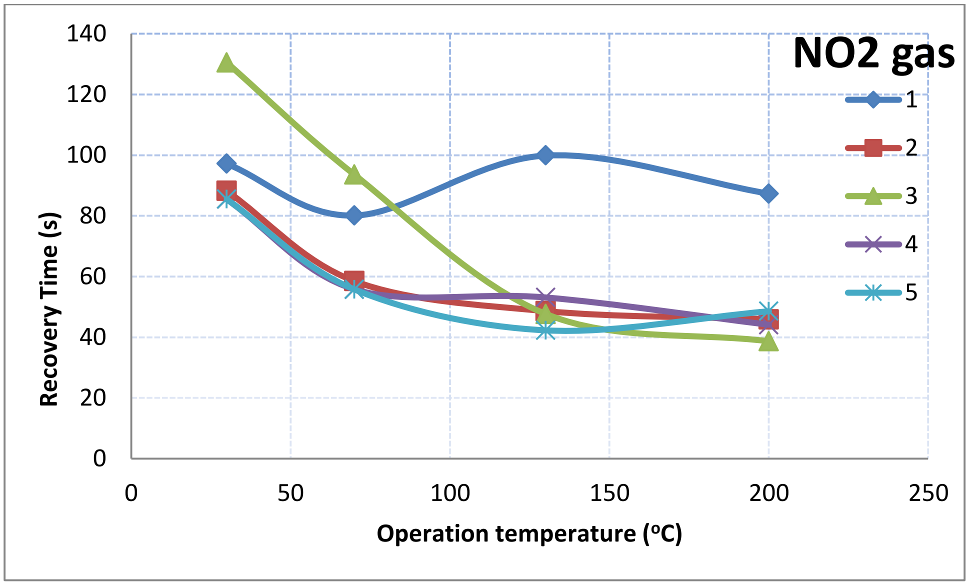

Figure 4a. The variation of Recovery time with - pure Cu1% 2- Cu 9% wt, GO 1% wt 3- Cu 8% wt GO 2% wt 4- Cu 7% wt , GO 3% wt 5- Cu 6% wt thin films (NO2gas).

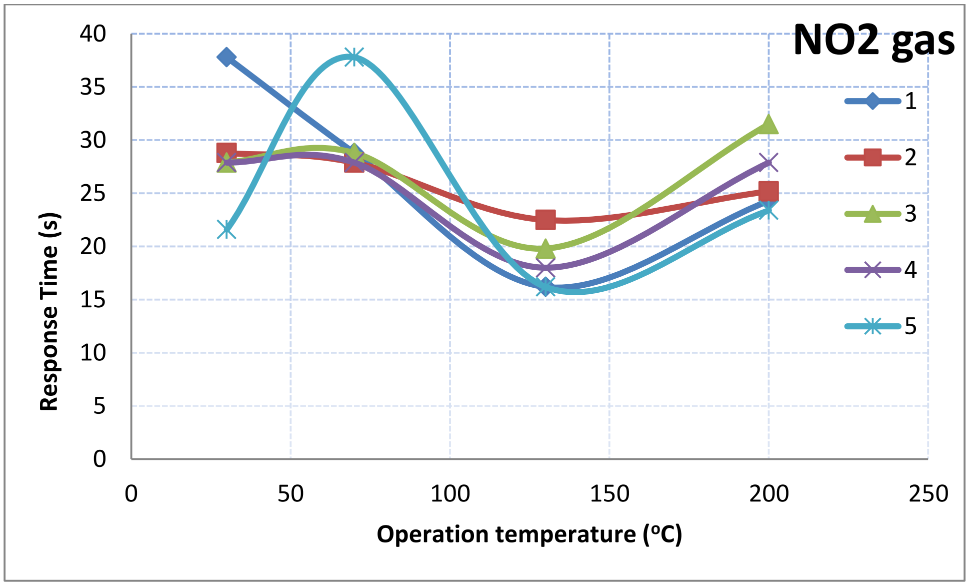

FIGURE 4b. The variation of response time with - pure Cu1% 2- Cu 9% wt, GO 1% wt 3- Cu 8% wt GO 2% wt 4- Cu 7% wt , GO 3% wt 5- Cu 6% wt thin films (NO$_2$gas).

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Table 3

Reaction Time and Recuperation Time with the Cu:GO thin film temperature (°C) for H2S and NO2 gas

Sample	Response Tim(s) at (200) °C with H_2Sgas	Recovery Time (s) at (200) °C with H_2Sgas	Response Tim(s) at (200) °C NO_2gas	Recovery Time (s) at (200) °C NO_2gas
pure $Cu_{1\%}$	36	88.2	8.1	63.9
$Cu_{9\%\ wt}$: $GO_{1\%\ w}$	39.6	76.5	16.2	55.8
$Cu_{8\%\ wt}$: $GO_{2\%\ w}$	8.1	72.9	29.7	121.5
$Cu_{7\%\ wt}$: $GO_{3\%\ wt}$	12.6	139.5	12.6	67.5
$Sb_2O_{3\ 6\%\ wt}$, $In_2O_{3\ 4\%\ wt}$	8.1	105.3	16.2	92.7

CONCLUSIONS

The samples are tested for NO_2 and H_2S at 200 °C. Sample sensitivity, response, recovery, and selectivity are examined. Cu:GO thin films were found to be good sensors. The films' sensing measurements show high gas and vapor sensitivity. Best sensitivity at 4% GO. Film sensitivity decreases with GO.Gas sensor recovery time increases and response time decreases at operating temperatures.

Conflict of interests.

There are non-conflicts of interest.

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الخلاصة

مقدمة

المادة: أغشية رقيقة نانوية مركبة من أكسيد الجرافين المُطعّم بالنحاس (Cu:GO).

التقنية: الطلاء بالدوران، الذي تم اختياره لسرعته وبساطته وقدرته على إنتاج أغشية عضوية رقيقة متجانسة على ركائز مسطحة

طرق العمل

متغير العملية: تم تغيير سرعة الدوران بشكل منهجي عند 3000، 4000، 5000، 6000، و7000 دورة في الدقيقة (مع تغييرات مقابلة في وزن/سُمك الفيلم).

الغازات المستهدفة: كبريتيد الهيدروجين (H_2S) وثاني أكسيد النيتروجين (NO_2).

ظروف الاختبار: درجات حرارة تشغيل ثابتة تتراوح من 100 درجة مئوية إلى 200 درجة مئوية.

النتائج

لوحظت علاقة عكسية واضحة بين درجة حرارة التشغيل وحساسية الغاز. انخفضت الحساسية مع ارتفاع درجة الحرارة ضمن النطاق المختبر (100–200 درجة مئوية).

تأثير على حركية المستشعر: أثرت زيادة درجة حرارة التشغيل سلبًا على الأداء الديناميكي للمستشعر:

زيادة زمن الاستجابة: استغرق المستشعر وقتًا أطول للوصول إلى أقصى استجابة له عند تعرضه للغاز.

الاستنتاجات

تُظهر المواد النانوية Cu:GO المُحضّرة إمكانات قوية كمستشعرات غاز فعّالة لغازي كبريتيد الهيدروجين وثاني أكسيد النيتروجين. وقد أثبتت طريقة الطلاء بالدوران أنها تقنية تصنيع ممتازة وقابلة للتطوير لإنشاء منصة استشعار موحدة. تُعدّ درجة حرارة التشغيل معيارًا حاسمًا يتطلب التحسين، حيث إنها تُشكّل مفاضلة: فارتفاع درجات الحرارة قد يُحسّن حركية التفاعل، ولكنه في هذه الحالة يُقلّل من الحساسية الإجمالية والاستجابة. يُقدّم هذا العمل منصة واعدة للكشف الحساس والانتقائي عن الغازات، مع تطبيقات محتملة.

الكلمات المفتاحية: غشاء رقيق، درجة حرارة التشغيل، الحساسية، مستشعر غاز، طلاء بالدوران