



Development and Characterization of SnO₂/Polypyrrole Nanocomposites for Room- Temperature H₂S Gas Detection

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Abstract:

The SnO₂-PPy nano-composite H₂S gas sensor was fabricated on a clean glass substrate by using Screen printing technique. The prepared material was characterized by X-ray diffraction (XRD) and scanning electron microscopy (SEM) to investigate its crystalline structure and surface morphology. The sensor achieves a maximum sensitivity of approximately 1.57 at 125 ppm, with a response time of 7 seconds and recovery time of 11 seconds, at room temperature. These results highlight B4 as a promising candidate for rapid, efficient H₂S monitoring and potential industrial safety applications.

Keywords: SnO₂, Polypyrrole (PPy), Nanocomposites, H₂S Gas Sensor, Screen printing technique, Sensitivity and statistic response.

I. Introduction:

Nanostructured metal oxide semiconductors have attracted considerable attention because of their distinctive electrical properties, high surface-to-volume ratio, and potential applications in chemical gas sensing. Their sensing performance is strongly influenced by particle size, morphology, crystallinity, and surface defects, which determine gas adsorption and charge-transfer processes. Among these materials, tin oxide (SnO₂) is widely investigated for detecting hazardous gases owing to its high sensitivity and chemical stability. However, its sensing performance can be limited by operating conditions and selectivity. Therefore, combining SnO₂ with conducting polymers offers a promising approach to improving gas-sensing characteristics [1-2].

Polypyrrole (PPy) is a conducting polymer with good electrical conductivity, chemical stability, and a porous structure that supports gas adsorption. In SnO₂-PPy composites, interactions between the semiconductor and polymer can modify charge transport and influence the electrical response during exposure to hydrogen sulfide (H₂S). As a reducing gas, H₂S interacts with adsorbed oxygen species on SnO₂, potentially returning electrons to the material and changing its resistance [3]. The response also depends on the PPy contribution, interfacial charge transfer, and composite morphology. The combination of SnO₂ and PPy may consequently provide additional active sites and facilitate gas diffusion. These advantages make SnO₂-PPy composites promising candidates for developing sensitive H₂S sensors capable of operating at room temperature for environmental monitoring and industrial safety.

II. Experimental

A. Synthesis of SnO₂ Nanoparticles:

High-purity (99.99%) analytical-grade chemicals were obtained from SD Fine, India. SnO₂ nanoparticles were synthesized using a sol-gel-based procedure, with stannous chloride dihydrate (SnCl₂·2H₂O) as the precursor. Approximately 2 g of the precursor was dissolved in 100 mL of deionized water, followed by the addition of 4 mL

of ammonia under continuous magnetic stirring. After 25 minutes, the mixture was aged for 10–14 hours to form a white precipitate. The precipitate was filtered, washed, mixed with 0.27 g activated carbon, dried at 80°C for 24 hours, and calcined at 700°C for 7 hours [4].

B. Synthesis PPy Nanoparticles:

Polypyrrole (PPy) was synthesized using a sol–gel-assisted chemical oxidative polymerization method. Initially, 1.892 g of anhydrous ferric chloride (FeCl_3) was dissolved in 7 mL of methanol under continuous stirring in a round-bottom flask. Subsequently, 8.4 mL of pyrrole (Py) monomer was added gradually, maintaining a FeCl_3 -to-pyrrole ratio of 2.33:1. The reaction mixture was stirred continuously in the dark to promote polymerization. The resulting black precipitate was filtered and washed repeatedly with distilled water until the filtrate became clear. Finally, the collected PPy was dried in an oven to obtain the polymer powder [5].

C. Preparation of Sensor:

Thick-film SnO_2 -PPy gas sensors were fabricated using the screen-printing technique. Initially, fine powders of pure SnO_2 , PPy, and their composites in different weight proportions were mixed with an organic vehicle containing 10% ethyl cellulose as a temporary binder, along with butyl carbitol acetate and terpineol, to obtain a uniform, thixotropic paste. The ratio of inorganic material to organic components was maintained at 75:25.

The prepared pastes [6-7] were screen-printed onto cleaned glass substrates. The deposited films were dried in an oven at 90–100°C for one hour to remove moisture and volatile organic constituents. Subsequently, silver-paint electrodes were applied to adjacent surface regions of each sensing film to facilitate electrical resistance measurements. The

electrodes were then dried at 70°C for 30 minutes. The fabricated sensors were categorized according to their respective SnO_2 -PPy compositions, as summarized in Table 1.

Table 1: Sensor labeling

Sr. No.	Sensor codes	Layers
1.	B1	SnO_2
2.	B2	80 SnO_2 : 20 PPy
3.	B3	60 SnO_2 : 40 PPy
4.	B4	40 SnO_2 : 60 PPy
5.	B5	20 SnO_2 : 80 PPy
6.	B6	PPy

III. Results and Discussions:

A. XRD (X-ray Diffraction) Study:

The X-ray diffraction (XRD) pattern of pure polypyrrole (PPy) generally displays a broad diffraction halo within the 2θ range of approximately 20°–30°, rather than distinct, sharp peaks [8]. This characteristic feature indicates the predominantly amorphous structure of the polymer. The broad profile results from the irregular arrangement of polymer chains, limited short-range structural ordering, and the absence of long-range crystalline periodicity. Unlike highly crystalline materials, PPy does not exhibit a well-defined lattice structure. Its disordered molecular arrangement influences charge transport and interactions with gas molecules, making the structural characteristics of PPy important for understanding its electrical properties and potential application in H_2S gas-sensing devices.

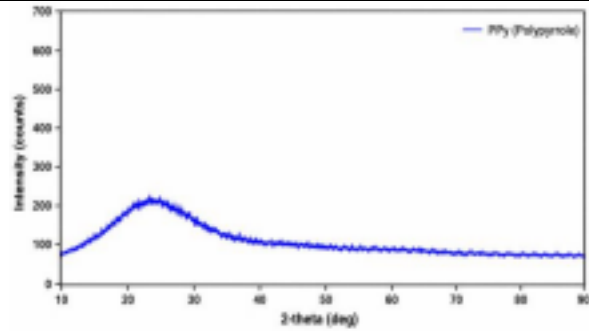


Fig. 1 XRD image of PPy

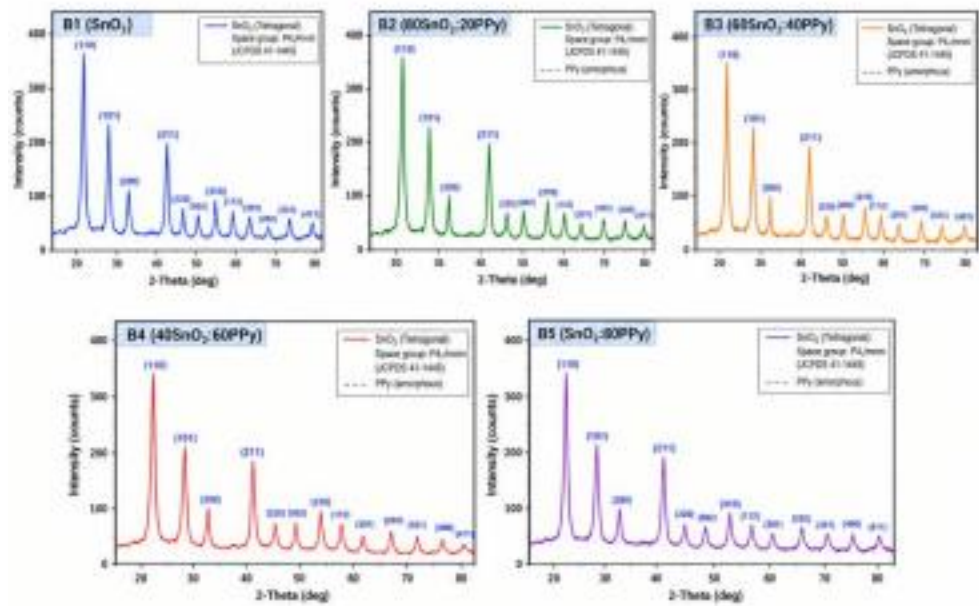


Fig. 2 : XRD pattern of SnO₂+ PPy composites

Table 2: Average crystallite size of SnO₂, PPy and their compositions

Sensor Code	Chemical Composition Of SnO ₂ : PPy (mole %)	Phases	FWHM (2θ) degree	Average Crystallite Size (D) in nm
B2	80SnO ₂ : 20 PPy	Tetragonal SnO ₂	0.92	11.34
B3	60SnO ₂ : 40 PPy	Tetragonal SnO ₂	0.87	10.45
B4	40SnO ₂ : 60 PPy	Tetragonal SnO ₂	0.71	9.11
B5	20SnO ₂ : 80 PPy	Tetragonal SnO ₂	0.78	13.66
B6	PPy	amorphous	0.127	64.26

Table 2 presents the average crystallite sizes of SnO₂–PPy composites with different compositions. The crystallite size decreases from 11.34 nm for B2 to 9.11 nm for B4, accompanied by a reduction in FWHM from 0.92° to 0.71°. Sensor B4 (40SnO₂:60PPy) exhibits the smallest crystallite size among the crystalline composites, potentially providing more active sites for H₂S adsorption and enhancing gas–surface interactions [9]. Therefore, B4 is a promising candidate for H₂S detection, although experimental sensing results are required to confirm its superior performance.

B. SEM Result:

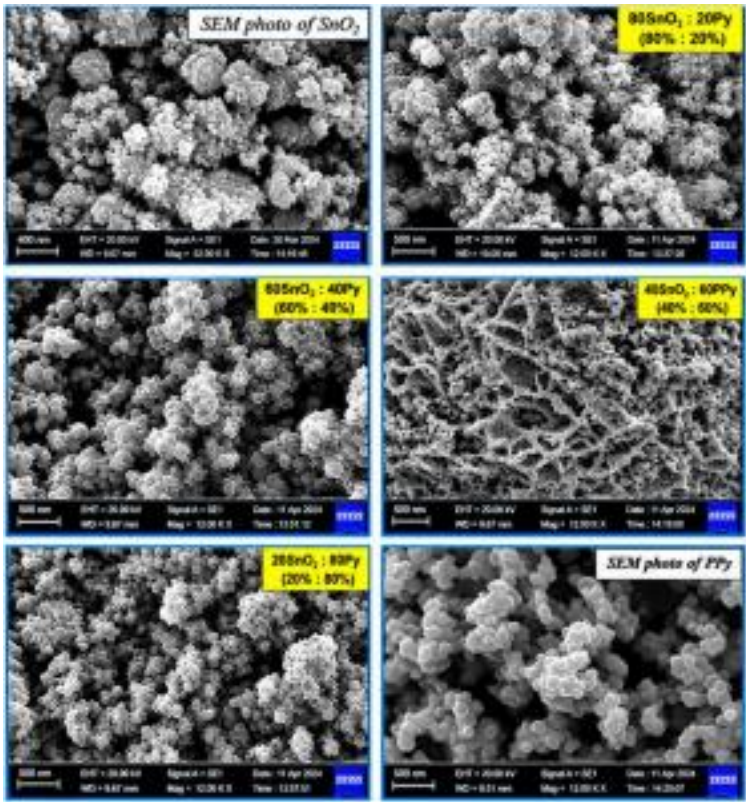


Fig. 3: SEM Pictures of B1 to B6 sensors

The SEM images [10] illustrate the surface morphology of SnO₂, PPy, and their composites with different compositions. The particles exhibit clustered structures, interconnected networks, and varying degrees of porosity. Among the composites, B4 (40SnO₂:60PPy) displays a porous, interconnected morphology that may facilitate H₂S diffusion and provide numerous active adsorption sites. These structural characteristics, combined with its smaller crystallite size, make B4 a promising sensor for H₂S detection. Experimental measurements are necessary to confirm its superior sensing performance. The porosity, particle size and morphology are listed in table 3.

Table 3: Particle size and morphology

Sensor Code	Composition (SnO ₂ : PPy)	Number of pores per inch	Particle Size (nm)	Morphology
B1	SnO ₂	80	70–90	Low dense
B2	80SnO ₂ : 20 PPy	108	70–100	Open, sponge-like porous network
B3	60SnO ₂ : 40 PPy	112	60–80	Loosely
B4	40SnO ₂ : 60 PPy	117	20–55	Dense, spongy
B5	20SnO ₂ : 80 PPy	107	65–90	Polymer-dominant, smoother with embedded particles
B6	PPy	89	70–120	Slightly low dense

The SEM analysis (Table 3) indicates that B4 (40SnO₂:60PPy) exhibits very high porosity (117 pores per inch), a

particle size of 20–55 nm, and a dense, spongy morphology. These features provide abundant active sites and facilitate H₂S gas diffusion, enhancing surface interactions and sensing response. Therefore, B4 appears promising for room-temperature H₂S detection [11-12].

C. Sensitivity measurement:

Sensor sensitivity is evaluated by comparing the resistance change upon exposure to H₂S gas with the sensor's resistance in ambient air. Mathematically, sensitivity can be expressed as:

$$S = \frac{R - R'}{R}$$

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Where, R' = sensor resistance in presence of gas

R = sensor resistance in the environment of air.

The sensitivity [13-14] of sensors B1–B6 was determined from resistance variations during exposure to H₂S concentrations ranging from 0 to 225 ppm at room temperature, 300 K. It is shown in Fig. 4.

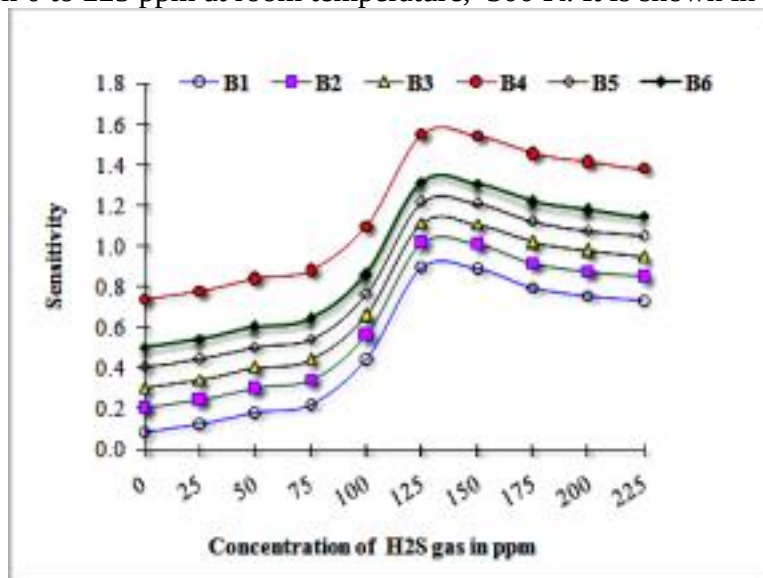


Fig. 4: Variation of sensitivity of B1 to B6 sensors at Room Temperature

All sensors exhibit increasing sensitivity with rising gas concentration, reaching a maximum near 125–150 ppm, followed by a gradual decline [15-17]. Among the tested samples, B4 (40SnO₂:60PPy) demonstrates the highest sensitivity, reaching approximately 1.57 at 125 ppm. Its superior performance may be attributed to its highly porous, spongy morphology, which provides abundant active sites for gas adsorption and facilitates H₂S diffusion. Therefore, B4 exhibits the most promising sensing response among the B-series sensors.

D. Static Response of sensors:

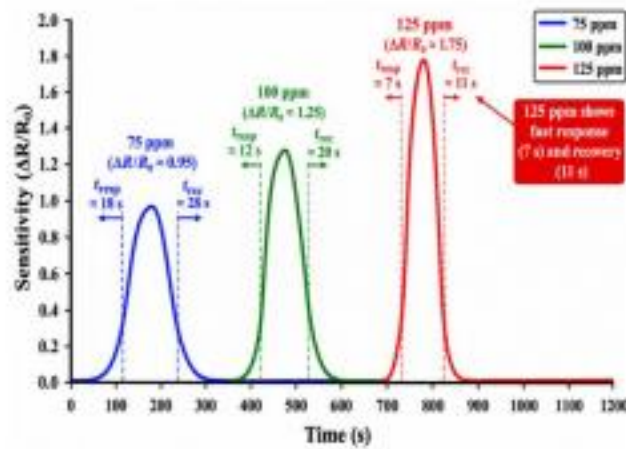


Fig. 5: Static response of B4 Sensor

Fig. 5, illustrated the static H_2S sensing response of B4 ($40\text{SnO}_2:60\text{PPy}$). The sensor demonstrates faster operation, achieving a response time of nearly 7 s and a recovery time of about 11 s at 125 ppm H_2S [18-20]. The improved dynamics can be attributed to the combined contribution of SnO_2 and highly active PPy, which facilitates gas adsorption, charge transfer, and surface interaction. The short response and recovery periods confirm that B4 possesses excellent responsiveness and strong potential for rapid H_2S monitoring.

IV. Conclusion:

The fabricated SnO_2 -PPy nanocomposite sensors demonstrate promising potential for room-temperature H_2S detection. Among the investigated compositions, B4 ($40\text{SnO}_2:60\text{PPy}$) exhibits superior sensitivity due to its smaller crystallite size, highly porous structure, and interconnected spongy morphology. The sensor achieves a maximum sensitivity of approximately 1.57 at 125 ppm, with a response time of 7 seconds and recovery time of 11 seconds. These results highlight B4 as a promising candidate for rapid, efficient H_2S monitoring and potential industrial safety applications.

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