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Sustainable Room-Temperature Hydrogen Sensing Based on Pristine Biomass-Derived Prosopis Africana Carbon Nanoparticles

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ABSTRACT
Biomass derived materials have recently attracted significant attention as sustainable and cost-effective candidates for gas sensing applications. However, most biomass-derived carbon sensors reported to date rely on metal-oxide hybridisation or hetero-atom doping to reach useful sensitivity, leaving the intrinsic hydrogen-sensing capability of pristine biomass carbon largely unexplored. In this study, nanoparticles derived from Prosopis africana charcoal (PACC) were developed and investigated for hydrogen (H_2) gas detection at room-temperature. The charcoal was produced from Prosopis africana stem via controlled pyrolysis at 500 °C for 3 h under limited oxygen conditions. The PACC sensing film was fabricated by blending the nanoparticles with linseed oil as an organic binder in a 40:60 wt% ratio, followed by annealing at 500 °C for 30 min. The morphological and structural properties of the sensing film were characterized using field emission scanning electron microscopy (FESEM), and energy-dispersive X-ray spectroscopy (EDX). Gas sensing performance was evaluated toward hydrogen concentrations ranging from 100 to 1000 ppm at room temperature, with cross-sensitivity to ammonia and methane also assessed. The sensor exhibited a relative current response of 13.6–16.7% across the 100–1000 ppm range, with the strongest response of 16.7% recorded at 100 ppm, together with reversible response/recovery behaviour and selectivity over ammonia and methane. To the best of our knowledge, this study represents the first report on room temperature hydrogen sensing using pristine, Prosopis africana charcoal nanoparticles, highlighting their promise as a low-cost and sustainable alternative for gas sensing applications.

Keywords: Hydrogen Gas, Gas Sensor, Biomass Material, Nanoparticles, *prosopis Africana*

INTRODUCTION

The global transition toward low-carbon energy systems has accelerated interest in hydrogen as a sustainable energy carrier. Hydrogen is expected to play a key role in decarbonizing sectors such as transportation, power generation, and industrial manufacturing due to its high gravimetric energy density and carbon-free combustion products. Consequently, significant investments are being made worldwide in hydrogen production, storage, distribution, and fuel-cell technologies. Despite these advantages, hydrogen presents unique safety challenges because of its low ignition energy, high diffusivity, and wide flammability range (4–75% in air)(Menon et al., 2025). Therefore, the development of reliable hydrogen leak detection technologies remains a critical requirement for the safe implementation of hydrogen-based energy systems.

Numerous hydrogen sensing technologies have been developed, including catalytic, electrochemical, thermal conductivity, optical, and semiconductor-based sensors. Catalytic sensors generally exhibit high sensitivity but often consume significant power and may pose safety concerns in explosive environments. Electrochemical sensors offer good selectivity; however, their performance may deteriorate over time due to electrolyte degradation. Thermal conductivity sensors provide simple operation but frequently suffer from limited sensitivity at low gas concentrations. Optical sensors exhibit excellent immunity to electromagnetic interference but often require complex and expensive instrumentation. Metal oxide semiconductor (MOS) sensors remain among the most extensively investigated hydrogen sensing platforms because of their high sensitivity and rapid response characteristics. Nevertheless, most MOS sensors require operating temperatures between 200 and 500 °C, leading to increased energy consumption and potential safety concerns. Consequently, there is growing interest in alternative sensing materials capable of operating effectively at room temperature (Yunusa et al., 2014).

In modern sensor technology, the use of carbon materials is becoming prevalent due to large availability of surface area, strong electrical properties, and environmental stability (Menon et al., 2025). Graphite and its derivatives such as carbon black, carbon sources such as coal, graphite, lignite, peat, and petroleum residue are extracted from the earth's crust (Llobet, 2013). For sustainable development, researchers are utilizing the biomass resources such as agricultural waste and forestry biomass as an alternative to earth-mined carbon resources (Fathy et al., 2020). The biomass-based production of carbon material promotes green electronics and sustainable development (Cancelliere et al., 2022). A simple and economic conversion process makes biomass-derived carbon attractive in many applications (Lepak-Kuc et al., 2021).

Biomass is an attractive carbon source because it is abundant, renewable, inexpensive and environmentally free (Shahi et al., 2020). In recent years, biochar applications invested in many fields (Rath et al., 2019), though the main application

of this material remains field amendment in agriculture . In addition, different biochars are becoming available from pilot plants producing carbon material, biogas and energy (Wong et al., 2022). Besides, in the last few years, biochar has been extensively studied as a substitute for more expensive carbon materials like carbon nanotubes, graphene, and others and has been utilized as sustainable material for electronics applications (Babani et al., 2023) (Jagdale et al., 2019)(Hamidon et al., 2023). Biomass-derived carbon materials have been extensively studied for sensing applications, however, most reported systems rely on hybridization with metal oxides or hetero-atom doping to achieve high sensitivity and fast response (Sankar et al., 2023) (Luo et al., 2023)(Dhall & Mehta, 2020a). In contrast, direct hydrogen sensing using unmodified biomass derived carbon remains largely unexplored.

Prosopis africana is an abundant biomass resource widely available in many regions of sub-Saharan Africa. The biomass possesses a high carbon yield after pyrolysis and can be converted into carbon-rich materials using relatively simple processing techniques. Previous studies have demonstrated the suitability of Prosopis africana-derived carbon for electronic and thick-film applications due to its favorable electrical properties, porous microstructure, and sustainable origin. Furthermore, utilizing Prosopis africana as a precursor for sensing materials promotes value addition to locally available biomass resources and supports the development of environmentally sustainable electronic devices (Babani et al., 2024).

Although significant progress has been achieved in hydrogen sensing technologies, several challenges remain unresolved. Many high-performance hydrogen sensors rely on noble-metal catalysts, metal oxide heterostructures, or elevated operating temperatures to achieve acceptable sensitivity and response speed (Dariyal et al., 2021). These approaches increase fabrication complexity, cost, and energy consumption. In contrast, room-temperature hydrogen sensing using unmodified biomass-derived carbon materials remains relatively unexplored, particularly for hydrogen concentrations relevant to leak detection applications. Therefore, there is a need to investigate sustainable carbon materials capable of providing measurable hydrogen sensing performance without catalyst loading, chemical doping, or external heating.

In this study, carbon nanoparticles derived from Prosopis africana biomass was utilized as the active sensing material for room-temperature hydrogen detection. The objective of this work is to investigate the feasibility of employing sustainable biomass-derived carbon nanoparticles as a low-cost sensing platform for hydrogen monitoring. The sensing film was fabricated using a screen-printing technique and subsequently characterized using thermal, structural, and morphological analyses. The hydrogen sensing performance was evaluated over a concentration range of 100–1000 ppm under room-temperature conditions. To the best of our knowledge, this is the first reported investigation of room-temperature hydrogen sensing based on Prosopis africana-derived carbon nanoparticles.

First, the dried stem of the prosopis Africana was converted to carbon material based pyrolysis technique as discussed in (Babani et al., 2024) which was processed into nanoparticle and formulated into thick film paste. The paste was deposited onto commercial alumina substrates via screen printing technique with silver interdigitated electrodes. Linseed oil acting as an organic binder was added to improve the adhesion onto the alumina substrates. Linseed oil binder was used in this work to overcome the inherent effect due to ethyl cellulose binder on sensor performance (Jha & Bhat, 2022). Linseed oil is extracted from a flax seed plant, as a drying oil due to its high alpha linolenic acid content (ca. ~60%). It is commonly used in the painting industry as a binder for its ability to dry and form film, hence acting as a good coating material (Shafiee, 2020).

MATERIALS AND METHODS

The Gas sensor used in this work consist of two layers, which are an interdigitated electrode (IDE) and sensing film, as shown in Figure 1. The IDE used in this work was a silver-conductive paste provided by Sigma-Aldrich (Steinheim am Albuch, Germany) and the sensing material used prosopis africana charcoal powder. IDE and the sensing film were deposited on the alumina substrate using a screen-printing method. Initially, IDE was deposited as first layer on the alumina substrate, followed by annealing in the furnace at temperature of 120 ◦C for 30 min. Air was used as a carrier gas in the furnace. In order to deposit PACC paste on the alumina substrate, PACC powder was prepared as a paste. The PACC was milled for 6 h using SPEX8000D to produce nanoparticle size powder where the ball to powder ratio (BPR) was 10:1. The 40 wt% PACC nanoparticles powder was mixed with 60 wt% organic binder which is a mixture of linseed oil with m-xylene and α-terpineol. Then, the mixture was stirred using magnetic stirrer on a hotplate at 40°C for 24h to obtain homogenous paste This method have been previously presented in (Hamidon et al., 2023)(Babani et al., 2023). Then, PACC paste was deposited on the top of the IDE and it was annealed in the furnace at 500 ◦C temperature for 1h: 30 min to effectively remove the binder. The fabricated gas sensor is shown in Figure 1 below.

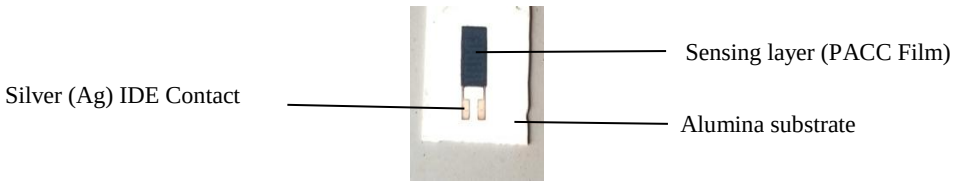


Figure 1: The Fabricated (H2) Gas Sensor, Showing two Layers; the IDE and he Sensing film Formed from Prosopis Africana Carbon

Characterization of the Sensing Film

The sensing film was characterized using different characterization techniques, Characterizations of PACC thick film paste were made using a thermogravimetric analyzer (TGA) and Rheological property analyzer. The sensing film characterizations were made using field emission scanning electron microscopy (FESEM), energy-dispersive X-ray spectroscopy (EDX), Raman spectroscopy and X-ray diffraction (XRD). Thermal analysis of paste was tested using TGA (Brand: Mettler Toledo (Model: TGA/DSC 1 HT)) with heating rate 10 ^{0}C/min and air as the carrier for the temperature range: 25–1000 ^{0}C. Rheology property using

Rheomater (Anton-Paar Rheoplus MCR3301). The surface morphology of the sensing film was analyzed using FESEM (Model: FEI Nova Nanosem 230 (Thermo Fisher Scientific), and element composition was examined by EDX inside the FESEM.

Gas Response Measurement

Figure 2. Shows experimental setup for gas sensor measurement. The gas chamber was connected to the mass flow controller (MFC), a source meter (Keithley 2450), a temperature controller, a vacuum pump and a computer. The vacuum pump is connected to the outlet of the gas chamber and gas flow from the pump is controlled by a valve. Labview software is used to monitor the changes of current (output) during exposure to the target gas.

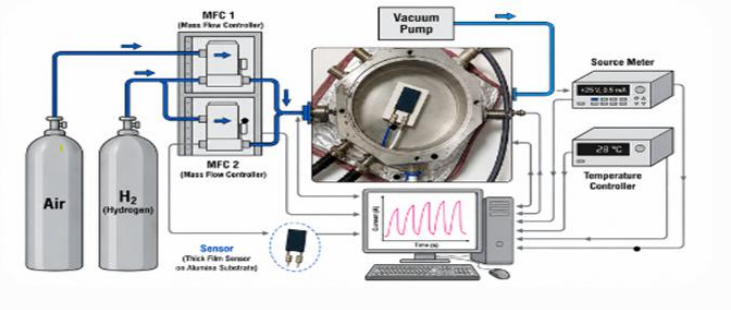


Figure 2: Experimental Setup for Gas Sensor Measurements, Showing a Gas Chamber Connected to Mass Flow Controllers (MFC1 and MFC2), a Temperature Controller and a Vacuum Pump connected to the Outlet of the Gas Chamber and also a Computer connected to the Gas Chamber

The control system for flow of the synthetic air and target gas is conducted using LabVIEW software. Initially, a carrier gas was flowed to the gas sensor until stable current was achieved at selected operating temperature. After stable current was obtained, the measurement of gas sensor to the target gas was started. When measurement has started, the pump is on during the flow of carrier gas, to ensure the surface of the gas sensor is cleared from any gases and the pump will be turn off during the target gas was flowed to the gas chamber, so that the gas sensor react with the target gas.. Each flow of the synthetic air and hydrogen for every cycle is fixed to 300 and 180 seconds respectively. For this work, the MFC settings is shown in Table 1.

Table 1: Settings of Mass Flow Controller for Hydrogen Gas Detection

Concentration of Hydrogen (ppm)	Value in MFC (ml/min)	Value in Air MFC (L/min)
1000	50	50
700	35	50
500	25	50
300	15	50
100	5	50

RESULTS AND DISCUSSION

Physical Characterization

TGA analysis was performed to determine the thermal behavior of the PACC. Figure 3 shows total mass loss of PACC paste over a temperature range of 25 to 1000 ◦C. At 500 ◦C, mass loss was measured approximately 60%, which indicated that the organic binder has fully evaporated at this temperature. Composition ratio of PACC powder and organic binder used in this work was 40:60. It can be seen that the organic binder was fully evaporated at temperature of 500 ◦C this aligns with the work of (Shafiee, 2020). Therefore, this temperature has been chosen as the annealing temperature for the sensing film

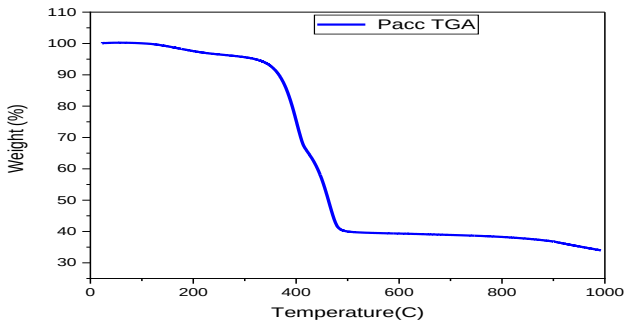


Figure 3:Thermogravimetric Analysis of PACC Paste Showing Total Mass Loss Over Temperature. Approximately 60% Mass Loss was Measured at 500 ◦C Indicating Full Evaporation of the organic Binder

The graph in Fig. 4 shows a decrease in viscosity with increasing shear rate, and shear-thinning behavior was observed, which is significant in screen printing technique. This shear-thinning behavior ensured that the paste could be printed through a sieve mesh (Babani et al., 2024). Rheological properties play an important role in thick paste films, especially when high shear stress is induced, as in the case of squeegee printing. The viscosity of the paste must be low so that it can pass through the screen during printing and return to a high viscosity after printing (Wu et al., 2023). The viscosity of PACC paste gradually decreased over the course of the measurement, starting with a higher viscosity, then slowly increasing to 1.0/s, and then rapidly declining towards 1000/s.

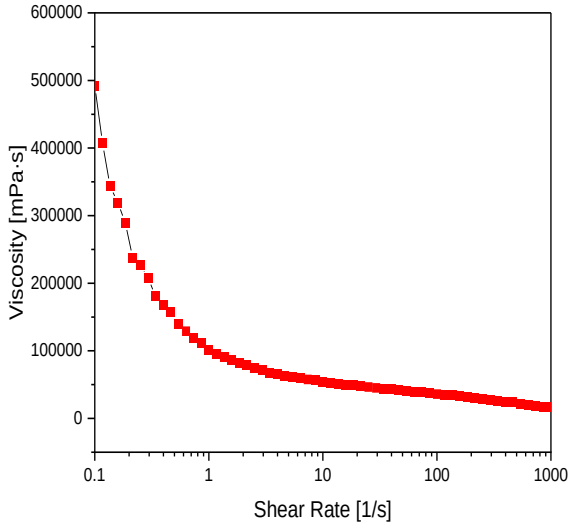


Figure 4:Viscosity as a Function of Shear Rate of PACC Paste. The Viscosity Decreases with Increasing Shear Rate, Ensuring Shear-Thinning for Screen Printing

Raman characterization was performed to study the structural phase and vibrational modes. The spectra are provided in Fig. 5. The observations of spectra exhibit the two most prominent peaks of amorphous nature, D-band, G-band and 2D appearing at 1350cm−1, at 1590 cm−1 and 2880 cm−1 respectively. These peaks are usually present in amorphous carbon attributing to C–C bond with vibrations of sp2-hybridized carbon. The ID/IG ratio indicates graphitization degree of carbons. The calculated ID/IG ratio from the peak is found to be (0.89), this value indicates a significant degree of structural disorder and is consistent with the work of (Babani et al., 2024).

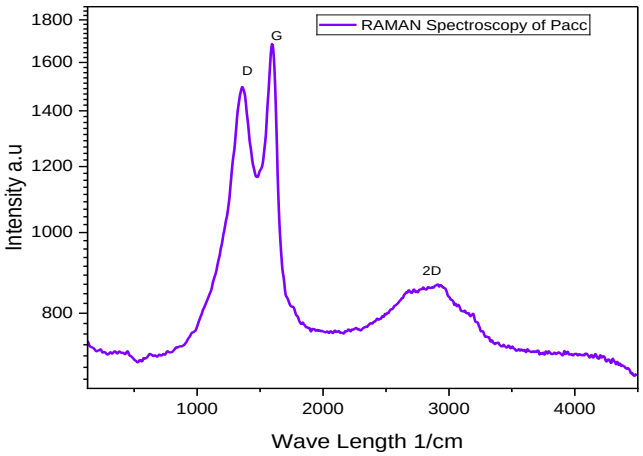
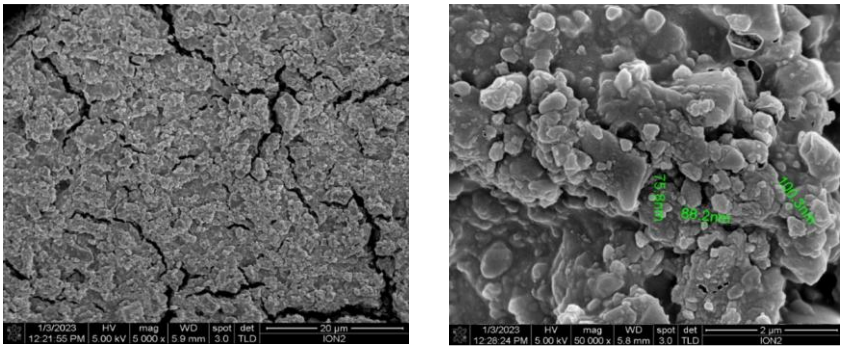


Figure 5: The Raman Spectrum of the PACC Film. The Spectra Exhibits two Most Prominent Peaks of Amorphous Nature, D-band, G-band and 2D Appearing at 1350cm−1, at 1590 cm−1 and 2880 cm−1 Respectively



(a) (b)

Figure 6: Surface Morphology of the PACC Sensing Film at Different Magnification; Ranging from 5000 and 50000 Magnifications Respectively

The surface structure of the sensing film was analyzed using field emission scanning electron microscopy (FESEM) as depicted in Fig. 6, at 5000 and 50000 magnifications**.**

In Fig.6a it could be observed that the layer exhibits porous structure with visible micro cracks which could enhance gas diffusion and adsorption. Similarly, in Fig.6b the nanostructured particle become clearly visible with particles size measuring from 75nm to 100nm. These features exhibited by the sensing film will significantly contribute to high surface area to volume ratio which are essential for gas adsorption and sensing and similar surface structure was also observed in (Ziegler et al., 2017) (Yasir et al., 2021).

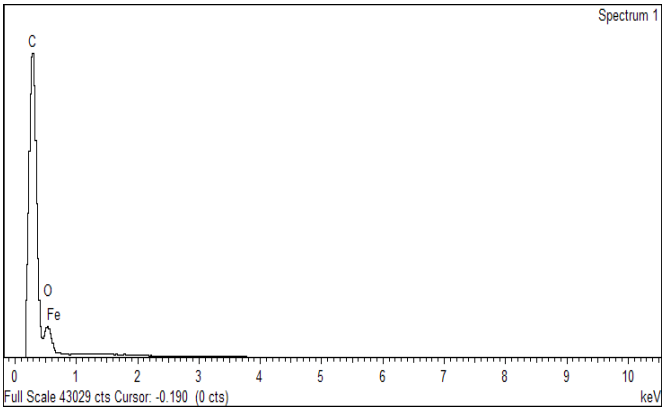


Figure 7: Electron Dispersive X-Ray (EDX) of the PACC Sensing film. The film is more than 80% Carbon and More than 10% Oxygen, with Traces of Potassium (K) and Iron (Fe).

In Fig. 7 the EDX spectra of the sensing film which shows detail elemental composition of the film. It could be observed that the film is constituted of more than 80% carbon with the oxygen taking more than 10%. Some traces of Potassium (K) and Iron (Fe) were also observed this could be due to applied binder and milling process to obtain nanoparticles. The observed high C: O ratio signified high conductivity value for the sensing film this result is consistent with the result found in (Jafri et al., 2018).

Gas Sensing Response

The sensing response of the fabricated PACC sensor is evaluated using the equation shown below

$$S_{RG} = \frac{I_g - I_a}{I_a} * 100 \quad \text{or} \quad \frac{R_g - R_a}{R_a}$$ (Al-Diabat et al., 2021)

Where Ia/R_g is change of current/ resistance in air and I_g is the change in current/ resistance flow when the sensor is exposed to hydrogen gas.

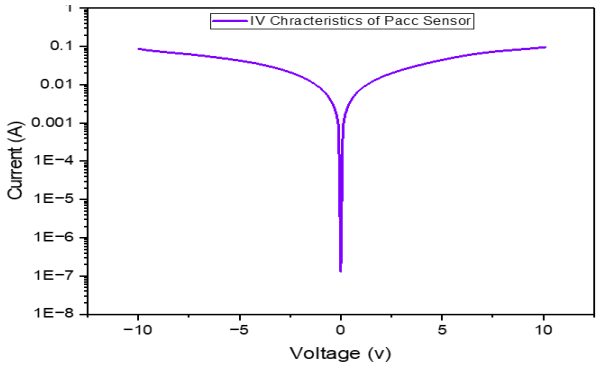


Figure 8: I-V Characteristics of the PACC Gas Sensor. A room-Temperature Measurement with Bias Voltage -10V to 10V

To initialize the sensor response measurement, I-V characteristic measurement of the sensor was first carried out by connecting the sensor to a source meter which is connected to a computer with LABVIEW^{TM} software for data acquisition. Figure 8 shows the I-V characteristics curve, the bias voltage applied is -10V to 10V and the measurement was carried out at room temperature. Linearity relationship is observed between the current and the applied voltage, it could be seen that symmetrical behavior was also observed which signifies a good ohmic contact between the PACC sensing film and the silver (Ag) interdigitated electrode. This measurement served as the basis for gas sensor measurement.

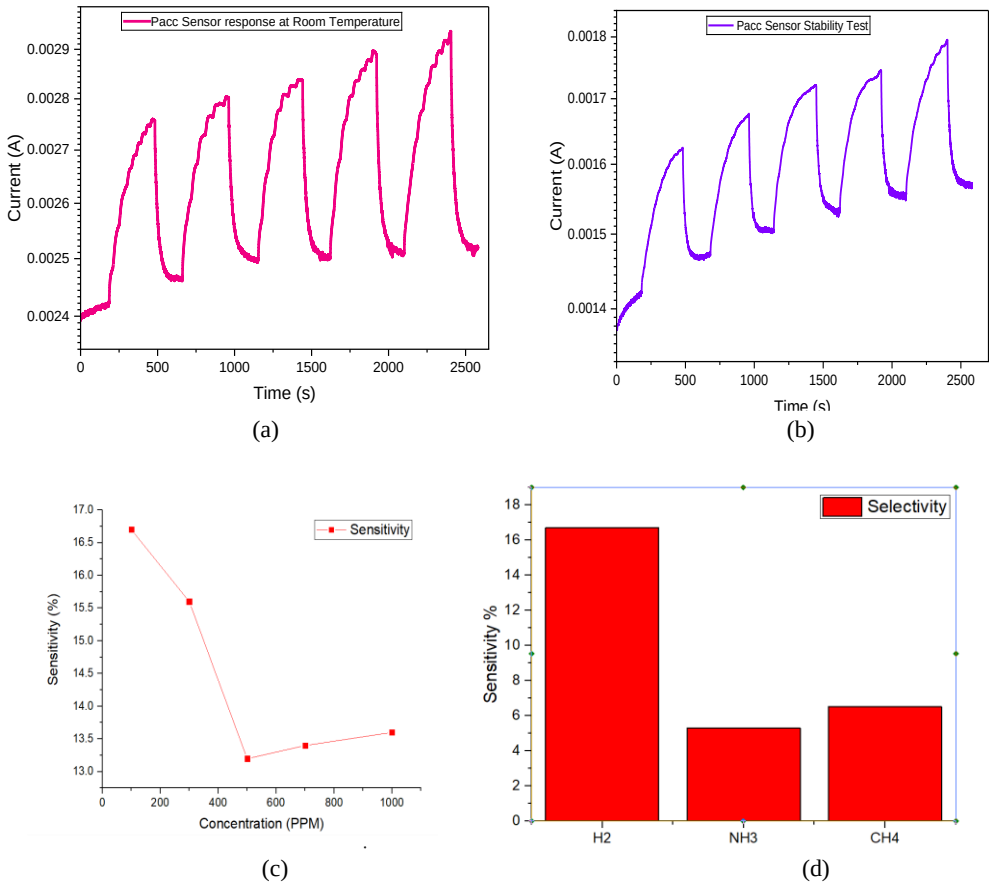


Figure 9: (a) PACC Gas Sensor Response (b) Gas Sensor Stability (c) Sensitivity Graph and (d) PACC Gas Sensor Selectivity Selectivity

The hydrogen sensing behavior of the fabricated PACC is depicted in Fig. 9. Sensor measurements were carried at room temperature using alternating exposure cycles of air and hydrogen gas at concentrations of 1000, 700, 500, 300, and 100 ppm. The dynamic response curve showed a clear and repeatable increase in current whenever hydrogen was introduced, followed by a decrease toward the baseline once air was reintroduced, see Fig. 9a. This confirm that the sensing layer responds to hydrogen under room temperature condition.

The sensor current increased from the baseline air value of approximately 0.00242 to 0.00251A to higher value between 0.00276 and 0.00293A during hydrogen exposure, this variation in current response indicates a typical N-type gas sensor response. The calculated sensitivity as depicted in Fig. 9c ranged from about 13.6% to 16.7%, indicating a measurable and stable interaction between hydrogen molecules and the sensing surface. Interestingly, the highest relative sensitivity was obtained at the lowest concentration (100 ppm), while the higher concentrations showed slightly lower percentage responses. This type of behavior has been widely reported and is often observed in porous carbon based sensors and can be explained by the availability of unsaturated active sites at lower gas concentration. When fewer gas molecules are present, each adsorbed molecule contributes more significantly to the overall electrical change. At higher concentrations, gradual occupation of available active sites may reduce the proportional increase in response (P. Wang et al., 2025).

Another important performance parameter in gas sensor measurement is Selectivity measurement, in Fig.9d. It could be observed that cross sensitivity test was carried on methane (CH_4) and Ammonia (NH_3). The figure clearly depicts that the sensor is selective to hydrogen compared to the two gases with higher sensitivity of 16.7%, 5.3%, and 6.5% for H_2, NH_3, and CH_4 respectively. The present investigation focused primarily on hydrogen response under ambient laboratory conditions. Humidity effects were not systematically evaluated and therefore represent an important limitation of the current study. Since water molecules may compete with hydrogen for adsorption sites, variations in relative humidity can potentially influence sensor response and baseline stability. Likewise, the oxygen dependence of the sensing process was not investigated. Because many proposed hydrogen sensing mechanisms involve adsorbed oxygen species, future studies should evaluate sensor performance under controlled oxygen concentrations ranging from oxygen-free to atmospheric conditions.

The response time of the sensor varied from approximately 38 s at 1000 ppm to 65 s at 100 ppm. This trend suggests that hydrogen adsorption occurs more rapidly when the gas concentration is higher because more molecules are available to interact with the sensing surface per unit time. At lower concentrations, the adsorption process becomes slower, leading to longer response times.

Similarly, the recovery time ranged from about 22 s to 28 s. Recovery was generally faster than the response process, which indicates that adsorption of hydrogen from the sensing surface occurs readily once air is reintroduced. This is a positive characteristic because it demonstrates reversible sensing behavior and supports repeated operation of the device (Tong et al., 2017).

Figure 9b presents the sensing performance after four weeks of storage. Although the sensor remained capable of detecting hydrogen concentrations between 100 and 1000 ppm, a noticeable baseline drift and reduction in sensitivity were observed. This behavior may be associated with environmental exposure, moisture adsorption, gradual aging of surface functional groups, or microstructural changes within the sensing layer. Despite these effects, the sensor maintained distinguishable and repeatable responses throughout the measurement cycle, indicating that the sensing functionality was preserved (Q. Wang et al., 2026). Future work will focus on humidity compensation, encapsulation strategies, and long-term aging studies to improve operational stability. Quantitative assessment of long-term drift, expressed as baseline-current variation per week or month, was beyond the scope of the present study and will be included in future investigations. Such measurements will provide a more rigorous evaluation of operational lifetime and re-calibration requirements.

Hydrogen Gas Sensing Mechanism

The sensing mechanism of the gas sensor surfaces hinges on the dynamic interplay between gas adsorption and desorption. Exposure to oxygen initiates the process, with its molecules abstracting electrons from the conduction band and subsequently chemisorbing on the surface and grain boundaries as diverse oxygen species this was also reported in (Al-Diabat et al., 2021)

$O_g - O_2\,(ads)$ and $O_2\,(ads) + e^- = O_2\text{-}(ads)$.

When these reactions occur, adsorbed oxygen reduced the conduction band and increase the negative charge on the material, thus creating energy barriers for electron transport in the layer.

This phenomenon will increase the resistance of gas sensor and consequently lowering current flow. When hydrogen is flowed to the gas sensor, the following reactions takes place;

$2H_2(gas) + O_2\text{-}(ads) \rightarrow H_2O + e^-$

The ionized oxygen will react with hydrogen molecules to produce H_2O and released electrons. The electrons will adsorb into the conduction band and energy barrier will be reduced. This phenomenon will reduce the resistivity of the gas sensor, where it can be seen by the reduction of gas sensor resistance and increasing current flow for reducing gas such as hydrogen. The Overall sensing mechanism is explained in details in figure 10.

In addition to oxygen-mediated charge transfer, alternative mechanisms may contribute to the observed sensing response. These include modulation of surface functional groups, variation in inter-particle contact resistance, and percolation effects within the carbon nanoparticle network. Further investigations involving oxygen partial-pressure variation, Hall-effect measurements, X-ray photoelectron spectroscopy (XPS), and theoretical modeling would be valuable for establishing the dominant sensing mechanism.

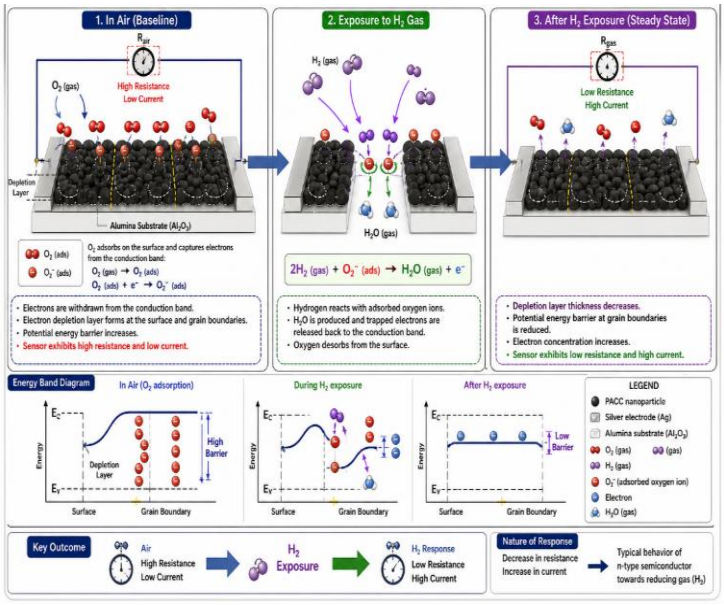


Figure 10: Sensing Mechanism of PACC Nanoparticle Sensor

From L-R: (i) The baseline: electrons are withdrawn from the conduction band and electron depletion layer is formed; (ii) The H_2 is exposed and reacts with adsorbed O^- and consequently H_2O is produced and oxygen is desorbed from the surface; (iii) The steady state after H_2 is where the thickness of the depletion layer decreases, electron concentrations increases and as a results, the potential energy barrier is reduced.

Table 2 presents a comparison between the present works with other gas sensors based on carbon based nanomaterials. This work on pristine biomass carbon for hydrogen gas detection is almost unavailable in literature. This further signifies the novelty of the specific biomass and process

reported here, rather than novelty of carbon-based room-temperature H_2 sensing more generally, since unmodified-carbon room-temperature H_2 sensors have previously been reported (e.g., candle carbon soot) and it could be observed that the results obtained from this work outperforms previous work in terms of the detection sensitivity where 15% and 16.7% is recorded at room-temperature for 1000 ppm and 100ppm H_2 concentrations.

Table 2: Systematic Comparison of Previous Works with Present Study

Material	Gas	Concentration	Temperature	Sensitivity	References
Candle Carbon soot CCS	H_2	5000ppm	RT	4%	(Dhall & Mehta, 2020b)
Pt- Graphene	H_2	10000ppm	175 ^{0}C	5%	(Hwan et al., 2011)
Porous Si/ Go/Pt	H_2	10000ppm	RT	6%	(Shiraz, 2017)
PACC	H_2	1000ppm	RT	13.6%	This work
Graphene/SnO_2 composite	H_2	100ppm	RT	15%	(Manuscript, 2015)
MWCNT	H_2	1000ppm	300 ^{0}C	6%	(Kim et al., 2011)
			RT	2%	
PACC	H_2	100ppm	RT	16.7%	This work

This work Recorded 1000pm and 100pm H_2 Concentrations at Room-Temperature with 15% and 16.7% Sensitivity Respectively.

In comparison with surface acoustic wave (SAW)-based hydrogen sensing platforms, the present PACC thick-film sensor offers advantages in terms of fabrication simplicity, low material cost, and room-temperature operation. However, SAW-based sensors can benefit from advanced signal processing, environmental compensation, and machine-learning-assisted classification algorithms capable of improving selectivity and drift resilience (Yunusa et al., 2015). Future research may explore the integration of biomass-derived carbon sensing layers with acoustic transducers to combine the sustainability and affordability of carbon-based sensing materials with the enhanced analytical capabilities of SAW platforms**.**

Recently reported organic vertical-stack hydrogen sensors have demonstrated oxygen-independent operation, environmental robustness, and detailed mechanistic investigations supported by computational modeling. While the present PACC sensor exhibits measurable room-temperature responses at relatively low hydrogen concentrations, additional studies involving oxygen variation, humidity cycling, encapsulation strategies, and mechanistic characterization would further strengthen understanding of the sensing process and practical deployment potential. The methodological rigor demonstrated in these studies provides a useful benchmark for future investigations of biomass-derived hydrogen sensing materials.

Beyond conventional gas sensing approaches, computer-vision-based hydrogen leak detection systems have emerged as attractive tools for large-area monitoring. Such systems provide non-contact leak visualization but may be affected by environmental conditions, line-of-sight limitations, and computational requirements. In contrast, chemiresistive hydrogen sensors provide direct local concentration measurements with low power consumption and simple electronics. Hybrid sensing architectures combining distributed chemiresistive sensors with imaging-based monitoring systems may improve reliability through redundant and complementary detection mechanisms, thereby enhancing safety in future hydrogen infrastructures.

The use of Prosopis africana as a sensing-material precursor aligns with the growing interest in sustainable and locally sourced functional materials. However, large-scale implementation should consider long-term availability, sustainable harvesting practices, and regional ecological impacts. Importantly, the sensing concept demonstrated in this work is not inherently restricted to Prosopis africana. Other biomass resources possessing comparable carbonization characteristics, including agricultural residues and lignocellulosic waste materials, may provide similar sensing functionality. Comparative studies involving multiple biomass precursors would be valuable for establishing broader structure–property relationships and assessing the generaliizability of the approach.

CONCLUSION

In this work we demonstrated the low-cost fabrication and evaluation of a hydrogen gas sensor based on thick-film technology using pristine biomass-derived carbon nanoparticles obtained from Prosopis africana charcoal. The nanoparticles were synthesized through a pyrolysis process without chemical activation. The fabricated sensor operated successfully at room temperature and exhibited typical sensing behaviour attributed to the reduction reaction of hydrogen gas on the sensing surface. The sensor achieved a maximum sensitivity of 16.7% and 15% at 100ppm and 1000pm H_2 concentrations respectively. The sensing response exhibited a nonlinear trend with increasing gas concentration, which is consistent with the existing literature. The observed sensing performance is strongly associated with the disordered carbon structure of the pristine biomass material as confirmed by Raman spectrosopy analysis. Furthermore, FESEM analysis revealed that the sensing film possessed a rough, porous and agglomerated surface morphology containing interconnected voids and nanoscaled particles. These structural characteristics are advantageous for gas sensing because they provide a high surface-area-to-volume ratio and abundant active sites for hydrogen adsorption. Overall, the developed pristine PACC sensor demonstrated promising hydrogen sensing capability with good selectivity, acceptable stability and moderate response-recovery characteristics at room temperature.

Future work will focus on improving sensitivity, selectivity, and operational stability through surface engineering and controlled functionalization of the carbon nanoparticles. Additional investigations will target lower hydrogen detection limits, humidity and oxygen dependence, long-term aging behavior, sensor-to-sensor calibration, and drift compensation strategies. Validation under mixed-gas environments and realistic hydrogen leak scenarios will also be conducted to evaluate practical deployment potential. Furthermore, integration with advanced sensing architectures, including acoustic-wave transducers and hybrid monitoring systems, will be explored to enhance selectivity and environmental robustness.

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