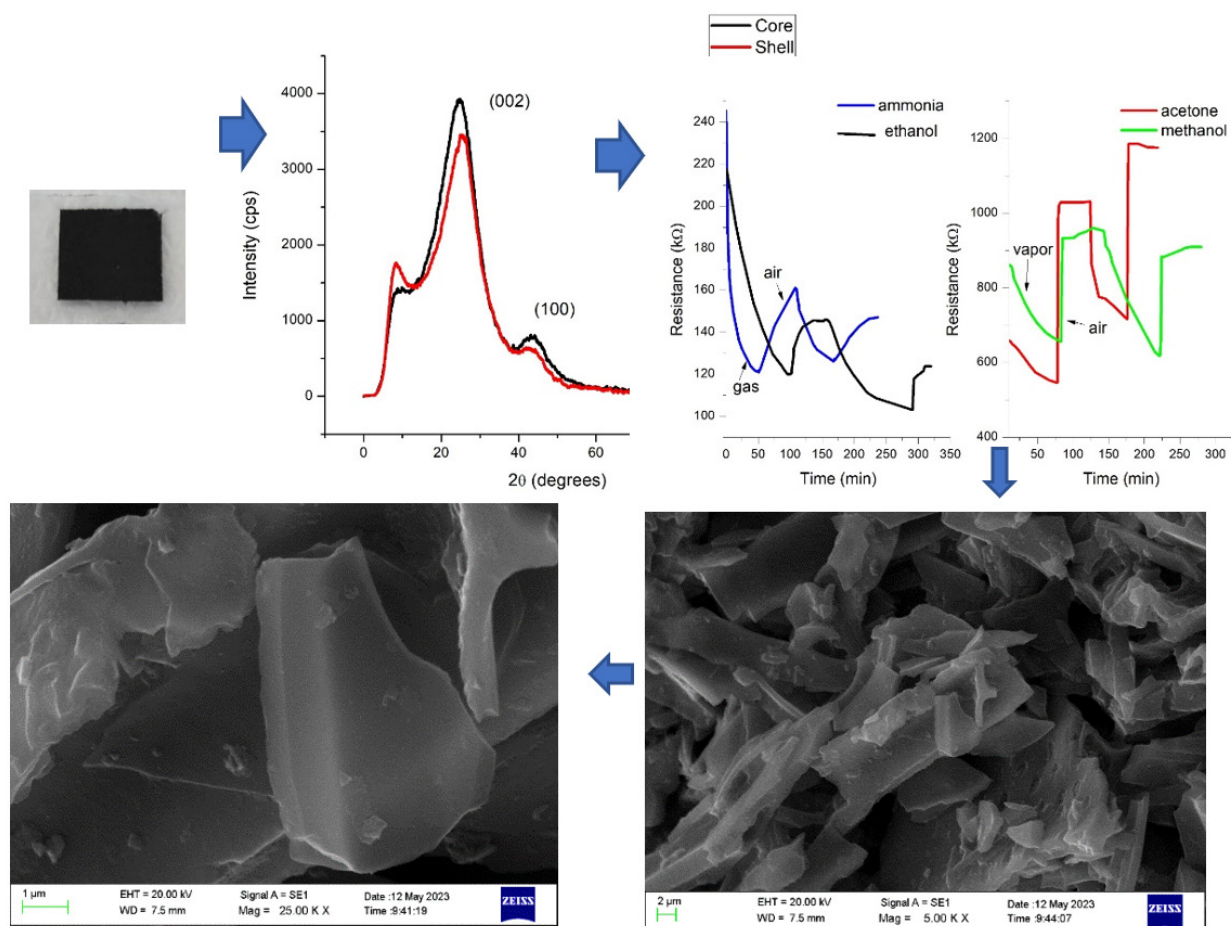


RESEARCH ARTICLE

Carbon gas sensors synthesized using acacia auriculiformis tree branches to detect methanol, ethanol, acetone vapors and ammonia gas

R.A.S.R. Ranasinghe, K.A.C. Rathnathilaka, P.G.D.C.K. Karunarathna and P. Samarasekara*



Highlights

- Carbon particles were fabricated from the branches of *Acacia auriculiformis* tree indigenous to Sri Lanka.
- Films of carbon were synthesized using the doctor blade method.
- Structural, optical, chemical and morphological properties of the samples were investigated using XRD, UV-Visible, FTIR spectrums and SEM images.
- The gas sensing properties of the samples were measured in methanol, ethanol, acetone vapors and ammonia gas.

RESEARCH ARTICLE

Carbon gas sensors synthesized using acacia auriculiformis tree branches to detect methanol, ethanol, acetone vapors and ammonia gas

R.A.S.R. Ranasinghe¹, K.A.C. Rathnathilaka¹, P.G.D.C.K. Karunarathna² and P. Samarasekara¹

¹ Department of Physics, University of Peradeniya, Peradeniya, Sri Lanka

² Department of Nano Science Technology, Wayamba University of Sri Lanka, Kuliyaipitiya, Sri Lanka

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Abstract: Metal oxides and carbon are the prime candidates of gas sensor devices. For the inaugural instance, carbonaceous particulate matter was meticulously derived from the branches of *Acacia auriculiformis* tree indigenous to Sri Lanka to detect vapor and gas. It is worth noting that biomass derived carbon had hitherto remain unexplored in the realm of vapor and gas detection. Carbon films were fabricated via the doctor blade method. The resistivity characteristic of these carbon samples exhibited discernible variations upon exposure to methanol, ethanol, acetone vapors, and ammonia gas. Notably, the gas-sensing properties of sample derived from the central core and the outer shell of *Acacia auriculiformis* tree branches were independently assessed in these vapors and gas at ambient temperature. Various analytical techniques, including X-ray diffraction (XRD), UV-visible absorption spectroscopy, Fourier transform infrared (FTIR) spectroscopy and scanning electron microscopy (SEM), were judiciously employed to scrutinize the structural attribute, optical band gap, chemical composition and surface morphology of the aforementioned carbon film samples, respectively. XRD analyses unequivocally confirmed the successful formation of carbonaceous films. FTIR spectra conspicuously delineated the presence of oxygen within the carbon films. Importantly, the optical band gap of our carbon films manifested within the range characteristic of organic carbon. Furthermore, the resistance of the carbon films demonstrated a significant reduction upon adsorption of each vapor. It is noteworthy that while gas sensitivities and response times were superior for carbon derived from the central core of the *Acacia* tree branches, the recovery times were notably expedited for carbon synthesized from the outer shell of these branches. The zenith of gas sensitivity, an impressive 187%, was recorded in response to 1000 ppm of methanol vapor, when employing carbon sourced from the central core of the acacia tree branches.

Keywords: Carbon thin film; *Acacia*; Gas sensor; XRD; UV-visible absorption spectrum

INTRODUCTION

Owing to the higher specific surface area, lower cost, higher porosity, chemical complexity and surface functionalization of activated carbon, activated carbon finds potential applications in the removal of pollutants, water treatment, adsorption and energy. The activation energy of activated carbon varies from 100 to 300 kJ/mol. The characterization of activated carbon synthesized using wood or biomass can be summarized as follows. Adsorption and reaction of

nitric oxide have been studied for activated carbon prepared using oil palm shells (Klose & Rincon, 2007; Lua et al., 2006). Date pits have been converted to activated carbon using phosphoric acid (Abdulkarim & Al-Rub, 2004). Activated carbon with different adsorption capacities in the range of 240-1176 mg/g has been fabricated using pinewood (Tseng et al., 2003). Adsorption capacities of activated carbon prepared from mahogany sawdust varies from 327.9 to 518 mg/g (Malik, 2004). Activated carbon synthesized using eucalyptus wood has been characterized with phenol adsorbate (Tancredi et al., 2004). Chestnut wood, cedar wood and walnut wood have been used to prepare activated carbon. BET surface area of chestnut wood samples were 777 and 584 m²/g (Díaz-Díez et al., 2004). BET surface area activated carbon prepared by oak wood varies from 642 to 985 m²/g with the change of the fabricated temperature (Zhang et al., 2004). Activated carbon synthesized using rubber wood has been studied for different adsorbates such as Cu(II), Bismark brown dye and Cr(VI) (Kalavathy et al., 2005; Kumar et al., 2005; Karthikeyan et al., 2005). The adsorption capacity of the activated carbon fabricated using the rubber wood varies in a wide range from 5.72 to 2000 mg/g (Kalavathy et al., 2005; Kumar et al., 2005; Karthikeyan et al., 2005). The highest adsorption capacity is reported for rubber wood among other biomasses (Kumar et al., 2005). The adsorption capacity of activated carbon prepared using fir wood varies from 180.3 to 1476.3 mg/g for different adsorbates such as Cr(VI), p-chlorophenol, p-nitrophenol, methylene blue, basic brown 1, acid blue 74, phenol and p-cresol (Khezami & Capart, 2005; Wu & Tseng, 2006). Highest BET surface area is reported for fir wood so far (Wu & Tseng, 2006). BET surface area of activated carbon fabricated using teak sawdust 1150 m²/g (Ismadji et al., 2005). BET surface area of walnut wood activated carbon is 1033 m²/g (Gómez-Serrano et al., 2005). The adsorption capacity of oil palm wood activated carbon with methylene blue adsorbate is 90.9 mg/g (Ahmad et al., 2007). The adsorption capacity of evergreen oak wood activated carbon is 255 mg/g for Zn(II) adsorbate (Del Mar Gómez-Tamayo et al., 2008). Reversible water vapor isotherms have been observed for activated carbon prepared from peltogyne wood from Surinam (Vartapetyan et al., 2005). Activated

*Corresponding Author's Email: pubudus@pdn.ac.lk



carbon has been prepared from eucalyptus and wattle wood by carbonizing the wood in N_2 at 400 °C (Ngernyen et al., 2006). BET surface area of activated carbon synthesized from cedar wood is 1705 m²/g (López de Letona Sánchez et al., 2006). Many researchers have used phosphoric acid to activate biomasses to make activated carbon (Klijanienko et al., 2008; Saleem et al., 2017).

The activated carbon of acacia tree branches can be summarized as follows. Activated carbon prepared from acacia (*Vachellia seyal*) tree branches has been used to treat wastewater containing methylene blue (Saleem et al., 2017). The total pore volume of activated carbon fabricated from acacia mangium wood varies from 0.015 to 0.090 cm³/g (Danish et al., 2011). Phosphoric acid concentration, temperature and activation time duration have been optimized to enhance the pore volume of activated carbon produced from acacia mangium wood (Danish et al., 2014). The total pore volume of activated carbon fabricated from acacia mangium activated by $ZnCl_2$ is 0.422 cm³/g (Danish et al., 2013).

Research on gas sensors can be summarized as follows. Most of the gas sensors are made of semiconductor oxides such as CuO, ZnO, Fe₂O₃, WO₃, ---etc. Doping of some elements to metal oxide enhances the gas sensitivity. The gas sensitivities of pure α -Fe₂O₃ films synthesized using the doctor blade method were 27.1, 23.2, 46.0 and 49.2% at 1000 ppm of ethanol vapor, ammonia vapor, carbon dioxide gas and acetone vapor, respectively. The highest gas sensitivity of Mn-doped α -Fe₂O₃ films measured in 1000 ppm of CO₂ was found to be 70.1% at the room temperature for 6% Mn doped α -Fe₂O₃ samples (Rajapaksha et al., 2021). TiO₂ films prepared using modified sol-gel technique have been used to detect ethanol (100 ppm), methanol (100 ppm), CO (100-300 ppm) and NO₂ (0.5-4 ppm) (Garzella et al., 2000). NH₃ has been detected using SnO₂ films fabricated using screen printing (Llobet et al., 2003). CuO particles and plates synthesized using the thermal deposition method could detect NO₂ (Li et al., 2008). NiO prepared using chemical deposition and pyrolysis process has been used to detect benzaldehyde (Yang & Guo, 2016). A little amount of NO₂ (50 ppb) has been detected using In₂O₃ fabricated by vapor phase transport technique (Gonzalez et al., 2015). Tungsten trioxide (WO₃) nanotubes with 200 nm pore diameter and 600 nm pore length synthesized by sol-gel technique have been used to detect NO₂ and CH₃OH (Gerlitz et al., 2009). The adsorption of gases by carbon nanotubes has been investigated using first-principles calculations and density functional theory.

Most nanocarbon materials attain a higher carrier mobility and a lower noise due to the quality of the crystal lattices. Nanocarbon materials are more stable because the effect of the grain boundaries is negligible. Their properties are assets in the fabrication of devices with better transduction. In addition, carbon is stable even under moisture conditions. Even though the surface pore structure mainly contributes to the adsorption of carbon, the internal pore structure affects less on the adsorption. The circumferential surface area of granules is another important factor. The ratio of the gas sensitivity to the cost of carbon materials is better. Because

the carbon-based devices need a lower electric power for the operation, they can be operated remotely with a lower cost. Owing to the lower cost and the portability of the devices, the transduction measurements are better than the measurements of optical properties. Because the activation energy required for the structural rearrangement of carbon materials is higher, carbon nanomaterials are more stable compared to many other sensing materials.

In this manuscript, the gas sensing properties of carbon prepared using acacia auriculiformis tree branches are explained. A method introduced by some other researchers was employed to synthesize activated carbon (Saleem et al., 2017). The gas sensitivity was measured in ethanol, methanol and acetone vapors.

MATERIALS AND METHODS

Preparation of carbon particles:

First the acacia auriculiformis tree branches were separated into the core and the shell. Then they were dried under the sunlight for three days. These dried samples were cut into small pieces. Thereafter, they were cleaned with hot distilled water to remove any dust, and they were heated at 120 °C in an oven for 24 hours. Each sample was mixed with the phosphoric acid of 85% concentration with volume ratio sample: acid = 3:2. Then each sample was heated at 120 °C in an oven for 24 hours. Each sample was subsequently heated in an oven at 600 °C for 2 hours. Then the sample was washed with hot distilled water until the pH value of water reached 6.5.

Preparation of films:

Polyethylene Glycol (PEG) was used as the binder. First 0.05 g of PEG powder was dissolved in 8 ml of distilled water and stirred at 300 rpm for 15 min at 45 °C. Then 0.27 g of carbon powder was put in 3 ml of PEG solution and stirred at 300 rpm for 1 hour at 50 °C. Layers of carbon prepared using core and shell were fabricated on conductive (ITO) and nonconductive glass plates using the doctor blade method. Then the samples were heated at 75 °C for 30 min on a hot plate in air. The area of the sample was 1.5x1.6 cm².

Characterization of the sample:

The X-ray diffraction (XRD) patterns of the films deposited on nonconductive amorphous glass were measured using a Rigaku Ultima IV X-Ray diffractometer with Cu-K α ($\lambda=1.5406 \text{ \AA}$) radiation with diffraction angle ranging from 0 to 50 degrees. The optical band gap of films deposited on nonconductive substrates was measured by a Shimadzu 1800 UV-Vis spectrophotometer with wavelength range from 190 to 1100 nm. Fourier transform infrared (FTIR) spectrums of the films prepared on nonconductive substrates were measured using a Jasco 6700 FTIR spectrometer with wavenumber range from 349 to 7800 cm⁻¹. The surface morphology of the films was investigated by means of a Zeiss EVO LS15 Scanning Electron Microscope (SEM). The sheet resistance of films was measured using a Jandel model RM3000+.

Gas sensitivity measurement:

When the samples were synthesized on conductive glass plates for the gas sensitivity measurements, the center part of the conductive layer of the glass plate was removed so that the electric current flows only through the film. First the resistance (R_0) of the film was measured. Then the sample and a standard resistor with the resistance value of R_0 were connected in series to a dc power supply of 5 V. The sample was placed inside a sealed chamber with a volume of 91.56 cm³. Gold coated copper wires were used for the electrical contacts of the sample. A Fluke multimeter model 289 was connected across the standard resistance to measure the voltage across it. Prior to the measurements, the voltage was applied to the circuit for 1 hour to stabilize the current. Then 1000 ppm of ethanol, methanol or acetone vapor was introduced to the chamber. When the reading of the Fluke multimeter became constant at saturation, the air was passed through the chamber until the voltage reading reached its initial value. The gas sensitivity was measured at the room temperature. Figure 1 shows a schematic diagram of the gas sensor.

RESULTS AND DISCUSSION

Figure 2 depicts the XRD patterns of carbon prepared from the core (black line) and the shell (red line) of the acacia auriculiformis tree branches. All the peaks belong to the phase of the carbon (Farma et al., 2019; Girgis et al., 2007). Peaks are broadened due to the amorphous nature of the carbon. Crystallite size (D) and strain (ε) were calculated using

$$D = \frac{0.91\lambda}{\beta \cos \theta} \text{ and } \varepsilon = \frac{\beta \cos \theta}{4}, \text{ respectively.}$$

Where λ is the wavelength of Cu-K α radiation ($\lambda=1.54060$ Å), and β is the full width of half maxima (FWHM) for XRD peak at angle θ . When the number of dislocations per block face is n , the dislocation density (δ) is given by

$$\delta = \frac{3n}{D^2} \text{ (Williamson \& Smallman, 1956).}$$

For isotropic distributions of dislocations, $n = \frac{1}{3}$.

Therefore, the dislocation density was found using

$$\delta = \frac{1}{D^2} \text{ (Williamson \& Smallman, 1956; Bilgin et al., 2005; Rathinamala et al., 2014).}$$

The calculated values of the crystallite size, strain and the dislocation density for (002) peak are given in TABLE 1. The crystallite size of carbon powder synthesized from the shell is slightly higher than that of the carbon powder synthesized from the core. The smaller the crystallites is the higher the effective surface area of the powder sample.

Transmittance FTIR spectra of carbon fabricated from the core (black line) and the shell (red line) of acacia auriculiformis tree branches are illustrated in figure 3. Only slight differences could be found between the two curves. Absorption peaks were observed at 975, 1060, 1189, 1344, 1540, 1700, 2100 and 2350 cm⁻¹. The peaks at 975, 1060, 1189 and 1344 cm⁻¹ represent the C-O or C-C stretching (Bakti & Gareso, 2018). The peak at 1540 cm⁻¹ belongs to C=C bonds. Here the peak at 1700 cm⁻¹ represents the carbonyl (C=O) group. The peaks at 2100 and 2350 cm⁻¹ belong to C≡C triple bonds.

Figure 4 elucidates the UV-visible absorption spectra of carbon fabricated from the core (black line) and the shell (red line) of acacia auriculiformis tree branches. The absorption edges of the core and the shell are approximately 625 nm. Tauc plots of carbon prepared from the core and the shell of acacia auriculiformis tree branches are delineated in figure 5. Here the red line indicates the tangential line drawn to the linear part of the curve. The optical band gaps of the core and the shell are 1.75 and 1.90 eV, respectively. The optical band gap of carbon prepared from the shell is slightly higher than that of the core. Although the band gap of the commercially available activated carbon is around 4.5 eV, the band gap of organic carbon is approximately 1.8 eV (Russo et al., 2019).

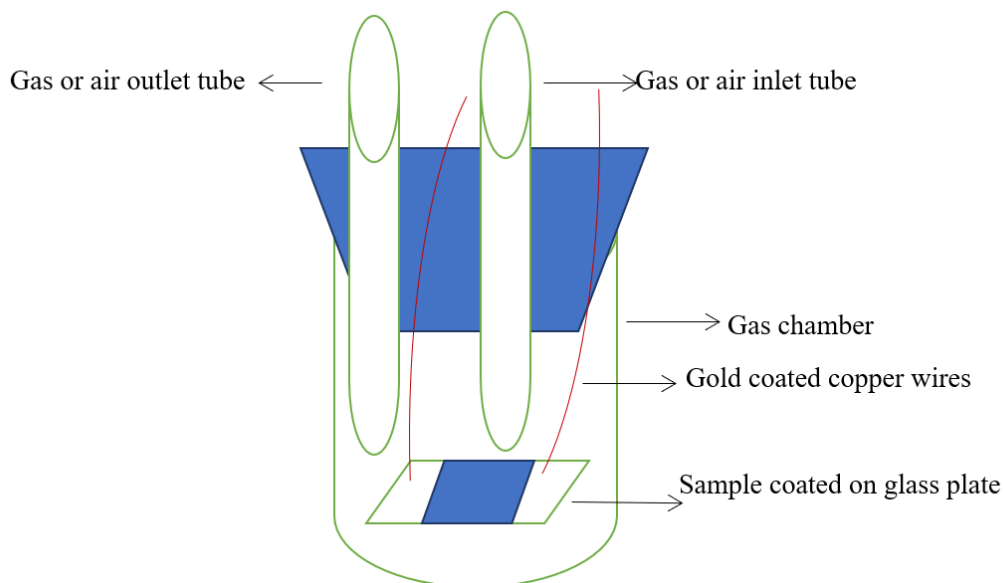


Figure 1: Schematic diagram of the gas sensor.

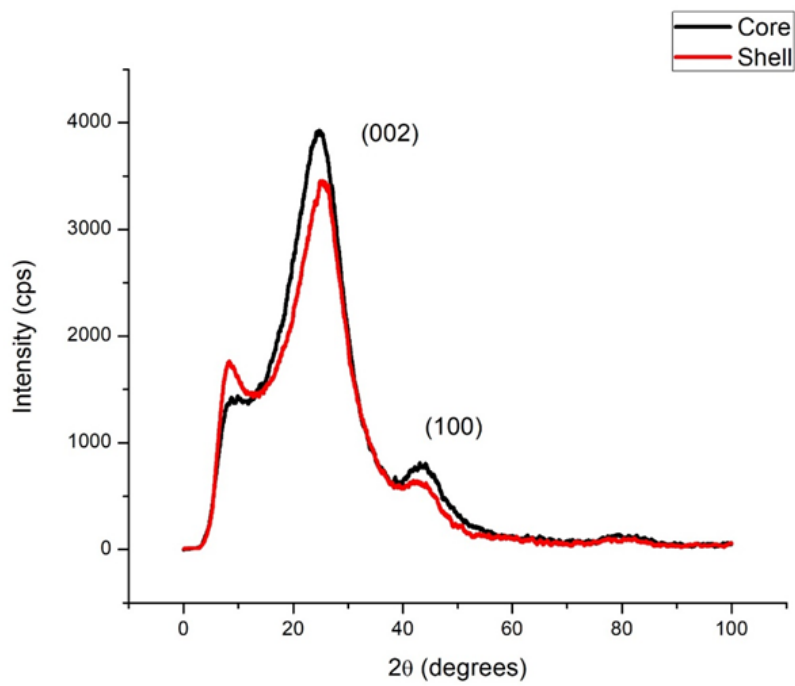


Figure 2: XRD patterns of carbon prepared from the core and the shell of the acacia tree branches.

Table 1: Crystallite size, strain and the dislocation density for (002) peak

	Crystallite size D/nm	Strain	Dislocation density/ lines per nm ²
Core	1.83	0.01915	0.30
Shell	2.18	0.01608	0.21

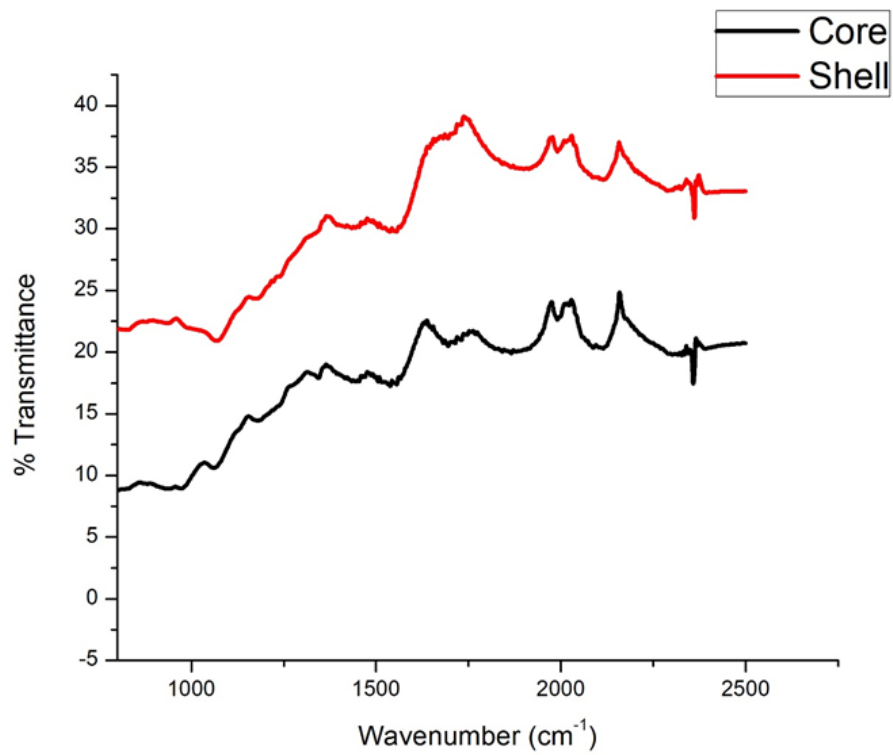


Figure 3: FTIR spectrums of carbon fabricated from the core and the shell of acacia tree branches.

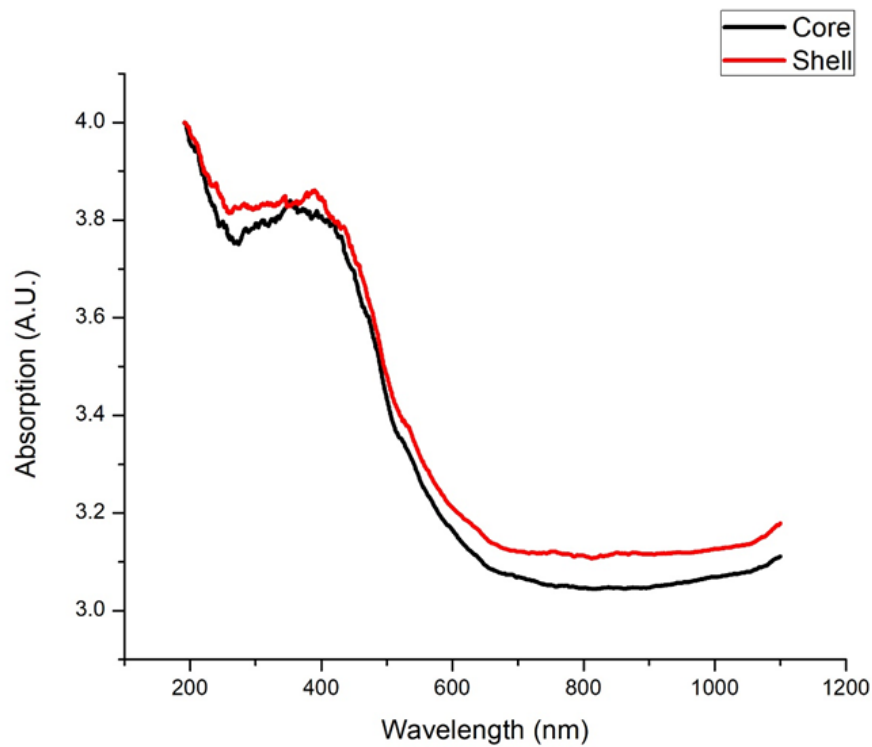


Figure 4: UV-visible absorption spectra of carbon fabricated from the core and the shell of acacia tree branches.

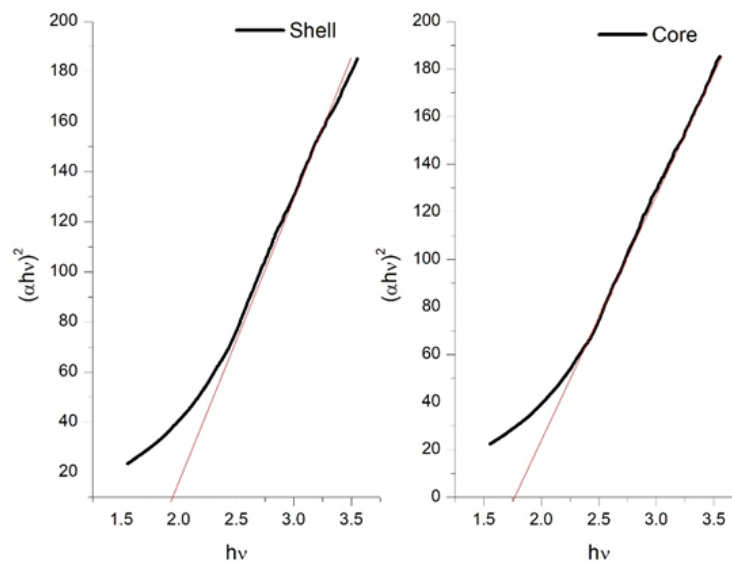


Figure 5: Tauc plots of carbon fabricated from the core and the shell of acacia tree branches.

Figure 6 shows the SEM images of carbon films synthesized from the core of acacia tree branches with magnifications of 5.00 k and 25.00 k. The particle size changes in a range from 1 μm to 30 μm with random distribution. Figure 7 depicts the micrographs of the carbon films prepared from the shell. The particle sizes in the films fabricated from the shell are smaller than those prepared from the core. Randomly distributed plate-like particles can be observed in both the films prepared from the core and the shell. The higher effective surface area of the plate-like particles is attributed to the better gas sensing properties.

Figure 8 delineates the SEM image of the cross section of the films prepared from the shell. The conductive glass plate appears at the bottom of the image. Thin sides of the plates are visible through the cross section of the film indicating that the flat sides of the plates with higher surface area parallel to the film plane are facing the gas or the vapor. This feature of the particles in the film is favorable to adsorb more vapor or gas atoms. The thickness of the films was approximately 45 μm . A similar image was observed for the cross section of the film synthesized from the core.

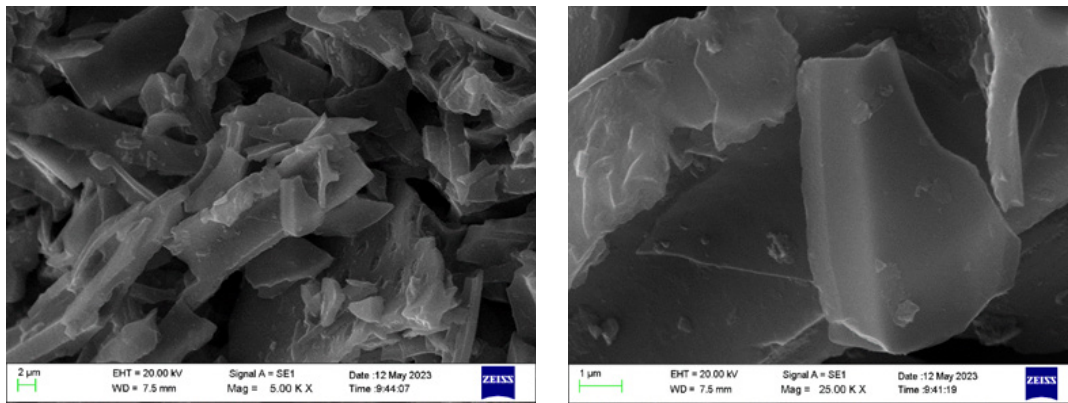


Figure 6: SEM images of carbon films synthesized from the core.

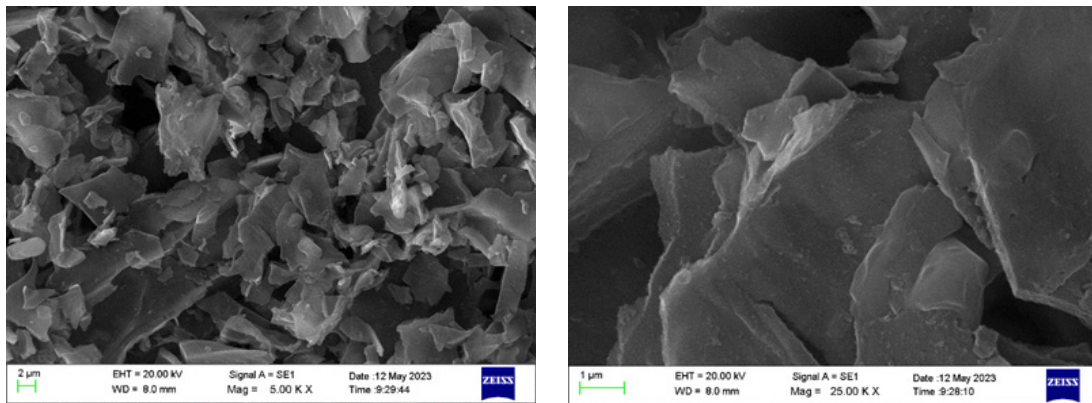


Figure 7: Micrographs of the carbon films prepared from the shell.

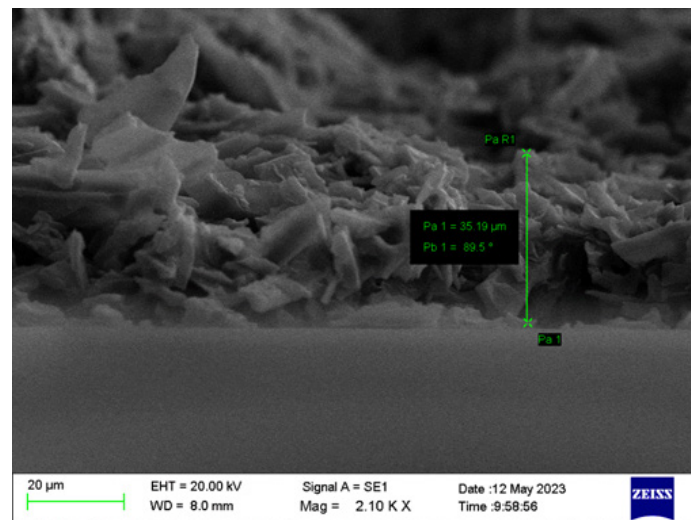


Figure 8: SEM image of the cross section of the films prepared from the shell.

The following equation is applied to calculate the gas sensitivity.

$$\text{Gas sensitivity} = \frac{|R_{\text{gas}} - R_0|}{R_0} \times 100\% \quad (1)$$

where R_{gas} is the resistance of the carbon film, when the carbon sample is saturated after adsorbing the vapor. R_0 is the initial resistance of the carbon film when the carbon film is in air. Because the sample and the standard resistor are connected in series, the same current flows through all the elements. After applying the Ohm's law for the series

circuit, the resistance (R) of the sample is given by

$$R = \left(\frac{5}{v} - 1\right) S \quad (2)$$

Where S and v are the resistance of the standard resistor and the measured voltage across the standard resistor, respectively. The dc power supply supplied 5 V to the circuit.

Figure 9 depicts the graph of the voltage measured across the standard resistor versus time for the carbon films prepared from the core of acacia auriculiformis tree

branches measured in 1000 ppm of ethanol, methanol, acetone vapors and ammonia gas. Then the resistance of the sample was calculated at each voltage using the above equation (2). Figure 10 exhibits the graph of resistance of carbon films prepared from the core versus time for all three vapors. The initial resistances of different samples are different due to a slight variation of the area and the thickness of the film. The gas sensitivity was calculated from equation (1) for all three curves given in figure 10. The gas sensitivity, response time and recovery time of the carbon films prepared from the core are given in TABLE 2 for the second cycle in figure 10. All the gas sensitivity measurements were repeated three times to verify the data.

The sheet resistance of the carbon film prepared from the core is $1.2\text{M}\Omega/\text{cm}^2$.

Figure 11 demonstrates the graph of voltage measured across standard resistor versus time for the carbon film prepared from the shell of the acacia auriculiformis tree branches measured in 1000 ppm of ethanol, methanol, acetone vapors and ammonia gas. Figure 12 delineates the graph of resistance of the carbon film prepared from the shell as calculated using the equation (2) versus time for 1000 ppm of ethanol, methanol, acetone vapors and ammonia gas. Our carbon samples could not detect CO_2 gas.

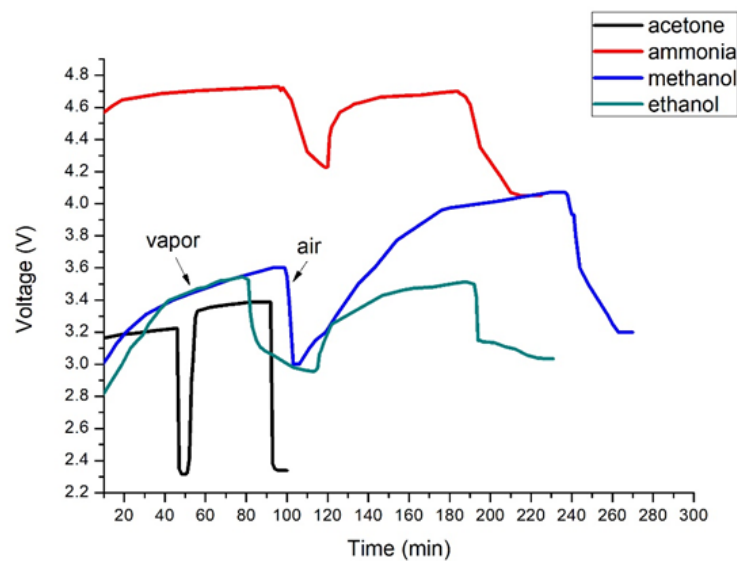


Figure 9: Graph of the voltage versus time for the carbon films prepared from the core of acacia tree branches measured in 1000 ppm of ethanol, methanol, acetone and ammonia vapors.

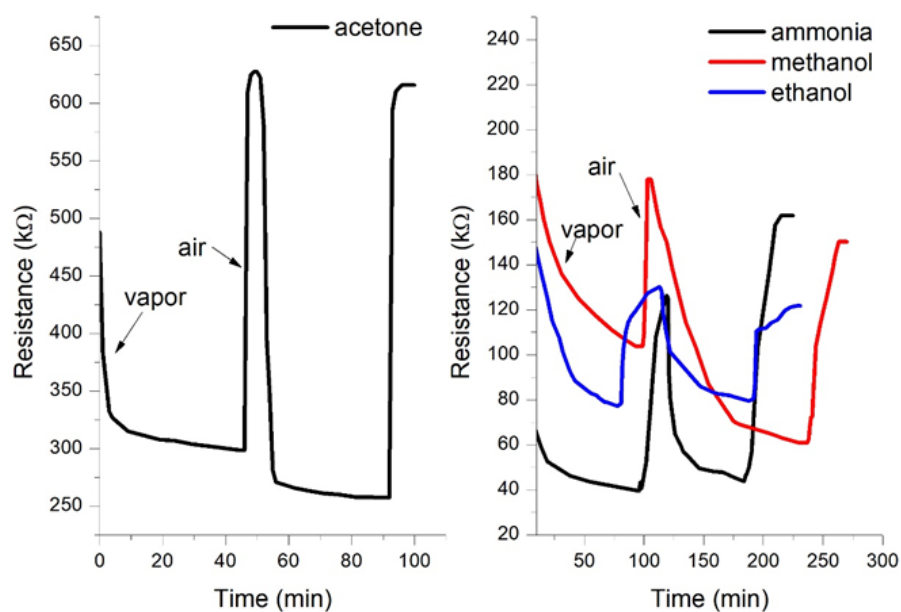


Figure 10: Graph of resistance of the carbon films prepared from the core versus time measured in 1000 ppm of ethanol, methanol, acetone and ammonia vapors.

Table 2: Gas sensitivity, response time and recovery time of the carbon films prepared from the core for second cycle.

Vapor	Gas sensitivity (%)	Response time (min)	Recovery time (min)
Acetone	139	5	2
Methanol	187	74	25
Ethanol	60	78	31
Ammonia	171	65	30

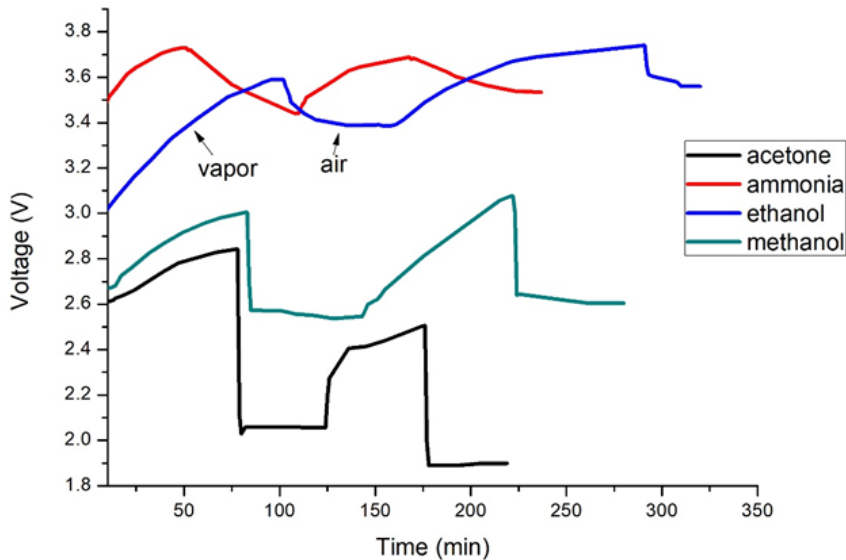


Figure 11: Graph of voltage measured across standard resistor versus time for the carbon film prepared from the shell of the acacia tree branches measured in 1000 ppm of ethanol, methanol, acetone and ammonia vapors.

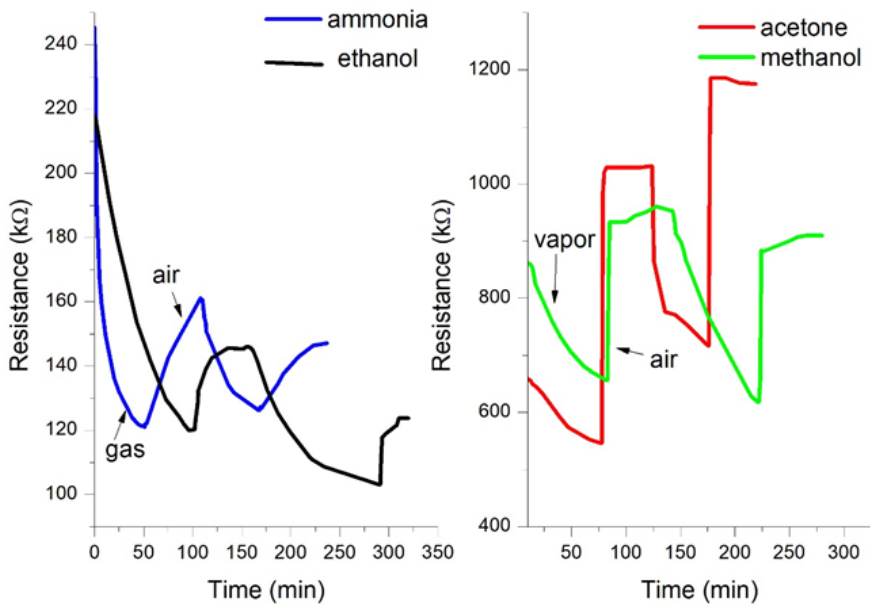


Figure 12: Graph of resistance of the carbon film prepared from the shell versus time for 1000 ppm of ethanol, methanol, acetone and ammonia vapors.

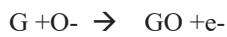
The gas sensitivity, response time and recovery time of carbon film synthesized from the shell of the acacia tree branches for the second cycle given in figure 12 are tabulated in TABLE 3. The gas sensitivity of carbon prepared from the core is higher than that of carbon prepared from the shell for all the vapors and the gas. The gas sensitivity measured in methanol is higher for both the

core and the shell among ethanol, acetone and ammonia. The porosity of the samples prepared from the core and the shell were found to be 5.68% and 0.52%, respectively. The higher porosity in the samples prepared from the core is attributed to the higher gas sensitivity of the samples prepared from the core.

Table 3: Gas sensitivity, response time and recovery time of carbon film synthesized from the shell for the second cycle.

Vapor	Gas sensitivity (%)	Response time (min)	Recovery time (min)
Acetone	44	52	2
Methanol	54	77	2
Ethanol	42	135	25
Ammonia	28	57	68

After adsorbing the gas or the vapor, the current across the circuit increases for all the vapors. This implies that the resistance of the sample decreases after adsorbing the gas or vapor. Because the peaks of carbonyl were found in the FTIR spectrums, the FTIR spectrums confirm the existence of oxygen in the sample. When the reducing gas (G) reacts with chemisorbed oxygen, it forces electrons into the conduction band. As a result, the resistance decreases.



Because the donor vapor molecule donates electrons to carbon, the conductivity of the carbon sample increases after adsorbing each vapor.

Carbon based materials such as carbon nanotubes, graphite and graphene have been already employed as gas sensors due to the unique properties of carbon. Carbon-based materials are mostly mixed with polymers, metals or metal oxides to obtain better gas sensing performances (Wanna et al., 2006; Valentini et al., 2004; Wienecke et al., 2003; Jiang et al., 2014; Zhang et al., 2021; Chu et al., 2018). Activated carbon doped with boron has been employed to detect NO₂ (Kim et al., 2020). The gas sensitivity of our carbon gas sensors is significant even without adding polymers, metal oxides or any other element. The production cost of our carbon particles is much lower than the production cost of carbon nanotubes. Any waste carbon gas sensor can be easily released to the environment without any pollution. In addition, the used carbon can be regenerated. Carbon samples easily adsorb gases due to their higher specific surface area and higher porosity. The adsorbed gases can be easily removed by increasing the temperature or the pressure of the carbon. The adsorption properties of the carbon depend on the molecular weight and the shape of the gases and the vapors. The higher the molecular weight is the better the adsorption ability. Therefore, the heavier molecules such as ammonia, methanol, acetone and ethanol can be easily adsorbed by carbon. Because carbon indicates excellent electroactive properties, the resistance of the gas sensor changes significantly after adsorbing a gas or a vapor.

The second cycle in our samples is shifted due to the following reasons. The amount of the shift is different for different gases or vapors even for the same sensing material. It can be attributed to the trapped vapor molecules in the film during the first cycle. When the first cycle ends up at a higher electric current, and the second cycle starts at a higher electric current. The decrease or increase of the barrier height can be the reason for it. In addition, it can be attributed to the increase or decrease of charge carrier density. A shift of cycles has been observed for the NO₂ adsorption of activated carbon and carbon nanotubes by

some other researchers (Kim et al., 2020; Li et al., 2003).

Although faster response and recovery are required in some applications, a higher gas sensitivity is favorable in some other applications. Carbon prepared from the core indicates the highest gas sensitivity in the methanol vapor, even though the response and recovery in methanol are slower compared to the film measured in the acetone. The performance of the gas sensor prepared using the core is worst in the ethanol among the ethanol, methanol, ammonia and acetone. When the concentration of PEG binder solution was increased, the response time gradually increased. Therefore, all the samples were prepared with 0.05 mg of PEG dissolved in water. The gas sensors are normally synthesized on high-cost gold micropatterns, silver or platinum electrical contacts to achieve higher gas sensitivities, lower response times and lower recovery times at lower ppm values of the gas (Nanto et al., 1986; Aleksanyan et al., 2022; Ani et al., 2021; Fioravanti et al., 2021). The response and recovery of our samples were higher, since our carbon films were not synthesized on expensive gold, platinum or silver layers.

CONCLUSION

The primary advantage inherent to this gas sensor resides in its cost-effectiveness, achieved through the utilization of carbon materials derived from the branches of Acacia trees. Furthermore, heightened gas sensitivities were ascertained in our specimens without the incorporation of gold, platinum or silver contact layers. The most favorable response and recovery times were observed in carbon films synthesized from the core of Acacia tree branches when subjected to acetone vapor. The highest degree of gas sensitivity was recorded in methanol vapor for specimens produced from both the outer shell and the inner core. The gas sensitivities for core-derived samples surpassed those of shell-derived samples, attributable to the heightened porosity and the diminished crystallite size in the former. The commensurate band gap measurement between core and shell samples suggests that variation in gas sensitivity is not attributed to band gap changes. Furthermore, the addition of any dopants was not required to obtain these higher gas sensitivities of our carbon samples. Although the second-most favorable gas sensitivity was detected in acetone vapor for shell-synthesized carbon samples, ammonia gas yielded the second-highest response for core-synthesized carbon samples. The optimum response and recovery times were recorded were in acetone vapor for samples obtained from both the core and the shell, signifying a faster reactivity with acetone vapor in comparison to ethanol, methanol vapors and ammonia gas. The extended response and recovery times can be attributed

to the absence of gold, silver or platinum layers utilized for electrical contacts in our samples.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interests.

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