Preparation, investigation, and temperature sensing application of rGO/SnO₂/Co₃O₄ composite

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ABSTRACT

The uprising era of technological applications seeks solutions that facilitate daily life activities. Sensors with their different types provide fast and reliable information. The employment of graphene oxide in these sensors complies with the general requirement for sensor’s functionalization and easily achieves the purpose for which the sensor was prepared. In this report, we have synthesized rGO/SnO₂/Co₃O₄ composite with a star-like structure through a facile chemical route. The mentioned structure was employed as a temperature sensor within a temperature range of 25–125 °C and a wide span of relative humidity values. In order to assess the quality of preparation and the sensing ability, the composite was inspected by the following techniques: XRD, FTIR, SEM, and thermal analysis in addition to the sensing measurements. The XRD results affirmed the successful incorporation of the SnO₂/Co₃O₄ onto the rGO with 18 nm average crystallite size. The SEM results revealed the characteristic star-like structure with a mean length of 100 nm. The main functional groups are reflected in the FTIR results. The outcomes elucidated a linear response between the resistance and temperature, where the temperature coefficient of resistance is estimated to be 0.006/°C. These results confirm the validity of this structure for temperature sensing applications.

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1 Introduction

In a rapidly evolving world, the necessity for solutions that provide better living conditions, save time, cost, and effort is a huge demand in the recent former years. Sensors can satisfy this need by delivering rapid information in a short period regarding the targeted application. From this perspective, the employment of temperature sensors is required in diverse application areas, such as food storage, agriculture, medicine, and internal environment control [1, 2].

The criteria for sensor performance assessment corroborate with various parameters, which include fast response and recovery times, stability, reproducibility, sensitivity, and operating range. The metal oxide nanostructure materials are special for sensing applications because they exhibit significant changes in their resistance, impedance, and capacitance due to reacting with environmental conditions. Significant parameters for the functioning of most sensors are (1) the exposed surface area, (2) the porosity of the material, and (3) structure discrepancy, in which the interaction with the surrounding environmental stimuli takes place. Temperature is the vital parameter to evaluate in diverse fields. Conventional resistance temperature detectors (RTDs) manufactured from metals demonstrate positive temperature coefficient (PTC) attitude, while thermistors are based on metal oxides, and ceramic materials exhibits a negative temperature coefficient (NTC). Although the advantages of thermistors, they are inappropriate from economical point of view as they consume high energy during their fabrication process [3–5].

Graphene oxide (GO) and reduced graphene oxide (rGO) are unique trendy materials that possess marvelous specifications, such as higher conductivity and mobility, thermal stability, and enlarged surface area [6]. Graphene represents the basic building block of graphitic materials; it is a single carbon layer produced from exfoliated graphite structure. Reduced graphene oxide (rGO) is prepared from the reduction of graphene oxide as cost-effective method. The rGO is an inexpensive and closely related material to graphene, but it offers lesser quality as it has some structural defects and remanent oxygen functional groups on its surface [7, 8].

Temperature sensing is employed for different areas of applications [9, 10]. As rGO is ticklish to temperature variation, it can easily be used as a temperature sensor [11]. Among other carbon nanomaterials, rGO is more appropriate to be used as a sensitive temperature material [12]. Mohammed Gamil et al. [13] reported the synthesis of graphene nanoplatelets as sensitive temperature sensor via drop casting technique, their sensor exhibited a good response in a wide range of temperature from room temperature (RT) up to 150 °C. Kim and Cui [14] studied the effect of glass substrate and anodic aluminum oxide (AAO) substrate on the graphene-based temperature sensor. Their results showed that the AAO substrate promotes the response time and sensitivity of temperature sensor. A transparent and flexible temperature sensor relied on polyaniline/graphene(PANI)–polyvinylbutyral (PVB) thin film has been fabricated by Jin Pan and et al. [15]. The fabricated sensor exhibited a negative temperature coefficient (NTC) in the temperature range of 25–80 °C.

The incorporation of metal oxide material onto the GO surface results in a composite material with improved electrical conductivity and enlarged surface area. Subsequently, this incorporation promotes the enhanced sensitivity of the material [16]. Various sensing approaches were followed using GO only [17, 18] or GO/SnO2 [19–21]. The tin oxide (SnO2) is a perspective n-type semiconductor with a wide bandgap of 3.7 eV at ambient conditions and an adjustable oxidation state [22]. Therefore, the incorporation of SnO2 onto the GO surface enhances the response of the sensor.

The Co3O4 nanoparticles are reported for their usage into the catalysis, energy storage devices, water treatment, and sensing areas [23–25]. Co3O4 is primarily conjugated with the graphene and carbon materials as a supporting material because of elevated surface area as well as raised conductivity magnitude [26, 27].

Despite the preceding approaches, the employment of the Co3O4 onto rGO/SnO2 is scarcely investigated for temperature sensing. To the best of our knowledge, no reports has been directed toward exploring the temperature sensing behavior of rGO/SnO2/Co3O4 structure at various humidity levels. The obtained structure has not been reported elsewhere. In other words, the main objective of this study was to prepare a star-like rGO/SnO2/Co3O4 nanocomposite. The resultant composite was examined to be employed as a temperature sensor. After screening a large number of previous literature, it
was concluded that almost no studies have interested in investigating the temperature sensing behavior of rGO/SnO2/Co3O4 structure at various humidity levels. Based on the previous acquainted results in our report [28] and motivated by this research deficiency, the current study explores the possibility of utilizing the synthesized rGO/SnO2/Co3O4 composite with a feasible preparation process as a temperature sensor. The obtained results revealed that the prepared star-like nanocomposite has a high sensitivity and fast response and thus can be efficiently used as a temperature sensor. The structural, morphological, thermal, and sensing mechanisms were revealed. This route paves the way to fast and sensitive sensors applications.

2 Experimental

2.1 Materials

Absolute ethanol and sodium hydroxide were purchased from Fisher chemical. Stannous chloride (SnCl2•5H2O) was acquired from Alfa easer. Cobalt nitrate Co(NO3)2•6H2O was obtained from Piochem. All chemicals and reagents were used as received without any further modification or treatment.

2.2 Synthesis of rGO/SnO2/Co3O4 nanocomposite

GO was synthesized by the modified Hummer method, more details regarding the preparation procedures are available in our previous work [29, 30]. Facile wet chemical precipitation method was employed for the synthesis of rGO/SnO2 nanocomposite. Shortly, 200 mg of GO was dispersed in 25 ml of distilled water using ultrasonication for 30 min. Afterward, 1.2 g of SnCl2•5H2O followed by 0.122 g of cobalt nitrate was dropped onto the previous solution under the sustained stirring for 30 min with the normal conditions of temperature and pressure. Parallel to the former synthesized mixture, another mixture was synthesized via combining 2.4 g of NaOH and 50 ml of distilled water which undergoes stirring for 1 h. Consequently, the second mixture was dropped onto the first one to attain the conclusive nanocomposite. The resultant nanocomposite was filtered and rinsed several times to remove the unwanted byproducts. The composite is hereafter exposed to microwave heat treatment for 10 min. The schematic representation of the synthesis process is illustrated in Fig. 1. The tin chloride was employed as the precursor for the SnO2. Basically, when SnCl2•5H2O is added to the water, it forms tin hydroxide as the resultant reaction between the Sn4+ reacts with water molecules. Furthermore, the graphene oxide has abundantly of epoxy, hydroxyl, and carboxylic acid groups and has the ability to disperse easily in water. Throughout this process, the pH of the reaction was increased to alkaline by adding NaOH solution where alkaline medium favors the star-like structure. The inclusion of Sn ions is depicted by the existence of FTIR bands.

2.3 Sensor fabrication

The fluorinated tin oxide-coated glass substrate (FTO) was used as a scaffold for sensing material deposition. A 1 mm gap was established between two conductive electrodes, where the sensing material is deposited by spin coating technique. In brief, about 20 mg of the desired material is mixed with a minimal amount of de-ionized water and ground in an agate mortar for 5 min and then deposited onto the scaffold using spin coater at 500 rpm for 5 min. The sensor was allowed to dry at 70 °C for 3 h. The sensor was aged at low and high humidity conditions to enhance the stability and reduce the signal-to-noise ratio. The sensor response was evaluated in a wide range of temperature ranging from 25 °C to 125 °C. The temperature sensor was tested in a homemade humidity-controlled chamber. More details regarding this chamber can be found in previous work [31].

2.4 Characterization techniques

The identification of the composite was achieved by the XRD diffraction instrument model (Malvern PANalytical Empyrean 3) fortified with CuKα radiation (45 kV, 40 mA, and λ = 0.15418 nm). The surface morphology examination and elemental analysis were verified by using field emission scanning electron microscope (FESEM), Quattro S, Thermo Scientific. The attached functional group was identified using an FTIR spectrometer (Vertex 70, Bruker) used within the 200–4000 cm−1 range. Thermal analyses were executed under air atmosphere using the Q600-SDT device. Broadband Dielectric
Spectroscopy (BDS) measurements were carried out in the frequency range from 0.1 Hz to 10 MHz using a Novocontrol high-resolution alpha dielectric analyzer. The sample was pressed into disk at kPascal and then sandwiched between gold-plated stainless-steel electrodes of 10 mm in diameter, in parallel plate capacitor configuration.

3 Results and discussion

3.1 X-ray diffraction assessment (XRD)

The apparent structure of the synthesized sample is inspected via the conventional X-ray diffractograms within the range of 5–70° (2° step). The XRD pattern of the rGO/SnO₂/Co₃O₄ nanocomposite is illustrated in Fig. 2. Verified affirmation of the coexistence of the initial constituents of the composite coincides with the acquired results. The XRD pattern exhibits characteristic peaks belonging to the rGO, Co₃O₄, and SnO₂. Ideally, the GO has a sharp and intense peak at around 11° corresponding to the (001) plane with a d-spacing of ~ 0.8 nm [32]; however, the reduction of the GO into rGO results in the disappearance of this sharp peak and the residence of a very tiny hump around ~ 24° and another negligible one around ~ 42° for the diffraction planes of (002) and (100) correspondingly [33].

The diffraction peaks at 2θ of 18.84°, 32.54°, 34.44°, ~ 45.05°, 59.42°, and 69.35° can be, respectively, indexed to (111), (220), (311), (400), (511), and (440) reflection planes of Co₃O₄. The XRD pattern of cubic Co₃O₄ is consistent with the ICSD card No. 01-074-2120. These results match the reported results for other research [34, 35]. The main diffraction peaks at
28.62°, 34.66°, 47.89°, and ~ 62.6° are attributed to (110), (101), (211), and (112) reflections of orthorhombic SnO₂. The diffraction peaks of SnO₂ are in agreement with the ICSD card No. 01-071-5327 [6]. Furthermore, the absence of the distinguishable rGO peaks in the composite might reveal the non-formation of face-to-face rGO stacking because of the presence of CO₃O₄ [33]. Other secondary peaks are mostly superimposed on the high-intensity peaks. No other diffraction peaks were noticed to be indexed which reflects the high purity of the structure. The characteristic particle size of the composite is grasped by applying the conventional Sherrer equation [36–38] relied on the average of the three most intense peaks

\[
D_{\text{crystallite size}} \text{ in nm} = \left( \frac{k \times (\lambda)}{\beta_D \times \cos \theta} \right)
\]  

(1)

The aforementioned parameters in the equation are denoted as the shape factor (k), the incident wavelength (λ) of the CuKα working source, the whole width at the mean height for the intensity of the peak (β), and the angle (θ) at which the diffraction takes place. The calculated average crystallite size by the Sherrer equation is ~ 18 nm.

Other parameters are estimated for the XRD as the dislocation density (δ), the microstrain (ε), and the crystallinity degree for the synthesized matrix (Xc).

The dislocation density is determined as the reciprocal of the power two of crystallite size like [39]

\[
\delta (\text{Dislocation density}) = \left\{ \frac{1}{D^2} \right\}
\]  

(2)

Generally, the broadening in the resultant peak (βw) is due to two sources, i.e., the occurring crystallite size broadening (βD), as well as the microstrain contribution (βε) [36, 40].

In general, \( \beta_w = [(\beta_D) + (\beta_\varepsilon)] \)

(3)

which might be represented as follows:

\[
(\beta_w) = \left[ \frac{k\lambda}{D \cos \theta} + 4\varepsilon \tan \theta \right]
\]  

(4)

And finally, after rearrangement, it is delivered as:

\[
\left\{ (\beta \cos \theta) = (4\varepsilon \sin \theta) + \left[ \frac{k\lambda}{D} \right] \right\}
\]  

(5)

A clear resemblance between the preceding acquired equation and the straight-line equation is affirmed, wherein the slope of the line is interpreted as the grasped microstrain (i.e., slope = ε), while the obvious intercept of the line with the vertical y-axis reveals the confirmation of the crystallite size. This relation between βCosθ and 4εSinθ is familiar as the Williamson-Hall relation [40].

in which, \(D = \frac{k\lambda}{\text{line intercept with y - axis}} \)

(6)

Moreover, the characteristic degree of crystallinity (Xc) for the executed composite is determined from the relation between the area under the crystalline

Fig. 2  a The resultant XRD diffractogram of the synthesized rGO/SnO₂/Co₃O₄, and b the Williamson-Hall plot for the composite with its linear fitting parameters
peaks ($X_{\text{crys}}$) and the area of all peaks ($X_{\text{All}}$)[41] feasibly calculated in the origin program.

$$X_c = \left\{ \frac{X_{\text{crys}}}{X_{\text{All}}} \times 100 \right\}$$ (7)

The scattered points of the relation between $\beta \cos \theta$ and $4 \epsilon \sin \theta$ represented in Fig. 2b are fitted to straight line, where the particle size was estimated and compared with those obtained from Scherrer equation. The acquainted values of the former XRD parameters are tabulated in Table 1.

### 3.2 Scanning electron microscope (SEM) analysis

The apparent morphology for the synthesized samples is displayed in Fig. 3. As elucidated from the figure, at the reduced magnification (~ 4 k-15 k, Fig. 3a, b), the structure inherently is characterized as dense and compact groups of the particles. Higher magnification of the samples (Fig. 3c–d) displays the resemblance between the synthesized structure particles and the star. The larger zoom on one of the star-like structure is signified at 80 k in Fig. 3e. The average length of this star structure (from edge to edge) is around 80–100 nm as displayed in Fig. 3e, as well as presented in the inset of Fig. 3f. The EDX for these samples (Fig. 4) reflects the existence of the starting materials with the appropriate weight percent within an acceptable ±10% error ratio. The previous remark highlights the successful incorporation of the Co$_3$O$_4$ onto the sample with the homogeneity between the sizes.

### 3.3 FTIR

The rGO/SnO$_2$/Co$_3$O$_4$ was recorded in the FTIR spectra at transmittance mode as shown in Fig. 5. The peaks observed at 4000 cm$^{-1}$ and 1439 cm$^{-1}$ correspond to the O–H stretching of –COOH in rGO and to the vibration of intercalated water, respectively. The characteristic peaks of oxygen moieties— are located at 3446 cm$^{-1}$, 3183 cm$^{-1}$, 2929 cm$^{-1}$, 2844 cm$^{-1}$, and 1439 cm$^{-1}$, respectively. Moreover, the new peaks of rGO/SnO$_2$/Co$_3$O$_4$ were interpreted by the deconvolution method as shown in Fig. 5. Five peaks appeared at 652 cm$^{-1}$, 740 cm$^{-1}$, 905 cm$^{-1}$, 1092 cm$^{-1}$, and 1290 cm$^{-1}$, which are attributed to the Sn–O stretching which may be due to the unique synthetic approach. The full peaks analysis is tabulated in Table 2.

### 3.4 Thermal analysis

Differential thermal analysis (DTA) and thermogravimetric analysis (TGA) have been investigated within a temperature range from room temperature (RT) up to 750 °C with a heating rate of 20 °C/min under air atmosphere. Through this study, the TGA is utilized to calculate the number of metal oxide nanoparticles loaded over rGO, besides to investigate the thermal degradation and stability of the prepared composite. The TGA thermogram of rGO/SnO$_2$/Co$_3$O$_4$ exhibited single weight loss starting at 420 °C attributed to the consumption of rGO. The amount of SnO$_2$ and Co$_3$O$_4$ was estimated to be 44 wt%. The microwave-assisted process of preparation affirms the entire reduction of GO into rGO in addition to the formation of SnO$_2$ nanoparticles. The overall reduction of GO to rGO is confirmed via the absence of weight loss in the functional groups area of the graph (i.e., ~ 200–300 °C) [42]. The differential thermal analysis of rGO/SnO$_2$/Co$_3$O$_4$ clarifies a single exothermic peak referred to the degradation of rGO. No other exothermic or endothermic peaks were detected due to the absence of any impurities (Fig. 6).

#### Table 1 The parameters extracted from the XRD plot for the rGO/SnO$_2$/Co$_3$O$_4$ composite

| $2\theta$ (°) | (hkl) | $\beta_D$ (°) | $D$ (Scherrer eq.) (nm) | $D$ av (Sh. Eq.) | $D$ (W–H plot) (nm) | $\delta$ (nm$^2$) | $X_{\text{crys}}$ | $X_{\text{All}}$ | $X_c$ (%) |
|--------------|-------|--------------|-------------------------|-----------------|---------------------|-----------------|----------------|----------------|--------|
| 18.63197 (111) | 0.38422 | 20.94460106 | 18.04 | 15 | 0.003 | 123.284 | 511.5625 | 24.10 |
| 22.898 (120) | 0.39136 | 20.70324051 | 32.58728 (400) | 0.51303 | 16.12671336 |
| 34.38547 (101) | 0.4999 | 16.6260215 | 48.13678 (211) | 0.45394 | 19.15968738 |

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3.5 Optical properties

The electronic band structure of the rGO/SnO$_2$/Co$_3$O$_4$ is depicted in Fig. 7. The UV–Vis absorbance as a function in the wavelength is illustrated in Fig. 7, while the insert represents the calculated bandgap using Tauc plot method.

\[ a h \nu = A (h \nu - E_g)^{1/2} \]  

(8)

where \( A \) is the energy independent constant, \( h \) is the photon energy, and \( a \) is the absorption coefficient. According to the absorbance spectra, the rGO/SnO$_2$/Co$_3$O$_4$ exhibits a steep absorption at about 210 nm. The optical bandgap was measured by tangent intersection at x axis and it was found to be 3.41 eV.

3.6 Electrical properties

Figure 8a shows the variation of the real part of complex conductivity (\( \sigma' \)) with frequency for the prepared sample. The ac conductivity obeys Jonscher’s power law, and it comprises of two regions. The first region is characterized by a plateau that shows independent behavior with frequency in most of the frequency range up to 1 MHz and the plateau value directly yields the dc conductivity.
This part is believed to originate from the motion of charge carriers. In the second region above 1 MHz, the conductivity starts to follow power law and depends on frequency [43, 44]. The dielectric loss ($\epsilon''$) representation reflects the conductivity contributions and different kinds of polarization (if present); however, sometimes for conductive and semiconductive samples, the conductivity contributions mask the presence of any other molecular dynamic. Figure 8b shows the...
variation of the imaginary part of permittivity ($\varepsilon''$) with frequency. The dielectric loss has no relaxation peaks, and it decreases with frequency. The fitting of the data shows a straight line with a slope of $-0.994$; this concludes that the only apparent dynamic is mainly due to dc conductance \cite{43, 44}. The electrical

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**Fig. 6** The acquired thermal analysis of the prepared rGO/ SnO$_2$/Co$_3$O$_4$

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**Fig. 7** The UV–Vis pattern of rGO/SnO$_2$/Co$_3$O$_4$, insight is the calculated bandgap energy
behavior of the sample is mainly due to the charge carrier’s transport which suggests the employment of the sample as a semiconductor offering the potential for using it as a sensor. The complex impedance was plotted vs frequency as shown in Fig. 9a. At lower frequencies, $Z'$ has higher values and characterized by frequency independent plateau reflecting frequency invariant electrical conductivity, while $Z''$ approaches to zero at lower indicating the absence of electrode polarization. At higher frequency, $Z'$ decreases sharply and it has dispersion region and $Z''$ has a peak centered at the dispersion region; the peak is associated with frequency relaxation process. The Nyquist plot between the real and imaginary part of impedance and the equivalent circuit fitting is shown in Fig. 9b. The observed semicircle in our sample is due to grain contribution and it shows a non-Debye type behavior.

3.7 Sensing application

The temperature sensor based on the rGO/SnO$_2$/Co$_3$O$_4$ star like structure was evaluated in the temperature range from 25 °C until 125 °C. The operating temperature range is limited as the main target of this sensor is directed toward ambient and near conditions. To evaluate the performance of the temperature sensor, the resistance variation was measured using a UNI-T digital multimeter. The sensor was allowed to stabilize for 5 min at the desired temperature to reach a stable measurement reading. The $I$–$V$ characteristic curve of the sensor is depicted in Fig. 10. The correlation between the applied voltage and current is linear confirming the Ohmic contact and the validation of operation.

The $I$–$V$ characteristic curve of the Co$_3$O$_4$/SnO$_2$/rGO temperature sensor was evaluated at different humidity levels (50% RH, 60% RH, 75% RH, and 80% RH) as demonstrated in Fig. 11. It was observed that the humidity has a very limited effect that can be...
neglected. For more investigation, the temperature sensor was evaluated from 25 °C up to 125 °C with a 25 °C increment (See Fig. 12).

The resistance variation as a function of temperature is presented in Fig. 12. The sensor exhibits a linear resistance variation as temperature increases. The absolute change in resistance is a key factor for assessing the performance of the humidity sensor. The absolute change in resistance per unit change in temperature is calculated to be 31.737 °C. The temperature coefficient of resistance (TCR) expressed by Eq. 9 is always utilized to evaluate the sensitivity of the sensor.

\[
TCR = \left( \frac{R - R_0}{R_0 \Delta T} \right)
\]

where \( R \), \( R_0 \), and \( \Delta T \) represent the resistance at the target temperature, the resistance at 25 °C, and the temperature difference, respectively. The temperature coefficient of resistance is estimated to be 0.006/°C. Since the prepared composite composed of different constituents, each of which contributes to the resistance variation under the influence of temperature. The resistance variation of the graphene under temperature effect is attributed to its intrinsic behavior. It is well known that the graphene can exhibit metallic and semiconducting behavior generally based on synthesizing method. The metallic properties often appear in physically produced graphene, while the semiconducting properties commonly occurred in chemically produced graphene. The utilized rGO through this study was synthesized using modified Hummer method and then reduced, thereby a remaining function group still exists, resulting in finite bandgap semiconductor [45].

The relative sensitivity is calculated using the following equation:

\[
Sr = \left( \frac{\Delta R}{R_0} \right) \times 100
\]

where \( \Delta R \) is the change in resistance, and \( R_0 \) is the resistance value at 25 °C.

A linear relation between the temperature variation -within a wide span of room temperature to around 130 °C- and the determined relative sensitivity is visualized in Fig. 13. Inherently, this linearity affirms the validity of the proposed sensor for the monitoring of temperature variation with an elevated accuracy. The obtained results were compared with the work of other researchers exploring the sensitivity of similar composites toward temperature. As indicated in
Fig. 11 The effect of relative humidity on the $I$–$V$ characteristic curve of rGO/SnO$_2$/Co$_3$O$_4$ star like structure.

Fig. 12 Resistance variation as a function of temperature.

| y = $a + b \times x$ | Resistance |
|----------------------|------------|
| Adj. R-Square        | 0.99347    |
| Intercept            | $5.65578 \pm 0.10882$ |
| Slope                | $-0.03241 \pm 0.0013$ |
Fig. 13 The relative sensitivity as a function of temperature

Table 3 The performance of the proposed sensor in comparison with other reported sensors in previous works

| Sensing material | Fabrication method | Measurement range; °C | Sensor sensitivity; %°C⁻¹ | Temperature coefficient of resistance (TCR); °C⁻¹ | References |
|------------------|--------------------|------------------------|---------------------------|-----------------------------------------------|------------|
| rGO/SnO₂/Co₃O₄ composite | Facile wet chemical precipitation method | 25–125 | 0.006 | This paper |
| rGO/LIG laser-reduced graphene oxide | Chemical preparation | 25–45 | 1.56 | [46] |
| | Sputtering followed by electrode patterning processing with ultraviolet (UV) laser | 30–100 | 0.37 | [4] |
| GNWs/PDMS film | polymer-assisted transfer method | 25–120 | 0.214 | [47] |
| rGO/ CNTs@PBT NW | Simple mechanical ultrasonication method | 25–45 | 0.737 | [48] |
| RGO-Ag nanocomposite | Dispersion method | 25–110 | 0.286 | [49] |
| rGO/ PET | Screen printing technology followed by air-spray coating | 30–100 | 0.6345 | [45] |
Table 3, the rGO/SnO$_2$/Co$_3$O$_4$ has a wide measuring temperature range compared to tabulated composites.

4 Conclusion

In this report, a ternary composite of rGO/SnO$_2$/Co$_3$O$_4$ is successfully prepared through a chemical method. The essential characterization devices to study the structure were introduced. The XRD and FTIR affirm the basic structure of the composite. The apparent morphology with the average size distribution of the structure is delivered by the SEM results which shows an average of 80–100 nm length components. The sensing application of temperature within 25–125 °C is demonstrated which shows a wide operating range and the temperature coefficient of 0.006/°C.

Author contributions

MM contributed to experimentation, writing the original manuscript, and reviewing and editing the final manuscript. MMM participated in material preparation, data collection and analysis, and optimum selection of material parameters, and experimentation. AGD contributed to experimentation and written the original manuscript. YE contributed to validation and visualization. AE contributed to conceptualization, investigation, experimentation, writing the original manuscript, review, and editing.

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Data availability

All data produced or investigated throughout this work are involved in this manuscript.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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