# Graphene Oxide/Polyaniline-Based Multi Nano Sensor for Simultaneous Detection of Carbon Dioxide, Methane, Ethanol and Ammonia Gases

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**ABSTRACT:** *In this study, a multi nano sensor was fabricated for the simultaneous detection of carbon dioxide, methane, ethanol and ammonia gases, and its electrochemical response to various concentrations of these gases was investigated. In order to fabricate this multi nano sensor, in the first phase, the Graphene-Oxide/Polyaniline (GO/PANI) nano-composite was synthesized. Chemical composition, morphology and the structure of the nano-composite was studied by Fourier Transform InfraRed (FT-IR) spectroscopy, Field Emission-Scanning Electron Microscopy (FE-SEM), High-resolution transmission electron microscopy (HR-TEM) and X-Ray Diffraction (XRD). The results indicate that the GO successfully synthesized and the polyaniline particles are well bonded on the surface of the GO sheets. In the second phase, the formed nano-composite was placed on silver coated electrodes and then, by placing the nanoparticles of aluminum oxide, zinc oxide, tin oxide and titanium oxide, the different parts of the multi-nano sensor were became more sensitive toward the four mentioned gases. The responsiveness and sensitivity of the multi-nano sensor to each of the gases were measured by amperometric experiments and the results showed that the sensitivity of multi-nano sensor fabricated to detection of the above gases is acceptable. The results of the electrochemical tests showed that the response of each multi-nano sensor component to a mixture of the above four gas is defined as a four unknown equation and with considering the responses of 4 multi-nano sensor components simultaneously to the 4-gas mixture, 4 × 4unknown equations are obtained, which by solving the equation one can be found the exact concentration of each of the 4 measured gases.*

**KEYWORDS** *Simultaneous detection; Nano-composite; Carbon-based nanomaterial; Multi-nano sensor.*

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## INTRODUCTION

Fabrication of gas sensors based on new nano-composites has attracted much attention in recent years. Among them, graphene-oxide based nano-composites have been widely used in electronic devices, medical equipment, etc., due to its excellent properties such as hydrophilic, thermal conductivity and electrical conductivity properties [1-6]. British chemist B.C. Brodie was the first researcher that discover properties of GO in 1855 and after that the research around that was growing [7]. Nowadays, the modified hummer method is the most common method for the synthesis of GO nanoparticles from graphite [8]. According to the required applications, GO sheets nanoparticles can be surface-modified in the form of nanocomposites and in combination with other materials and polymers. This carbon structure has been highly regarded today due to its high specific surface area and diversity of functional group. The composite derived from graphene-oxide and conductive polymers exhibits unique properties. Researchers have found that the electrical conductivity of the GO/PANI composite is considerably higher than each of GO and poly-aniline. They found that GO composite was used not only as a mold for the growth of polyaniline, but also it has been used as a dopant [9,10]. The purpose of this study is fabrication a multi-nano sensor that can simultaneously detect carbon dioxide, methane, ethanol and ammonia in an analyte sample. GO was synthesized to fabricate this multi-nano sensor, and then its surface was modified using polyaniline. Polyaniline is a heavy polymeric branch so that its successful applications in various industries have attracted much attention, and its monomer is inexpensive and available. Polyaniline has unique properties such as electrical conductivity, optics, and electro-activity properties. One of the flaw of poly-aniline is its poor mechanical properties. One of the attractive applications of polyaniline is a barrier property of GO sheets. Because of the conductivity of GO and PANI and its strengthening in the nanocomposites composed of these two materials, there are many electrical applications for it. Due to the multilayer and porous structure of polyaniline particles formed on flatten and uniform surface of GO, it is possible to use this exceptional composition as a surface absorber of gases for the production of a gas multi-nano sensor [11]. In this study, at first, the PANI was synthesized and then the GO and GO/PANI nanocomposites were synthesis and their morphological and chemical properties were compared [12]. Then, the formed nano-composite was placed on silver coated electrodes and then, by adding the nanoparticles of aluminum oxide [13], zinc oxide [14], tin oxide [15-17] and titanium oxide [18], to the different parts of the multi-nano sensor, a multi-nano sensor sensitive to carbon dioxide, methane, ethanol and ammonia were produced. The responsiveness and sensitivity of the multi-nano sensor to each of the gases were measured by performing electro-analytical tests.

## EXPERIMENTAL SECTION

### *Materials*

An expandable graphite powder with an average particle size of 300 micrometer was purchased from the Kropfmuehl graphite, Germany. Nano powder of gamma aluminum oxide with a particle size of 20 nm and 99% purity, anatase titanium oxide nano powder with a particle size of 10 to 25 nm and 99% purity, zinc oxide nano powder with a particle size of 10 to 30 nm and 99% purity, tin oxide nano powder with a particle size of 35 to 55 nm and 99.7% purity, sulfuric acid ($H_2SO_4$) 98%, hydrochloric acid (HCL) 37%, single layer aniline monomer, Sodium nitrate ($NaNO_3$) and potassium permanganate ($KMNO_4$) and hydrogen peroxide were purchased from MERCK, Germany. Ammonium persulfate $(NH_4)_2S_2O_8$ was obtained from Sigma-Aldrich, Germany.

### *Synthesis of Polyaniline*

For the synthesis of polyaniline, 6.4 mmol of aniline was added to 20 mL of hydrochloric acid 1 M and stirred by the agitator, then 1.6 mmol of ammonium persulfate solution was dissolved in the solution and the reaction was carried out at room temperature while the solution was stirring for 24 hours, the resulting solution was collected and centrifuged and then washed with deionized water to reach the pH=6. The final product, which became dark green, is poly aniline [19]. The polymer formation mechanism can be seen in S1 (Supplementary information).

### *Synthesis of Graphene Oxide*

In a typical procedure, Graphene Oxide (GO) was produced using modified hummers method from pure graphite powder [20,21]. In this method, 1 g of graphite powder with 120mL of sulfuric acid ($H_2SO_4$) and 1 g

sodium nitrate were mixed and stirred for 30 minutes. Then 6 g of potassium permanganate ($KMnO_4$) was added into mixing solution under mild stirring condition. This mixture was stirred for 24 hours at ambient temperature. Then the solution was diluted with deionized water and oxidation reaction was completed by $H_2O_2$and observed the color of solution turns from dark green to yellow brick which indicates that the oxidation reaction is carried out. The residuals were then washed with HCl and deionized water for 4 times and centrifuged at 3500rpm for 10 minutes. The washed GO solution was dried to produce the powder of GO[20,21].

***Synthesis of graphene-oxide/polyaniline (GO-PANI)***

The prepared graphene oxide by a modified Hummer method was superficial modification using a poly-aniline (PANI). To do this, 3.2 mmol of aniline and 0.8 mmol of ammonium persulfate were dissolved in 15 mL of 1 molar hydrochloric acid solutions and stirred by the agitator for 30 minutes on the ice bath. Then, 10 mL of the solution containing 0.25 g per liter of graphene oxide was added to solution and the reaction was carried out at room temperature for 24 hours and stirring. At the end, the precipitate was collected by centrifuging and it was washed with deionized water to reach the pH=6. The final product of graphene oxide-poly aniline is dark green. The GO/PANI formation mechanism can be seen in S2 (Supplementary information) [22,23]. In order to prepare nano composites of graphene oxide/poly aniline, it was dried using oven at 45°C for 24 hours.

***Design and preparation of electrodes***

The electrode designed for this study has special locations for placement of GO-PANI nano-composites along with various metal oxide nanoparticles. This electrode allows that several different nano sensor being operated simultaneously and very close to each other in one package through simultaneous placement of a different metal oxide nano powders in each portions and the different portions of multi-nano sensor have reaction to sample of gas under tested and simultaneously displays different reactions and the signals are measured without interference (S1.A, Supplementary information). The design was fabricated as a silver coated printed circuit board (in corporation with Alpha Circuit Co.). In this electrode, the thickness of the metal layer is 35 micron and the bottom of the metal fiber layer is made from fiberglass. To prepare the electrode, 2 mg of synthesized powder of GO-PANI nano-composite was added to 500µL of distilled water and placed in an ultrasonic bath for half an hour. At each of the locations indicated on the electrodes, 10 µL of the dispersant produced by the sampler was shown and the electrodes were placed in an oven for 2 hours at 45 °C. In this way, 6 electrodes were prepared (S1.B, Supplementary information).

***Fabrication of multi nano sensors***

In this study, with the addition of various amounts of different metal oxide nanoparticles to the prepared electrodes, 6 multi nano sensors were made that are similar in appearance, but differ in the amount of added metal nanoparticles. The mechanism for detecting these gases, we generally call them Human Exhalation gases (HEGs), is as follow in each component of this multi nano sensor of graphene- oxide [24,25].

$$O_2(g)+ne^- \Leftrightarrow Oxn^-(ad)+holen^+ \quad (1)$$

$$HEG(g)+Oxn^-(ad) \Leftrightarrow HEG^-O+ne^- \quad (2)$$

$$HEG(g)+Oxn^-(ad) \Leftrightarrow HEGn^-(ad)+O_2(ad) \text{ and/or additive} \quad (3)$$

$$HEG(g)+Oxn^-(ad)+holen^+ \Leftrightarrow HEG(ad)+O_2(g) \quad (4)$$

Equation (1) is the oxygen absorption equation for metal oxides, and equations 2 to 4 are equations that can occur in the intersection of the molecule HEG and metal oxide. Equation (2) is the general reaction of oxidation of HEG, which is reaction at the grain surface with oxygen ions. Equation (3) shows the competitive absorption between HEG and $O_2$, and equation (4) shows the substitution of oxygen absorbed by the HEG molecule. The type of reaction that occurs between the surface of metal oxide and HEG can be affected by many factors, such as surface chemical components, surface morphology and microstructures of sensitive surface layers, as well as temperature and humidity [26].

To fabrication of these 6 multi nano sensors, 24 small containers were selected and 2 mL of distilled water was added in each of them. Then, in the first six containers, 1, 2, 4, 8, 16, and 32 mg of aluminum oxide nanoparticles were added, respectively. The same amounts of zinc oxide nanoparticles were added to second six containers (7-12),

respectively. The same amounts of tin oxide nanoparticles were added to third containers (13-18), respectively. And finally the same amount of titanium oxide nanoparticles were added to fourth containers (19-24), respectively and each 24 containers were placed in an ultrasonic bath for half an hour.

Then, on the place marked with the letter A of the first electrode (S4, Supplementary information), 10 µL of 0.5mg/mL nanoparticles of aluminum oxide dispersant, was placed by the sampler, and then on the place marked with the letter B of this electrode, 10 µL of 0.5mg/mL nanoparticles of zinc oxide dispersant, was placed and similarly, on the places marked with letters C and D, nanoparticles of tin oxide and titanium oxide nanoparticles with similar concentrations and similar values were placed by sampler. Thus, the multi nano sensor (No. 1) was fabricated. For other 5 electrodes, in the same way, the dispersants of 1, 2, 4, 8 and 16 mg/mL were prepared and multinano sensors 2 to 6 were fabricated respectively. Then multi nano sensors were placed in an oven to drying and fixation for 2 hours at 45℃ temperature and finally 6 nano sensors was fabricated, therefore, each one sensitive to carbon dioxide (place A), methane (place B), ethanol (place C) and ammonia (place D). But due to the difference in the amount of metal nanoparticles on the electrodes, their sensitivity is different, which has been measured and reported in electro-analytical studies.

## RESULTS AND DISCUSSION

### *Characterization*

Field emission scanning electron microscopy (FE-SEM), X-Ray Diffraction (XRD), and Fourier Transform InfraRed (FT-IR) spectroscopy were applied to characterize the graphene-Oxide/polyanilinenano-composite. In addition, synthesis of graphene-oxide/polyaniline andgraphene oxide were investigated separately and simultaneously for better results. The FT-IR PERKIN ELMER device (USA) was used to perform the test. XRD analysis was used to determine the fuzzy composition and to determine the distance between the graphene oxide atoms layers and also the graphene nanoparticles sheets, which was modified with polyaniline using by PHILIPS X-RAY SPECTROMETER PW 1800 TYPE (Netherlands) which has a Cu-Ka strings and 1.5406-angstrom. The FE-SEM analysis with MIRA TESCAN and HR-TEM analysis using TECNAI G2 F20S-TWIN-200 KV device were used to identify PANI bonds on the GO surface in term of chemical and physical properties and structure and morphology of the GO and GO-PANI.

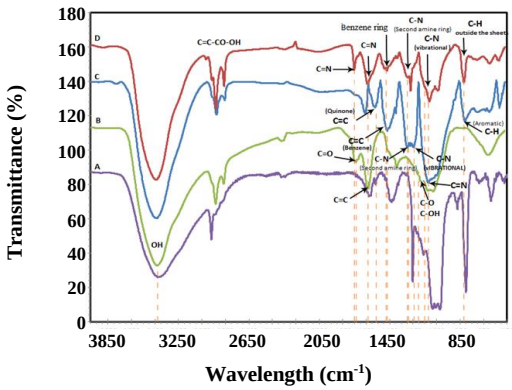


***Fig. 1: FT-IR Chemical Analysis of Graphite (A), Graphene Oxide (B), Polyaniline (C), and Graphene oxide/Polyaniline (D) samples.***

*FT-IR analysis*

FT-IR analysis is used to study the surface chemistry of PANI, GO and GO-PANI which shown in Fig. 1.

As shown in Fig. 1, for pure polyaniline (PANI), carbon-carbon double bonds in quinone and benzene rings showed peaks at 1568cm$^{-1}$ and 1484cm$^{-1}$ region. The observed peak in the 1298cm$^{-1}$ region is corresponded to the C-N in second amine ring and the peak observed in the 1241cm$^{-1}$ region is corresponded to vibrational C-N in the protonic acid formed in the polyaniline and the peak observed in the 1123 cm$^{-1}$ region is corresponded to the vibrational C=N and in the 819cm$^{-1}$is corresponded to the C-H in the aromatic rings [22]. On the other hand, for graphene oxide, as it is seen, O-H (hydroxyl group) bonds in the 3437cm$^{-1}$ region, the C=O bond is corresponded to carbonyl or carboxyl groups in the 1734cm$^{-1}$ region and C=C bond in the phenolic ring in the 1630cm$^{-1}$ region and the vibrational bonds of C-O and C-OH are observable in the 1218cm$^{-1}$ region [27-29], which shows the successful synthesis of the GO. On the other hand, for the GO-PANI nanocomposites, as seen in the Fig. 3, in the 1745cm$^{-1}$ and 1630cm$^{-1}$ region, the C = N bond and the 1487cm$^{-1}$ region are correspond to the structure of the benzene ring in the polyaniline [30]. On the other hand, 1302cm$^{-1}$ region is corresponded to C-N bonds in the second amine ring and 1152cm$^{-1}$ region is corresponded to the vibrational C-N. The 801cm$^{-1}$ region is due to C-H bonds outside the sheets [23]. These amine groups and the PANI benzene ring

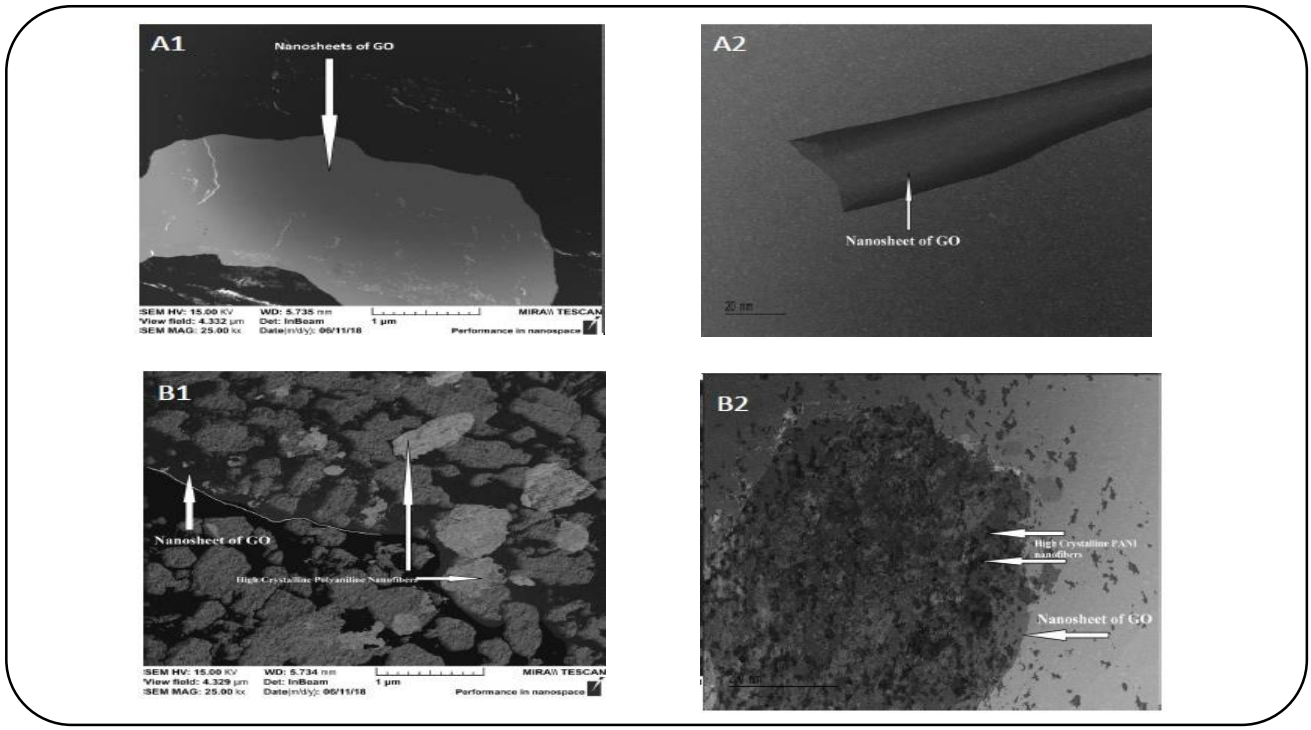


***Fig. 2: FE-SEM and HR-TEM analysis of Graphene Oxide (A1, A2) and Graphene oxide/Polyaniline (B1, B2) samples***

on the graphene oxide (GO) sheets show that polyaniline nano fibers are well covered the GO surface and the GO-PANI nanocomposites are properly synthesized.

*FE-SEM and HR-TEM characterizations*

The morphology of GO and GO-PANI was studied through FE-SEM and HR-TEM characterizations. As shown in Fig. 2.A1, graphene oxide has uniform and neat sheets. On the other hand, the graphene oxide/polyaniline nano-composites, as seen in Fig. 2.B1, is observable as non-uniform sheets in which polyaniline is positioned between the sheets, which indicates the formation of polyaniline particles on flat and uniform graphene oxide sheets. In HR-TEM images (Fig. 2.A2, 2.B2), it is also observed that graphene oxide is formed by a flat sheets and graphene oxide/polyaniline has fine polyaniline particles among the graphene oxide sheets [23,22].

*XRD results*

The fuzzy combination of GO and GO-PANI was examined through the XRD test. As shown in Fig. 3, the pattern of graphene oxide diffraction is a sharp peak at 2θ =10.25° (001 plane), which representing a crystal structure for GO that interlayer spacing is 8.72 angstroms and it is verifying successful synthesis of graphene-oxide and the reflection peak(100) at 2θ = 42.07° suggests that GO exhibits turbostratic disorder [28,27]. The XRD pattern for GO-PANI shows that, in addition to the GO's peak, which shows itself at 9.951° (003plane), the own peaks of polyaniline are also occurs in diffraction pattern of 2θ =21.41° (011 plane), 19.951° (100plane), and 25.151° (110plane)[28], and representing the structure of the PANI polymer chain, and shows itself as a broad peak for GO-PANI, which is seen at 002 plane, indicating that the PANI nano-fibers with the GO surface is entered to the bond and they have been well covered with graphene oxide. The amount of interlayer spacing for GO-PANI is 12.57 angstroms [28,31,32].

***Multi nano sensors performance evaluation***

For performing the electro analytical experiments, the four-channel amperometric analysis for each of the four sections (A, B, C and D) from each of the multi-nano sensors were performed and the graph obtained from each experiment consists of four diagrams (related to the four sections of each multi-nano sensor) for comparison and analysis of the performance of multi-nano sensor was recorded. To performing of the Electroanalytical

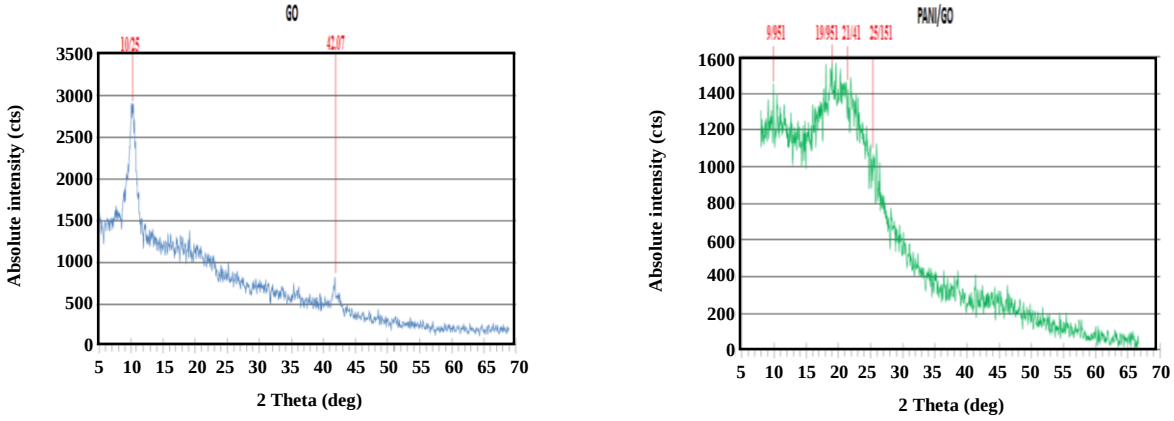


***Fig. 3: X-ray diffraction pattern of GO (A) and GO-PANI (B).***

analyzes of methane, ethanol, ammonia and carbon dioxide concentration gas the DIM200 gas diluter from the AMA Instruments GmbH, a German-made device was prepared.

*Amperometric analysis*

To perform the amperometric test on four sections (A, B, C, and D) of the multi-nano sensor No. 1 were connected to the four channels of the analyzer. Then, while the amperometric results of all four channels were stored in four graphs simultaneously in a graph, the multi-nano sensor was exposed to methane gas at a concentration of 0.1 ppm by a gas diluent for 20 seconds. Then, the concentration of gas was increased at 20 seconds intervals to concentrations of 1, 10, 50, and 100 ppm, respectively, and all the results were stored as a graph containing 4 graphs for the multi-nano sensor No. 1 (Sensor1Metan). In the next step, ethanol gas replaced with the methane gas. Experiments with ethanol gas at concentrations of 0.1, 1, 10, 50, and 100 ppm were performed on this multi-nano sensor and the results were stored for multi-nano sensor No. 1 (Sensor1Etanol), and then followed by ammonia gas and carbon dioxide gas was replaced and the experiments were repeated on this multi-nano sensor and the Sensor1Ammoniac and Sensor1CarbonDioxide graphs were obtained. Then these experiments were carried out for sensors number 2 to 6, and were named and stored in the same way as the graphs. Finally, for each multi nano sensor, four graphs and a total of 24 graphs were obtained. All experiments were carried out at 25℃. The nano sensor No. 5 graphs are shown in Fig. 4.

*Analysis of the results of amperometric experiments*

To analyze the results of the experiments, the final responses and the steady state of each of the four components of each nano sensor were considered for each gas with a specific concentration and were plotted as a graph for each multi nano sensor (Fig. 5). These graphs, which have 4 sections related to 4 gases, have 4 diagrams related to 4 parts of the multi-nano sensor analyzer. In these diagrams, it is clear that each of the four multi-nano sensor component has different responses to each of the four gases, with the intensity of each response is different, so that in an unknown gas sample, which is a mixture of all four gases with different concentrations, to accurately determine the concentration of each of the gases it is necessary to process of the responses of each of the four components of the multi-nano sensor simultaneously and to use mathematical relations in this regard. By observing and examining the results, it is evident that the multi-nano sensor No. 5, which has been used80µg of metal oxide in its fabrication in each component, has a linear and optimal behavior over the whole range of measurements. Therefore, this multi-nano sensor was selected for mathematical examination.

*Mathematical Examination of Multi-Nano sensor No. 5*

Since all parts of the multi-nano sensor No. 5 have linear performance in their entire range of measurements, it can be found the exact concentration of each gas through assumption that the unknown gas is a mixture of four carbon dioxide gases, methane, ethanol and ammonia gas and other inert gases by using mathematical relations. Certainly, these relationships are as long as correct that the concentration of any of the gases does not pass through

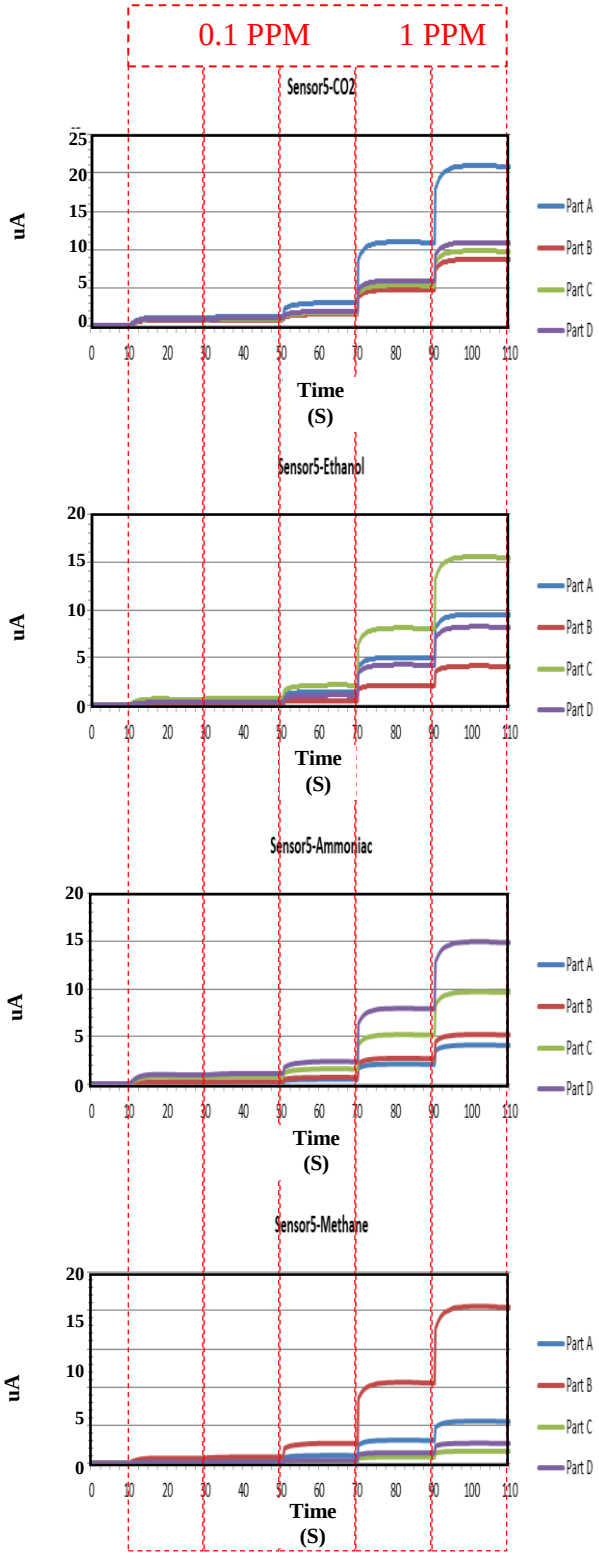


***Fig. 4: Graphs obtained from electroanalytical experiments on multi-nano sensor No. 5***

the measuring range, and none of the sensor components are entered to the saturated and non-linear range. Therefore, the response of 4 multi-nano sensor components to a mixture of the four gases forms four unknown equations (4 × 4) so that as long as the above assumptions are met, the exact concentration of each of the four gases can be calculated by solving it. To determine the coefficients of 4 × 4 unknown equation, the response of each sensor section from four sections (A, B, C and D) to each of the gases with specific concentration was considered in the experiments and then the equation (5) was formulated which expresses the mathematical relation between the response of each component of the sensor and the concentration of the unknown gases. In this equation X is the concentration of carbon dioxide gas, Y concentration of methane, Z concentration of ethanol gas and T concentration of ammonia gas in the unknown gas mixture. The values of RA and RB and RC and RD are the response of A, B, C and D of the multi-nano sensor to the unknown gas mixture, respectively, which is obtained in each measurement of the multi nano sensor No. 5, and by solving equation 5 for this multi nano sensor, the exact concentration of each gas in the mixture of 4 gases and other inert gases (air) is determined.

$$\begin{cases} 0.2X + 0.1Y + 0.09Z + 0.04T + 2.6 = RA \\ 0.08X + 0.4Y + 0.04Z + 0.05T + 2.19 = RB \\ 0.09X + 0.03Y + 0.15Z + 0.09T + 2.2 = RC \\ 0.1X + 0.05Y + 0.08Z + 0.14T + 2.33 = RD \end{cases} \quad (5)$$

*Evaluation of the ultimate performance of multi nano sensor No. 5*

To determine the accuracy of multi-nano sensor No. 5 and the ability to determine the concentration of mixed gases by this method, the multi-nano sensor was placed in a container containing 25 ppm carbon dioxide gas, 10ppm methane, 20ppm ethanol gas and 5ppm ammonia gas for 20 seconds. The response of each of the four nano sensor components was simultaneously measured and stored (Fig. 6). With respect to the measured responses of Eq. (5), we obtain the Eq. (6).

$$\begin{cases} 0.2X + 0.1Y + 0.09Z + 0.04T + 2.6 = 10.5 \\ 0.08X + 0.4Y + 0.04Z + 0.05T + 2.19 = 9.2 \\ 0.09X + 0.03Y + 0.15Z + 0.09T + 2.2 = 8.1 \\ 0.1X + 0.05Y + 0.08Z + 0.14T + 2.33 = 7.6 \end{cases} \quad (6)$$

By solving this equation, the concentration measured for carbon dioxide gas was 24.779 ppm, methane gas was

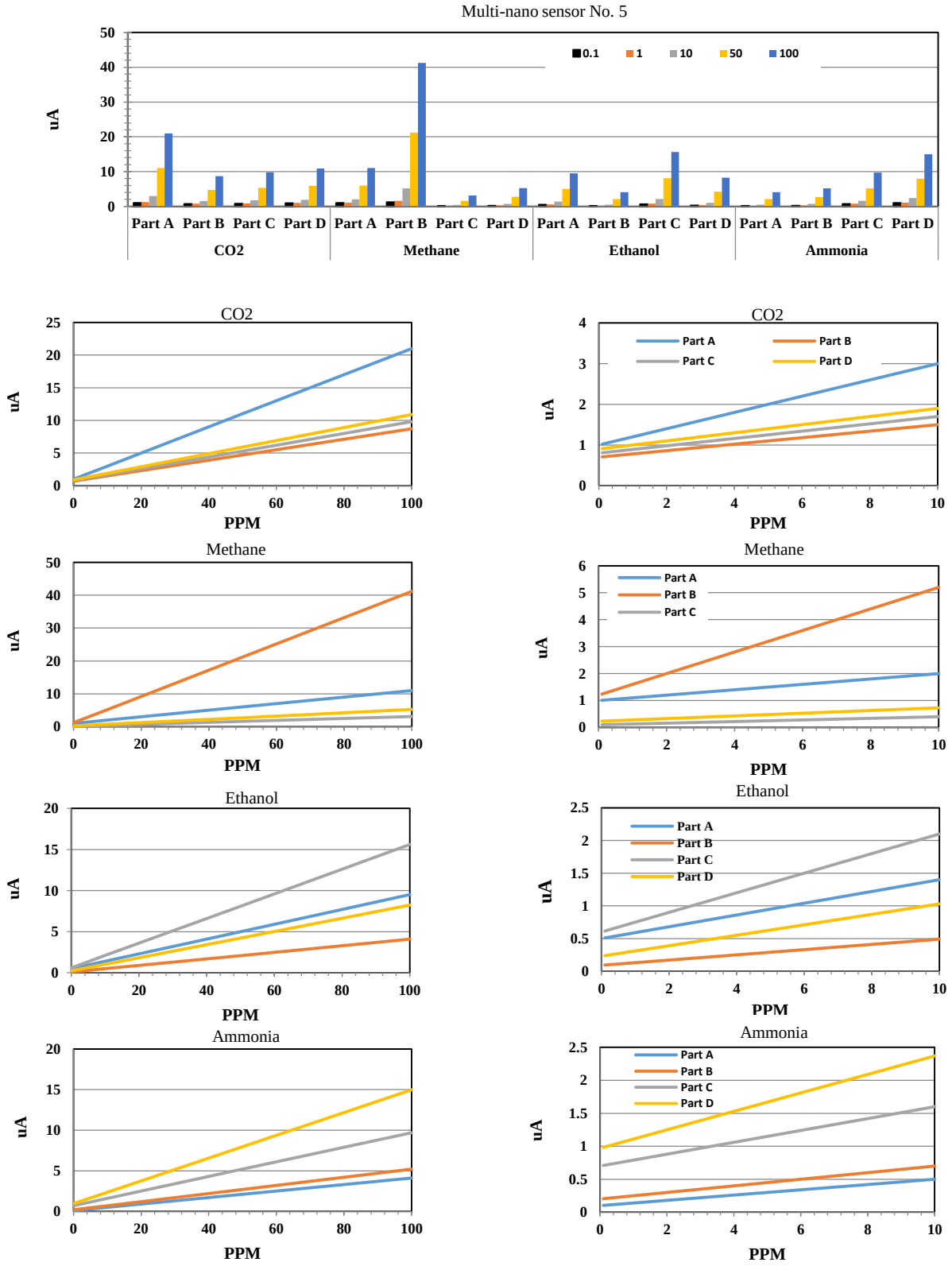


*Fig. 5: The final responses and the steady state graphs of each of the four components of nano-biosensor No. 5 to each gas with a specific concentration.*

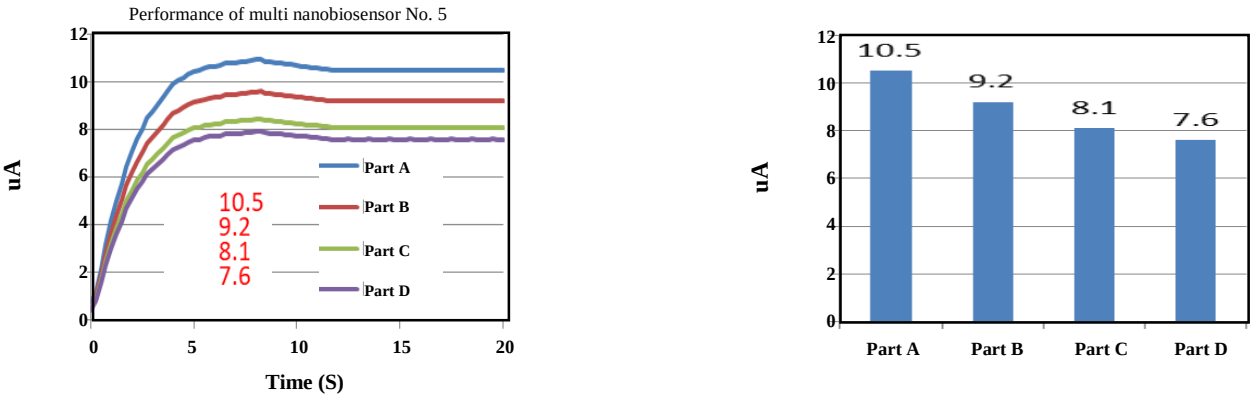


***Fig. 6: The response graph of each of the 4 multi-nano biosensor components to a mixture of 25ppm carbon dioxide gas, 10ppm methane gas, 20ppm ethanol gas and 5ppm ammonia gas.***

9.972 ppm, ethanol gas 19.238 ppm, and ammonia gas was 5.389 ppm. For another study the multi-nano sensor was placed in a container containing 10 ppm methane, 20 ppm ethanol gas, 5 ppm ammonia gas and no carbon dioxide gas for 20 seconds. The response of each of the four nano sensor components was simultaneously measured and stored (Fig. 7). With respect to the measured responses of equation 5, we obtain the equation 7.

biosensor components to a mixture of 10ppm methane gas, 20ppm ethanol gas, 5ppm ammonia gas and no carbon dioxide gas

$$\begin{cases} 0.2X + 0.1Y + 0.09Z + 0.04T + 2.6 = 5.6 \\ 0.08X + 0.4Y + 0.04Z + 0.05T + 2.19 = 7.2 \\ 0.09X + 0.03Y + 0.15Z + 0.09T + 2.2 = 5.9 \\ 0.1X + 0.05Y + 0.08Z + 0.14T + 2.33 = 5.1 \end{cases} \quad (7)$$

By solving this equation, the concentration measured for carbon dioxide gas was 0.245 ppm, methane gas was 9.906 ppm, ethanol gas 19.623 ppm, and ammonia gas was 4.860 ppm. These experiments was carried out several times with different concentrations of gases and by comparing the measured results and the known concentrations; the measurement error of the sensor was obtained for measurement for each gas in average 0.2ppm and maximum 0.7ppm.

## CONCLUSIONS

As seen from results, in this study, a multi-nano sensor was fabricated for the simultaneous detection of carbon dioxide, methane, ethanol and ammonia gases, and its electrochemical response to various concentrations of these gases was investigated. For fabrication of this multi-nano sensor, the graphene- oxide/polyaniline nano-composite was synthesis using a chemical synthesis for 24 hours directly from graphene oxide and polyaniline monomer. In this method, ammonium peroxide sulfate was used, which is a very good oxidizing agent for the chemical oxidation of aniline and its conversion into polymer chains of polyaniline on the surface of graphene oxide and the formation of a graphene-oxide/polyaniline nano-composite conductor. By inserting the graphene-oxide/polyanilinenano-composite on the silver electrode and adding various amounts of metal oxide, 6 nano sensors were fabricated; it was determined by electrochemical studies that multi nano-biosensor No. 5 containing 80 µg of metal oxide in each component has anoptimal and linear performance in the range of measurements. Finally, it was revealed that one can be measured the exact concentration of each of the gases in the unknown sample using the simultaneous response of all components of the multi-nano sensor and the use of mathematical relations (4 × 4 unknown equations). Since each multi-nano sensorcomponent acts as an independent equation, it is possible to increase the number of equations and unknowns by adding more sensing components to multi-nano sensorthat are more sensitive to other gases, and in fact, to measuring *n* different gases one can be used a multi-nano sensor with *n* sensitivity sensors to various gases and the formation of *n* × *n*unknown equations. It should be noted that all components must have a linear function in the range of measurements, but it does not necessarily require that each component is only sensitive to a gas and it is sufficient that its response to different gases being varies. This multi-nano sensor can be used

to fabrication of devices for detecting living and dead bodies who containment under the collapse of buildings.

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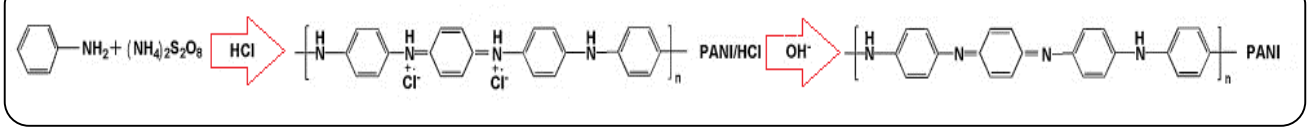
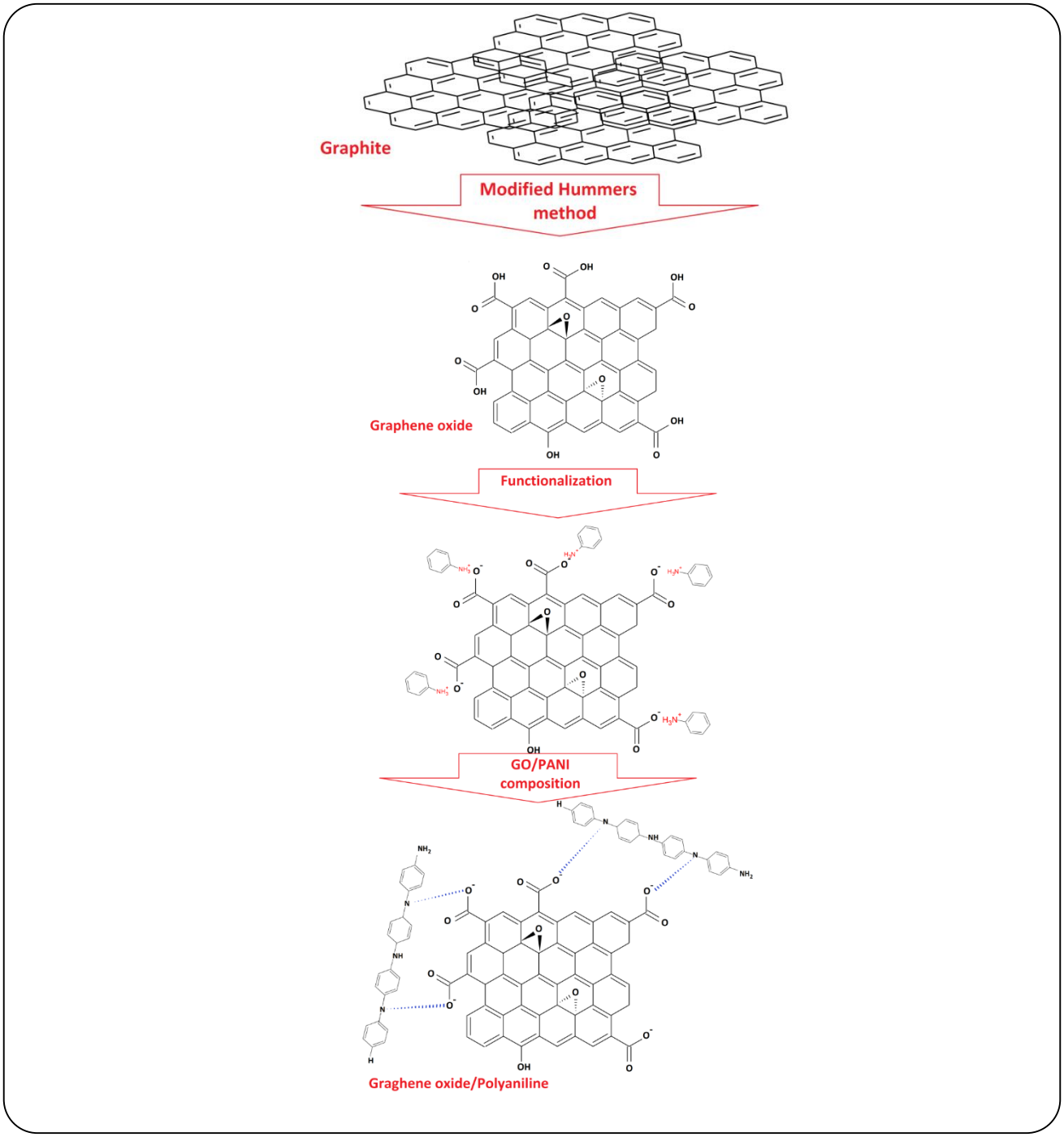
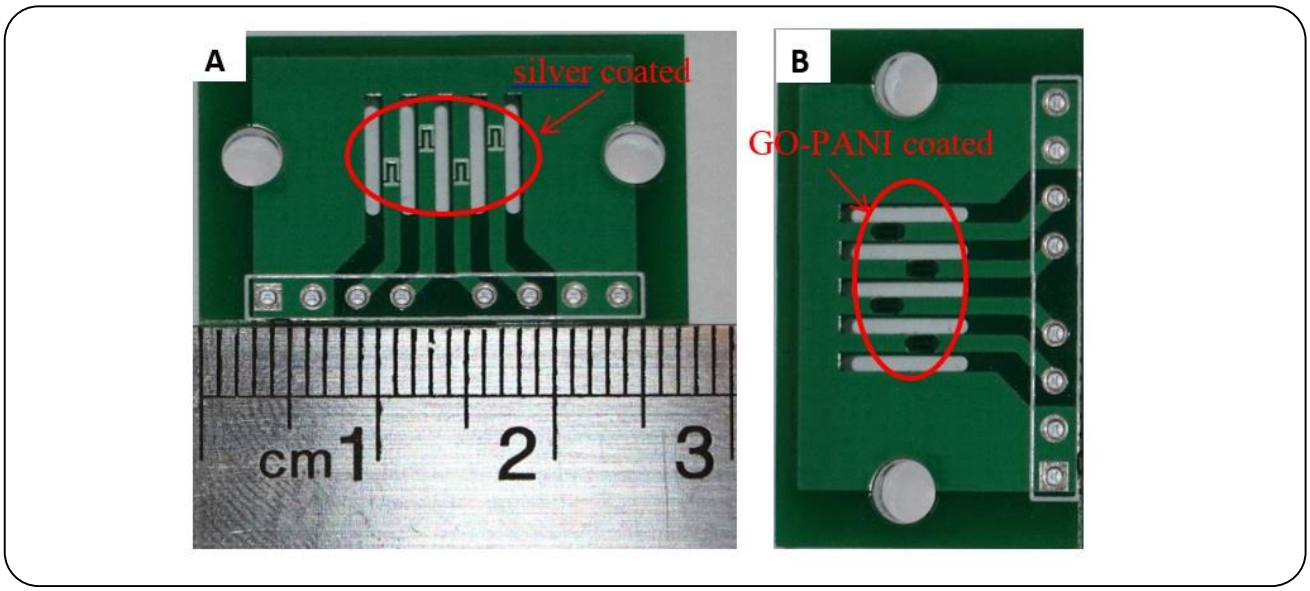
**Supplementary Information**



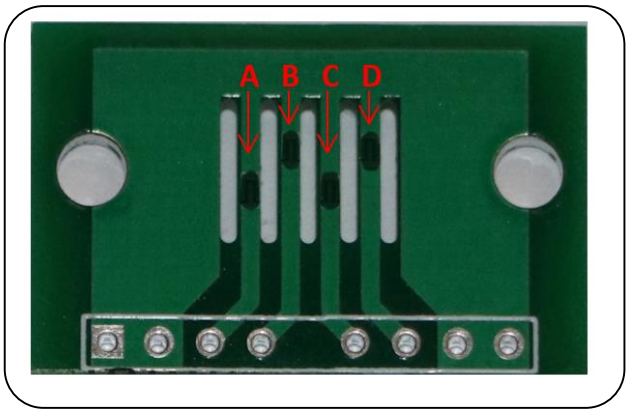

***S1: Polyaniline formation mechanism.***




***S2: Schematic representation of GO/PANI formation.***




***S3: Silver coated electrode (A) and prepared electrode (B)***




***S4: Each prepared electrode have 4 places marked with letters A, B, C and D.***