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# Tuning of Gate Electrostatics to Amplify Mercury Sensing Performance of Functionalized **Field Effect Transistor**

Nimisha<sup>®</sup>, Avik Sett<sup>®</sup>, Virendra Kumar Tewari, and Tarun Kanti Bhattacharyya<sup>®</sup>

Abstract-According to the World Health Organization (WHO), mercury is one of the top ten toxic groups of substances that can pose the greatest threat to human life. Very minor contamination with mercury can adversely impact the nervous, digestive, and immune systems of the lungs, kidneys, skin, and eyes, resulting in severe health problems, including death. Conventional detection techniques are incredibly complex, costly, and lack portability. This article describes a highly sensitive, selective, and stable field effect transistor (FET)-based sensor for efficiently detecting mercury ions in water. Glutathione-reduced graphene oxide (glu-rGO) is chosen as the sensing material. The operating gate voltage of the device is optimized to -4.98 V to achieve maximum response. At a gate voltage of -4.98 V, the device's sensitivity is evaluated as 1.04  $\mu$ A/ppb for 1.2 ppb mercury compared to 0.51  $\mu$ A/ppb at zero gate voltage. The device is tested against six common heavy metal ions and is found to be highly selective toward mercury. Therefore, the glu-rGO-



based FET device is promising for future portable, economical, and user-friendly mercury ion detector systems.

Index Terms—Mercury sensor, parts per billion (ppb) level detection, reduced graphene oxide-field effect transistor (RGO-FET), selective, sensitive.

#### I. INTRODUCTION

UE to the accelerated growth of the semiconductor indus-U try and electronic devices, toxic metallic pollutants such as As, Pb, Cd, and Hg have become a global concern because of their detrimental environmental and biological effects [1]. These heavy metals are nonbiodegradable and can readily attach to the environment's food chain, posing significant threats to human and animal health. Due to the fatal effects of these pollutants on public health and the environment,

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numerous organizations have established the utmost allowable concentration of the ions in food, drinking water, blood, etc. Environmental Protection Agency (EPA) has set potable water safety limits for mercury, lead, cadmium, and arsenic to be 2, 15, 5, and 10 parts per billion (ppb), respectively. The accumulation of  $Hg^{2+}$  in the human body can result in dysfunction of vital organs, dysfunction of nucleic acids, immune system defects, and even mortality. Detection of Hg<sup>2+</sup> ions in water without interference from other ions has, therefore, become the greatest challenge. The conventional measuring procedures that include atomic absorption/emission spectroscopy (AAS), inductively coupled plasma mass spectrometry (ICP-MS), chromatographic separation, and anodic stripping voltammetry (ASV) are expensive, time-consuming, and involve complicated measuring procedures [2], [3]. Alternately, numerous sensors have been developed for the detection of  $Hg^{2+}$  ions [4], [5], including colorimetric, [6], [7], [8] fluorescent [9], [10] electrochemical [11], [12], and surface-enhanced Raman scattering with metal nanoparticles or carbon nanotubes (CNTs). These metal particles and CNTs serve as the signal transducer and enhancement factor. These devices exhibit large surface area and superior structural, electronic, and optical properties which elevates the response speed and sensitivity. Despite

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these benefits, a portable, highly selective, and sensitive sensor with uncomplicated operating procedures bearing low manufacturing cost is the need of the hour [13], [14], [15]. There are only a few reports on functionalized reduced graphene oxide field effect transistor (FET)-based sensors [5], where all the reports are based on resistive two-terminal devices. These sensors exhibit good response; however, their selectivity and sensitivity need to be improved significantly. Therefore, there is a considerable need to develop a low-cost, portable analytical platform with a stable, selective, and sensitive sensing layer for user-friendly mercury ion concentration analysis.

Graphene is one of the carbon allotropes that integrates exceptional electrical, optical, and mechanical properties. Graphene is the thinnest material (0.34 nm) with an enormous surface area. Through the reduction of graphene oxide (oxygenated graphene sheets covered with epoxy, hydroxyl, and carboxyl groups), enormous quantities of graphene can be produced, making functionalized graphene-based materials more accessible. Due to its sensitivity to electrical perturbations from the surrounding environment, graphene has been incorporated into novel sensors for detecting heavy metal ions, toxic gases, and biomolecules [16], [17]. Its advantages include small device size, high sensitivity, high selectivity, low energy consumption, fast response, and a user-friendly analytical platform.

In this work, we developed an FET-based Hg<sup>2+</sup> sensor that enhances the selectivity of the device in the presence of other interfering ions, as the ionization potential (voltage required to remove the outermost electron) is different for all heavy metal ions present in the water. Its sensitivity is enhanced by administrating a gate voltage of -4.98 V. To impart selectivity of the sensing layer toward mercury, the graphene oxide sheets were reduced using L-glutathione [18], [19]. Glutathione is a common substance made up of amino acids and contains thiol functional groups. Previous reports on the functionalization of graphene surfaces have relied on complex molecules or costlier synthesis of nanoparticles, which also have a tendency to agglomerate and degrade stability [20]. Other reports based on the functionalization of metal nanoparticles incur complex synthesis procedures and high costs for the precursor materials [21], [22], [23]. Hence, there is a pressing need to develop highly efficient sensing probes attached to active sensing surfaces that can be synthesized easily and economically. Functionalization with glutathione is an economical and highly efficient alternative to functionalizing the graphene surface with thiol probes. Graphene introduces a higher surface area and L-glutathione introduces thiol groups into the active channel region of the sensor, which contributes to the elevated selectivity toward mercury ions [24]. Previous work on mercury sensors from our group incurs the drawback of using expensive gold precursors and toxic acids [20]. Moreover, an increase in sensitivity was also the vision of this work. Hence, glutathione functionalization along with the FET-based platform can easily eliminate the previous drawbacks and enhance the performance of rGO-based sensors.

The graphene oxide sheets reduced by L-glutathione exhibit n-type behavior at zero gate voltage and demonstrate p-type



Fig. 1. Schematic of the sensing device with set up (fabricated device inset).

behavior when a negative gate voltage is applied. At a gate voltage of -4.98 V, the sensing layer responds most effectively toward the Hg<sup>2+</sup> ion. Several characterizations like field emission scanning electron microscopy (FESEM), Raman Spectroscopy, and Fourier transform infrared spectroscopy (FTIR) were performed to substantiate the morphology and composition of the sensing material. The sensing layer, glu-rGO, confers a high degree of mercury ion selectivity compared to other interfering ions. The transfer characteristics of the FET device imply that its sensitivity is at its highest when the gate voltage ( $V_{gs}$ ) is -4.98 V. Just before saturation, the output characteristics of the device reveal exceedingly high sensitivity to Hg<sup>2+</sup> ions (140  $\mu$ A/ppm at 5 ppm) at  $V_{ds}$  1.5 mV. The primary benefit of this sensor is its ease of fabrication and operation along with tremendous selectivity.

### II. SENSOR FABRICATION AND CHARACTERIZATION A. Device Fabrication and Experimental Setup

For device fabrication, a  $p^+(100)$  type, boron-doped (resistivity 0.001–0.005  $\Omega$ -cm) silicon wafer was used as a substrate. A 100 nm SiO<sub>2</sub> layer was achieved by thermally oxidizing the wafer. About 30 nm of titanium interlayer was deposited to enhance the adhesion of gold to SiO<sub>2</sub>. About 200 nm of gold was deposited by dc sputtering over the titanium layer. The gold and titanium layers were lithographically patterned to create source and drain electrodes with a width of 240  $\mu$ m and a channel gap of 30  $\mu$ m. As the wafer is heavily doped, a shadow mask was used to create the back gate. The schematic of the sensor and fabricated device is depicted in Fig. 1. The sensing setup comprises a PLV 50 probe station which consists of three probes used to apply voltages to the source, drain, and gate of the transistor. The signals are applied and sensed through a B1500 semiconductor parameter analyzer. The target solutions are drop cast over the sensing channel and allowed to get adsorbed for 15 min. The change in drain current is noted and later analyzed for selectivity, sensitivity, and response of the sensor.

The ion solutions  $Hg^{2+}$ ,  $Cd^{2+}$ , and  $Pb^{2+}$  were prepared by adding chloride compounds to DI water. In order to produce an  $As^{5+}$  ion solution, sodium arsenate heptahydrate salt was dissolved in DI water.  $Cu^{2+}$  and  $Fe^{2+}$  ions were produced by adding their respective oxides to DI water. For each metal ion, solutions were diluted subsequently to attain ppb level concentration. The measured pH of the solutions was 6. With the help of a micropipette, 2  $\mu$ L of metal ion solutions were drop-cast over the sensing layer of the device.

#### B. Synthesis of the Glu-rGO Sheet

The synthesis of graphene oxide (GO) was carried out through exfoliation of the graphite layers chemically. The most common chemical process followed is the modified Hummers method, as discussed in the article [24]. About 1.6 g of graphite powder was allowed to mix with 0.8 g of sodium nitrate and then stirred continuously for 32 h. The stirring was carried out in 35 mL of concentrated sulfuric acid (98%). Once the stirring process was completed, the mixture was placed in an ice bath maintaining a temperature of 0 °C. This temperature was maintained for 20 min. After this process, potassium permanganate (5 g) was added very slowly to the solution, such that the temperature of the mixture does not exceed 10 °C. Following this, the solution was brought to room temperature, by placing the container on a hot plate and maintaining its temperature at 40 °C. An exothermic reaction was initiated by the addition of 75 mL DI water onto the mixture. Here, the temperature of the mixture reaches 98 °C. The reaction is allowed to occur for 15 min after which it was forcefully stopped by placing the container in a water bath. During this process, the color of the solution turns brown to black. The solution was kept stirring, and after 45 min, 250 mL DI water and 6 mL hydrogen peroxide (30%) were added to the brown residue. The solution turns bright yellow which indicates the formation of high-quality GO. The residue was washed with 37% hydrochloric acid. The solution was centrifuged several times to attain a pH of 7. Further ultrasonication was done on the GO solution to separate the stacked sheets and exfoliate them efficiently.

L-glutathione reduced (Lgr) was added to the GO solution for simultaneous reduction and functionalization. The solution was stirred followed by ultrasonication at 50 °C for 2 h. Further, the solution was heated to 60 °C for 4 h. The solution was cooled to room temperature. Finally, another ultrasonication step is carried out for one hour at room temperature, and glutathione-functionalized reduced graphene oxide (glu-rGO) sheets are obtained. A concentration of 2 mg/mL glutathione was used for simultaneous reduction and functionalization of the graphene surface. The reduction was attempted with five such concentrations. Below 2 mg/mL, the functionalization was not enough to impart a higher response. However, above 2 mg/mL, the graphene oxide reduced to a greater extent, which lowered its resistance drastically. This caused detection challenges as the current level was high enough to detect the variations in current leading to reduced sensitivities. The response optimization with a concentration of glutathione is represented in Fig. S1 (Supporting Information). The optimization is carried out in the presence of 160 and 320 ppb of  $Hg^{2+}$  concentration.

#### C. Characterization of Glu-rGO Sheets

The structural, morphological, optical, and electrical properties of glu-rGO sheets were investigated to predict their sensing properties. FESEM was used to analyze the morphology of the prepared glu-rGO sheets. Reduced graphene



Fig. 2. (a)–(c) FESEM of glu-rGO sheets and (d)–(f) HRTEM images of glu-rGO sheets.



Fig. 3. (a) FTIR analysis of glu-rGO and (b) Raman spectra of glu-rGO.

oxide (rGO) is a form of graphene oxide that has been thermally or chemically reduced to eliminate oxygen functional groups and restore graphene's  $sp^2$  carbon matrix.

Fig. 2(a) and (b) represent the formation of sheet-like glurGO along with wrinkles and pleats, which serve as several active defect sites. These defects enhance the adsorption capability of  $Hg^{2+}$  ions. Fig. 2(c) depicts the wrinkles formed over the glu-rGO sheets. Fig. 2(d)–(f) shows the HRTEM image of the glu-rGO sheets, which depicts the presence of very few layers in the sensing material, along with wrinkles. A smaller number of layers leads to higher sensitivity due to a higher surface-to-volume ratio and a higher percentage of atoms participating in the sensing process.

Fig. 3(a) depicts the FTIR analysis of glu-rGO, which consists of a broad OH vibration peak from 3200 to 3800 cm<sup>-1</sup>, an S-H stretching peak at 2600 cm<sup>-1</sup>, and a C=C stretching peak at 1636 cm<sup>-1</sup>. These peaks correspond to hydroxyl, thiol, and aromatic rings. Mercury exhibits a strong attraction for sulfur because of its ability to form bonds with the soft Lewis bases. The interaction between mercury and sulfur is commonly marked by creating a complex in which the mercury atom is coordinated with the sulfur atom of the thiol group. Fig. 3(b) depicts the Raman spectra of glu-rGO. It has a *D* band located at 1352 cm<sup>-1</sup>, which is a dispersive band that originates from non-sp<sup>2</sup> sites, including sp<sup>3</sup> sites of graphene, as depicted in Fig. 3(b). The *G* band at 1594 cm<sup>-1</sup> results from sp<sup>2</sup> sites in the material [25]. The *D/G* band intensity is approximately 0.84, indicating a material with high edge



Fig. 4. (a) XPS survey scan for all elements in glu-rGO, (b) high-resolution scan for carbon, (c) high-resolution scan for nitrogen, (d) high-resolution scan for oxygen, and (e) high-resolution scan for sulfur.



Fig. 5. (a) Transfer characteristics at  $V_{ds}$  1.5 mV with and without Hg<sup>2+</sup> (enlarged view of the plot inset for positive  $V_{gs} \triangleleft$  and (b) sensor response as a function of gate voltage.

defects. These defects play a very crucial role in the adsorption of mercury ions.

Fig. 4 depicts the XPS study of the prepared glu-rGO. It is observed to consist of carbon and oxygen elements contributed from rGO sheets. Nitrogen and sulfur elements are contributed from thiol and amine groups of the glutathione functionalized molecules. Fig. 4(a) depicts the wide energy survey scan to identify all elements present on the surface of the glu-rGO. The presence of C, O, N, and S corresponds to the glu-rGO sensing layer. Fig. 4(b)–(e) shows the high-resolution scan for carbon, nitrogen, oxygen, and sulfur present in the glu-rGO sensing layer. In Fig. 4(b), the peak at 284.8 eV corresponds to C–C, while 287.69 eV corresponds to the C=O bond. The spectra also exhibit satellite peaks at 280.06, 282.04, and 291.80 eV due to  $\pi - \pi^*$  satellite group, respectively.



Fig. 6. (a) Output characteristics of the FET device at  $V_{gs} = 0$  V for Hg<sup>2+</sup> varying from ppb to ppm level and (b) output characteristics of the FET device at  $V_{gs} = -4.98$  V for Hg<sup>2+</sup> varying from ppb to ppm level.

Fig. 4(c) represents the high-resolution scan of N 1s, and it consists of the deconvoluted peak at 399.4 eV due to the presence of amine group in the glutathione molecule. Fig. 4(d) represents the O 1s spectra with a peak at 531.4 eV corresponding to the presence of hydroxyl group. Fig. 4(e) represents the high-resolution scan for S 2p. It consists of peaks at 163, 164.1, 168.2, and 161.9 eV for S  $2p_{3/2}$ , S  $2p_{1/2}$ , S<sub>2</sub>O<sub>3</sub> (thiosulfate), and  $-SO_3$ -C respectively. It also consists of a satellite peak at 169.9 eV. Hence, through XPS analysis, the functionalization of reduced graphene oxide by glutathione is clearly evident.

#### III. RESULTS AND DISCUSSION

### A. Electrical Characterization of the FET Device

Electrical characterization of the FET device is done with the help of PLV-50 and B1500A semiconductor parameter



Fig. 7. (a) Sensitivity of the glu-rGO-based device toward heavy metal ions, (b) selectivity of the glu-rGO-based device toward heavy metal ions at both gate voltages ( $V_{gs} = 0$  and -4.98 V), (c) selectivity of the glu-rGO-based device at  $V_{gs} = 0$  V, and (d) transient response of the sensor when exposed to different concentrations of Hg<sup>2+</sup> ions.

analyzer. The detailed schematic is discussed in Fig. 1. The transfer characteristics of the FET sensor were determined by sweeping the gate voltage ( $V_{gs}$ ) from -15 to +15 V with the drain-to-source voltage ( $V_{ds}$ ) biased at 1.5 mV. Transfer characteristics were obtained after adding 4 ppm Hg<sup>2+</sup> ions (2  $\mu$ L solution applied by micropipette) to the FET device's channel region. Fig. 5(a) shows that the drain current increases as the gate voltage decreases. The transfer curve illustrates the development of a p-channel FET device of accumulation type. The transfer curve reveals a negative threshold voltage ( $V_{th}$ ) of -5 V for the FET sensor, consistent with a p-channel enhancement mode device.

The threshold voltage is observed to be shifted to the positive side when Hg<sup>2+</sup> ions are introduced in the channel. In the presence of the mercury ions, the sensing layer (glu-rGO) binds Hg<sup>2+</sup> ions. This increases the concentration of holes at the surface, leading to the current increase above the baseline. The device's calculated transconductance (g<sub>m</sub>) at  $V_{gs} = -4.98$  V is 1.81  $\mu$ A/V. After adding Hg<sup>2+</sup>, the g<sub>m</sub> of the device increased to 3.294  $\mu$ A/V due to an increase in the number of carriers in the channel. At higher gate voltages, there is a reduction in the sensitivity of the Hg<sup>2+</sup> ions, as depicted in Fig. 5(b).

Fig. 6(a) and (b) demonstrate the output characteristics  $(I_{ds}-V_{ds})$  for the FET sensor at  $V_{gs} = 0$  and -4.98 V, respectively. The sensing layer is sensitive to Hg<sup>2+</sup> ions due to the presence of the thiol groups at the sensor surface. At  $V_{gs} = 4.98$  V, the Hg<sup>2+</sup> sensing capabilities of the glu-rGO FET

sensor are amplified compared to zero gate bias. As glu-rGO exhibits n-type characteristics below -5 V, the electron recombines with the positively charged ion. The n-type behavior of the sensing layer at zero gate bias is illustrated with Hall measurement data in Table S1 (Supporting Information).

When the Hg<sup>2+</sup> ion comes into contact with the sensing layer, recombination leads to a decrease in current. However, at the gate voltage of -4.98 V, the material behaves as p-type, resulting in fewer electrons and a larger number of holes. When the device is exposed to additional Hg<sup>2+</sup> ions, accumulation of positive charge occurs over the sensor surface, leading to an increase in drain current.

The device sensitivity is calculated for 1.2, 2.4, 3.6, 6, 7.2, 8.4, and 10 ppb  $Hg^{2+}$  concentrations. However, it is found that sensitivity is a function of concentration. The sensitivity of the device is higher at lower concentrations due to the presence of surplus active adsorption sites in the channel, and it is equal to the 717.9  $\mu$ A/ppb at zero gate voltage. At  $V_{gs} = -4.98$  V, the sensitivity is found to be 1.64 times (1183.3  $\mu$ A/ppb) the sensitivity at zero gate voltage, as shown in Fig. 7(a). At higher concentrations, the sensitivity reduces due to the occupation of active adsorption sites. The selectivity of the device is tested among six heavy metal ions in water. Fig. 7(b) elucidates very high selectivity toward mercury ions compared to the other competing heavy metal ions. The selectivity of the sensors are tested at both gate voltages ( $V_{\rm gs}=0$  and -4.98 V). It is observed that the sensitivity of the device becomes extremely high at the tuned gate voltage, which in turn boosts the selectivity of the sensor to a great extent. The selectivity of the device at  $V_{gs} = 0$  V is shown separately in



Fig. 8. (a) Sensing mechanism of glu-rGO and its affinity toward mercury, (b) behavior of the sensor at different humidity levels, and (c) stability of the device for 60 days.

Fig. 7(c), as the higher response at  $V_{gs} = -4.9$  V overshadows the sensor's response at zero gate voltage. The response of the sensor toward a particular heavy metal ion is given as

Response (%) = 
$$100 * (I_{\text{base}} - I_{\text{ion}})/I_{\text{base}}$$
 (1)

where  $I_{\text{base}}$  is the baseline current of the sensor and  $I_{\text{ion}}$  is the current after ion adsorption.

Real-time monitoring of the sensor was performed through the addition of different concentrations of mercury ions after regular time intervals. When the sensor was exposed to mercury solution, a spike was observed every time. This was due to the additional resistance of DI water. As the ions get adsorbed and the channel gets dry, the current settles down to a new baseline. The change in current depicts the response percentage. Fig. 7(d) shows the behavior of the sensor when exposed to mercury solution continually, after regular intervals.

This transient response demonstrates the commercialization capability of the sensor for real-time monitoring.

#### B. Sensing Mechanism

Graphene is a unique layer of hexagonally arranged carbon atoms. The chemical counterpart of graphene (reduced

graphene oxide) possesses multiple functional groups, including epoxy, hydroxyl, carboxylic, and carbonyl, which can adsorb heavy metal ions such as Hg<sup>2+</sup>, As<sup>3+</sup>, Pb<sup>2+</sup>, Cd<sup>2+</sup>, etc. [26]. However, previous reports indicate that the thiol functional groups of graphene are primarily responsible for Hg<sup>2+</sup> adsorption [20]. These functional groups contain a lone pair of electrons capable of initiating chemical interactions with  $Hg^{2+}$  ions [27]. Furthermore, the dimensions of the ion, its electrical charge, the pH level of the solution, and the presence of other ions in the solution all impact the ability of Hg<sup>2+</sup> to be adsorbed onto graphene. The sensing layer glu-rGO comprises both the amine and thiol groups, where the amine groups attach to the hydroxyl groups of the graphene sheet and the thiol groups are responsible for the detection of  $Hg^{2+}$  ions. After the reduction of graphene oxide, several oxygenated groups disappear through a chemical reaction with reducing agents. However, a large number of hydroxyl groups are found to be present in the sensing layer, as confirmed by the FTIR spectra in Fig. 3(a). These hydroxyl groups have higher adsorption energy toward nitrogen-containing groups [25]. The amine end gets attached to the graphene sheet, and the thiol group remains exposed for the purpose of metal ion detection. When mercury ions impinge on the sensor surface, the ions get

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TABLE I COMPARISON BETWEEN DIFFERENT MERCURY SENSORS

Sensing	Sensitivity	LOD	Selectivity	Reference
Material			Coefficient	
RGO-GNP-TGA	300nA/ppb	1ppb	2.02	[20]
BSA Conjugated	6nA/ppb	0.36ppb	1.34	[28]
ZnO sphere				
DNA	10nA/ppb	5ppb	1.98	[29]
functionalized				
CNT				
Metallothionine	200nA/ppb	1ppb	1.85	[30]
functionalized				
RGO				
DNA/MoS <sub>2</sub> /Au	50 nA/ppb	9.9 ppb	4.2	[31]
FET				
DNA-rGO FET	500 nA/ppb	1 ppb	3.12	[32]
glu-rGO -FET	1µA/ppb	1ppb	3.33	This Work

attached to the thiol counterpart of the functionalized graphene sheets shown in Fig. 8(a).

#### C. Device Humidity and Stability Test

Most commercial sensors exhibit baseline drift and degradation in the presence of humidity. Hence, it is essential to analyze the sensor's performance at various RH levels. Fig. 8(b) shows the sensor's performance at RH levels of 50%–95%. It is observed that the sensor shows a highly stable behavior till RH 80%. However, at around 90% RH, the sensor shows a minimal drift. This proves the humidity-resistive nature of the sensor device and its potential to be used in various environments. The stability of the sensor device was tested for about two months. The sensors were tested against 1.2, 160, 320, and 700 ppb, respectively. The sensor exhibited a very stable response over the duration of two months. This clearly demonstrates the high chemical stability of the functionalized sensing layer. Appropriate functionalization and selective removal of unwanted functional groups lead to enhanced stability, as depicted in Fig. 8(c). The reproducibility of the sensor was tested: 1) with the same sensor (four times) and 2) between four devices, at 160 and 320 ppb of  $Hg^{2+}$ , respectively. The reproducibility results are depicted in Fig. S2 (Supporting Information).

Table I compares the existing mercury sensors with glurGO-based mercury sensors. The selectivity coefficient is described as the ratio of the response to the target analyte to the response of the most cross-sensitive analyte. The comparison shows that our sensor is better than the previously fabricated sensor regarding selectivity and sensitivity toward mercury ions.

#### **IV. CONCLUSION**

In conclusion, this work investigates the effect of gate electrostatics in functionalized reduced graphene oxide FETs. An alternative method for increasing the device sensitivity to Hg<sup>+2</sup> ions by a factor of two compared to the resistive sensors was framed. Characterization of the sensing (channel) material reveals that rGO has been appropriately functionalized. The drain-to-source bias is optimized at 1.5 mV to obtain the most significant conductivity change when Hg<sup>+2</sup> ions are present. The transfer characteristics demonstrate the variation in mercury response with gate voltage. At a gate voltage of -4.98 V, the device is exceedingly sensitive to mercury due to optimal carrier concentration in the channel. The mercury sensitivity of the device is determined to be 1.04  $\mu$ A/ppb. It is found that the device is highly selective toward mercury compared to five other interfering ions. Utilizing functionalized reduced graphene oxide reduces the sensor's fabrication cost. Comparing glu-rGO FET with conventional techniques and other reported sensing materials, it can be concluded that glu-rGO can be used as a low-cost, room-temperature, lowpowered, and portable mercury sensor.

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