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研究課題名（和文）Functionalized-graphene sensor on the hydrophobic surface for the selective detection of ppb-level volatile organic compounds (VOCs)

研究課題名（英文）Functionalized-graphene sensor on the hydrophobic surface for the selective detection of ppb-level volatile organic compounds (VOCs)

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研究成果の概要（和文）：我々は、200 x 200 nmのサイズのグラフェンナノリボンFETの表面に金属ナノ粒子と活性炭分子篩を修飾することに成功した。活性炭 分子篩によって機能化されたグラフェンFET を使用して、150 °C以下のセンサ温度で 50 ppb 濃度のエタノールガス分子検出を実現した。アルミニウムナノ粒子で機能化されたグラフェンは、リアルタイム大気中でアンモニアガス分子に対して優れた感度と選択性を示した。また、表面弾性波技術を用いることでさらに低濃度のアセトンガス分子を検出した。 グラフェンを用いた表面弾性波ガスセンサは、実際の大気下でアセトンガス分子 (800 ppt) に対するガス応答の向上を示した。

研究成果の学術的意義や社会的意義
Scientific and social significance of your research achievements
We have achieved the detection of acetone molecules at parts per trillion at room temperature. Our device can be utilized to detect disease at an early stage in human beings and provide a healthy life to everyone.

研究成果の概要（英文）：We have successfully functionalized metal nanoparticles and activated carbon molecular sieve on the surface of graphene nanoribbon FET with a size of 200 x 200 nm. 50 ppb concentration of Ethanol gas molecules was detected under 150°C using activated carbon molecular sieve functionalized graphene FET. In addition, Aluminum nanoparticles functionalized graphene showed exceptional sensitivity and selectivity towards ammonia gas molecules at real-time atmosphere. Furthermore, We have performed surface acoustic wave technique to detect even lower concentrations of acetone gas molecules. Graphene based surface acoustic wave gas sensor exhibited an enhanced gas response towards acetone gas molecules (800 ppt) under a real atmosphere.

研究分野：Electronic nose, Gas sensing, 2D materials FET

キーワード：Graphene　Health care　Acetone　Ethanol

１．研究開始当初の背景

Single Molecule detection of volatile organic gas molecules from the human breath and Skin. In particular, ethanol, acetone and ammonia which particular belong to the biomarkers. To improve the lifespan and health conditions of human beings, an advanced device that can monitor their health conditions regularly in a real-time environment is required.

２．研究の目的

In the first part of this research, we systematically studied the effect of graphene FET towards different organic volatile gas molecules at different temperatures. In the second part research, we have functionalized the graphene with different nanoparticles, zeolite and activated carbon. Finally, we have performed surface acoustic wave graphene gas sensor for high sensitivity towards acetone gas molecules.

３．研究の方法

Functionalization of graphene FET will be fabricated and its gas sensing response will be evaluated. By introducing Acetone, NH3, and Ethanol gas molecules.

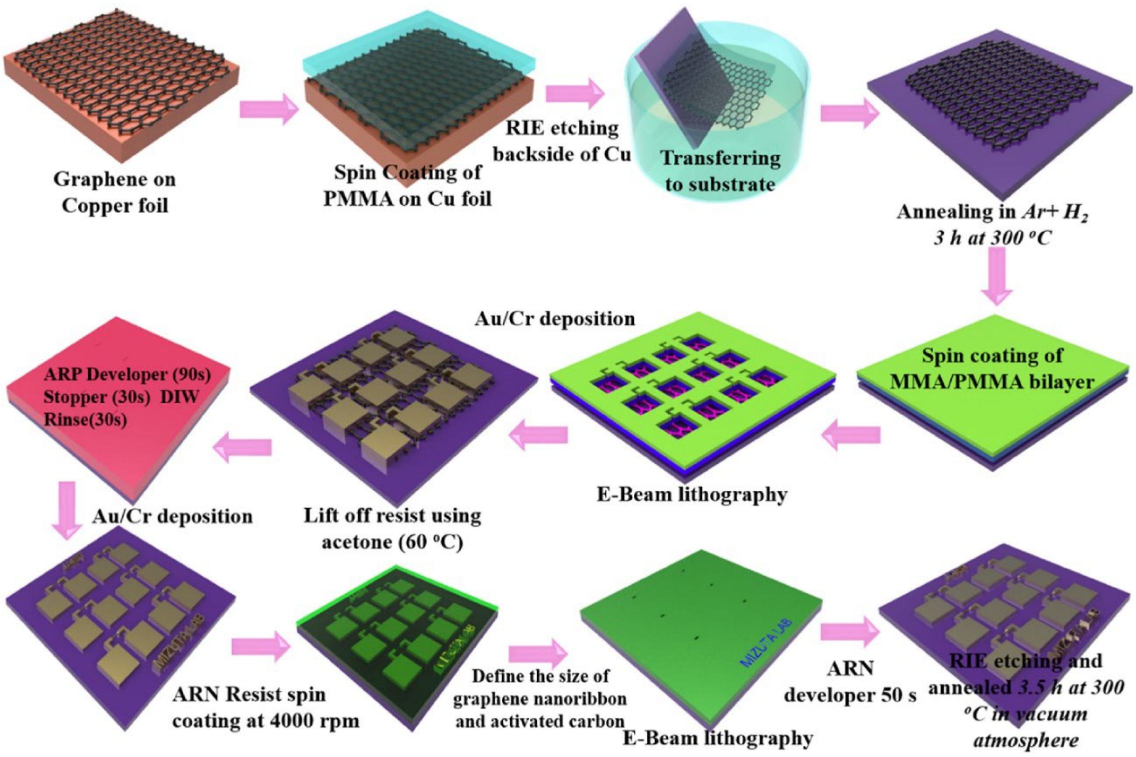

Figure. 1. Schematic of the fabricated CMSF-GFET gas sensor device.

Device Fabrication: Monolayer CVD graphene purchased from a graphene platform was utilised for fabricating the device. The copper substrate was etched using oxygen plasma etching and a 0.1 M ammonium persulphate solution. Before transferring the graphene to the substrate, the Si/SiO_2 substrate was cleaned with acetone and isopropanol. The transferred graphene was annealed in an Ar/H_2 (9/1) environment for 3 h at 300 °C. An 80 nm thick (Cr/Au) electrode was deposited using the electron beam lithographic (EBL) technique, followed by lift-off. Subsequently, a 40 nm (Cr/Au) contact electrode was deposited using the EBL technique. The GNR and CMS layers were defined by electron beam lithography using a negative Novolac resin-based (ARN 7520.07) resist, followed by resist development and oxygen plasma etching. The negative resist on the surface of the GNRs was converted into CMSs by annealing the fabricated device at 300 °C for 3.5 h in a vacuum atmosphere (Figure. 1).

1. Activated carbon molecular sieve functionalized graphene FET gas sensor

Initially, we fabricated a CVD graphene nanoribbon field effect transistor (GNR FET) to detect the gas molecules at room temperature. The results indicated that the CVD graphene shows a very low response towards acetone and ethanol gas molecules due to higher p-doping. To overcome this issues, we have fabricated activated carbon functionalized graphene to detect volatile gas molecules. The Activated carbon molecular sieves functionalized graphene FET (CMSC GNR FET) showed ultra-high sensitivity towards ethanol gas molecules at 150 °C compared to CVD graphene as shown in Figure 2a. In addition, different concentrations of gas molecules are introduced towards activated carbon molecular sieves and CVD graphene. The results indicated that activated carbon functionalized graphene showed an extremely enhanced response even at 50 ppb concentration compared to CVD graphene as depicted in figure 2b. The CMSF-GFET gas sensor showed higher selectivity toward ethanol gas molecules than acetone, formaldehyde, hydrogen, and benzene, as shown in Fig. 2c

2. Al metal functionalized Graphene FET

Sensitivity and selectivity in real real-time atmosphere are highly desired for healthcare applications. An Aluminum nanoparticle with a 5 nm was functionalized on the surface graphene field effect transistor (Al-GFET) gas sensor fabricated and the gas sensing response was studied at room temperature. The Al-GFET showed ultra-high sensitivity towards 250 ppb at ammonia gas molecules at room temperature as shown in figure 3. In addition, we have analyzed the device at different atmospheres like nitrogen, oxygen and air atmosphere. Furthermore, charge neutrality point disparity (CNPD), based on the charge neutrality point difference between the tuning voltage (+ 40 and - 40 V) induced graphene-gas molecules van der Waals (vdW) is demonstrated.

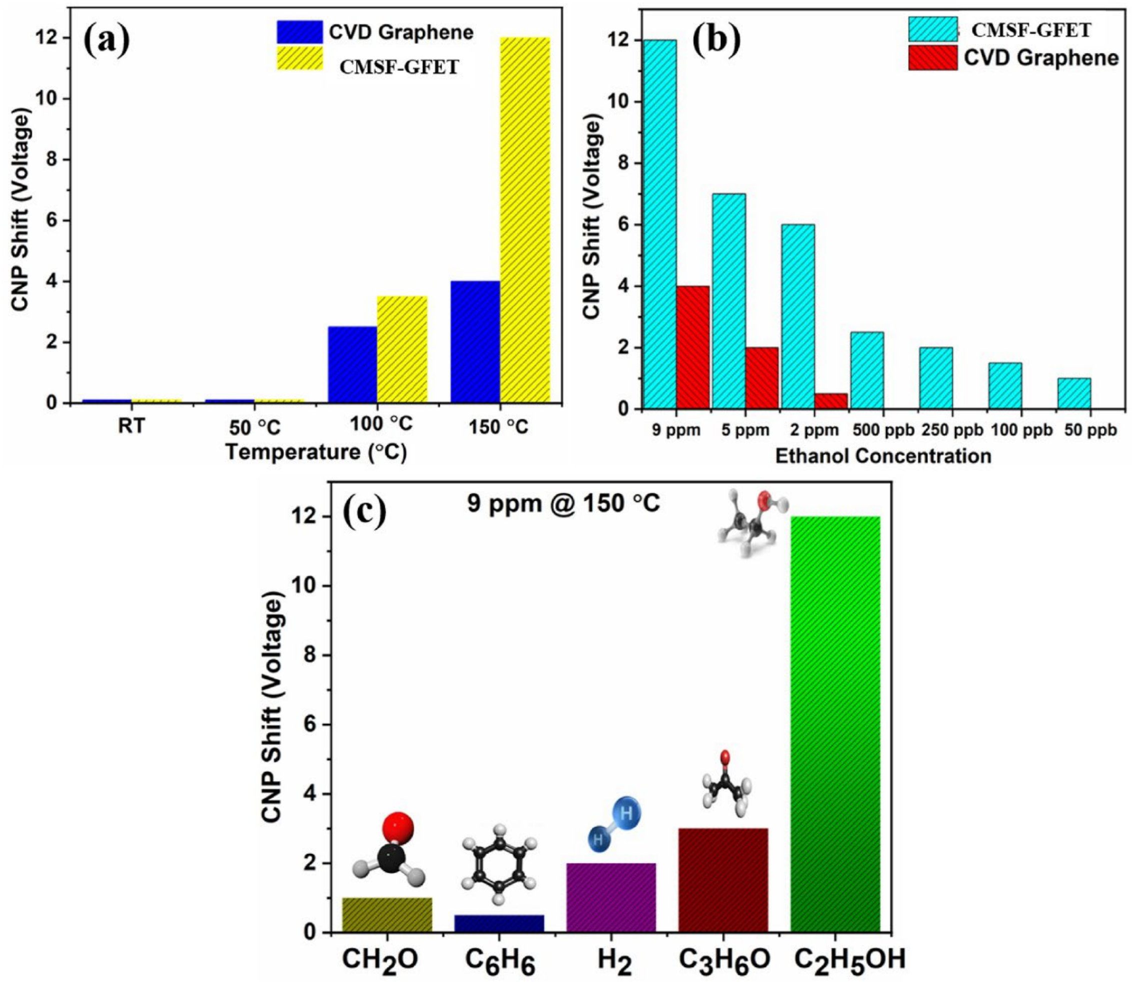

Figure 2. (a) Ethanol (9 ppm) gas responses of the CVD GNRFET and CMSF-GFET sensors at different temperatures, (b) responses of the sensors to different ethanol gas concentrations at 150 °C, (c) selectivity of the CMSF-GFET gas sensor at 150 °C toward 9 ppm formaldehyde, benzene, hydrogen, acetone, and ethanol.

3. Surface Acoustic wave graphene gas sensor

we fabricated partially suspended monolayer graphene surface acoustic wave gas sensors (G-SAWs) with a love-mode wave to effectively detect ppt-level acetone gas molecules at room temperature. The sputtered SiO_2 thin film on the surface of a black 36°YX-$LiTaO_3$ (B-LT) substrate acted as a guiding layer, effectively reducing the noise and insertion loss. The G-SAWs exhibited enhanced gas response towards acetone gas molecules (800 ppt) in a real-time atmosphere. The high sensitivity of the G-SAW sensor can be attributed to the elasticity and surface roughness of the SiO_2 film. In addition, the G-SAW sensor exhibited rapid response and recovery at room temperature. This study provides a potential strategy for diagnosing different stages of diabetes in the human body.

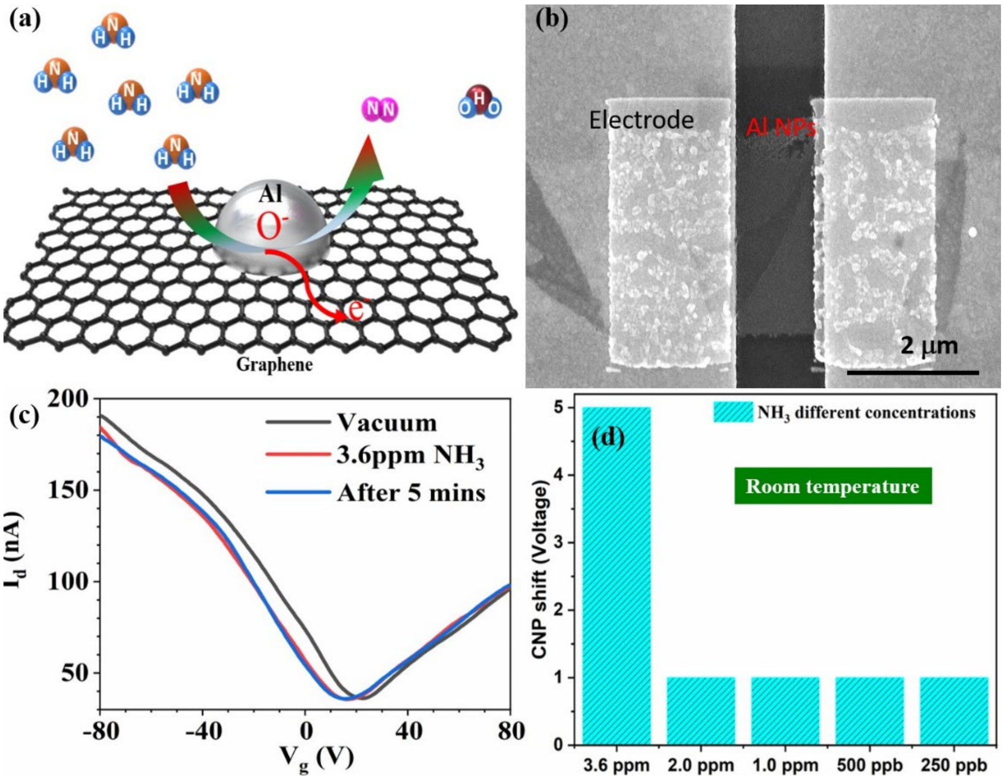

Figure 3 a. Schematic representation of Al functionalized graphene towards NH3 gas molecules, b. SEM images of Al-GFET fabricated device, c. Gas response of device towards ammonia gas molecules at room temperature, d. Gas response towards different concentrations.

４．研究成果

1. Key Achievements

We have achieved ultra-sensitive detection of ammonia and ethanol gas molecules at different temperatures. We have successfully functionalized metal nanoparticles and activated carbon molecular sieve on the surface of graphene FET with a size of 200 x 200 nm. In addition, charge neutrality point disparity was measured at different atmospheres to identify the gas molecules by tuning the gate voltage. The charge neutrality point difference was observed towards ammonia and ethanol gas molecules which show ultra-high sensitivity of 250 ppb and 50 ppb concentrations. For high sensitivity and selectivity gas detection, Al functionalized graphene FET was fabricated and demonstrated. As proof of concept, The G-SAWs exhibited enhanced gas response towards acetone gas molecules (800 ppt) at room temperature.

2. Future perspective

In the next phase of research work, we have planned to suspend functionalized graphene to study gas sensing using a Surface acoustic wave gas sensor. In addition, we also planned to study the different structures of graphene nanoribbons. We will also compare different methods of gas sensors and find out a better sensor which will be implemented for real-time health sensor monitoring.

５．主な発表論文等

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〔図書〕　計0件

〔産業財産権〕

〔その他〕

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６．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

７．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

８．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関