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JAPAN ADVANCED INSTITUTE OF SCIENCE AND TECHNOLOGY

Japan Advanced Institute of Science and Technology

Doctoral Dissertation

Low-Frequency Noise Analysis of Suspended Graphene Nanoribbon for Gas Molecule Identification

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Abstract

The human body naturally expels many different gases through respiration and skin. These gases can be monitored and used as a noninvasive diagnosis tool for many diseases. With this application in mind, there have been many studies on high-sensitive gas sensors. Usually, a large number of different compounds have to be monitored at the same time for an accurate diagnosis. In order to achieve this, it is common practice to use an array of different sensors along with machine learning techniques. Another possibility, still not well explored, is to use the electronic noise of only one device to differentiate the compounds.

In this work, the possibility of using the low-frequency noise of suspended graphene nanoribbons (GNR) fabricated through chemical vapor deposition (CVD) for gas identification is explored. Commercially available CVD graphene (Graphenea) on a 300 nm SiO_2 and Si substrate was used. The metal contacts (Cr + Au) were patterned with electron beam lithography and deposited through physical vapor deposition, followed by a lift-off process. The GNR was defined with electron beam lithography, and the graphene was suspended by etching the SiO_2 with buffered hydrofluoric acid (BHF). The noise measurement was performed by monitoring the current of the device using a lock-in technique. Experiments with oxygen show that oxygen causes an increase in the low-frequency noise of the GNR by the appearance of a random telegraph signal (RTS). The RTS observed is anomalous (it only appears at some time periods), with an average dwell time in the high-resistance state of 2.9 ms, and an average dwell time in the low-resistance state of 2 ms for one device with GNR width and length of 200 nm. In another device (same dimensions) it was noticed that the average dwell time increased from around 6 ms to 35 ms during the measurement period. A possible explanation for the observed RTS is that it is caused by oxygen molecules' movements (vibration, rotation, and diffusion) before they can finally find an energetically more stable configuration. Once this configuration is found, the molecules chemisorb on the graphene and the RTS stop.

The initial experiments with oxygen are promising. However, part of the metal contacts is also suspended because the BHF diffuses rapidly under the graphene. As a result, the metal areas that have graphene underneath are also suspended. Two main issues are present because of this. The first one is that there is a higher possibility of device collapse. The second issue is that the RTS may be caused by the adsorption of oxygen on the graphene underneath the contacts. Devices with metal-graphene-metal (MGM) contacts were fabricated to solve these issues. In this new structure, the SiO_2 in the contact region is etched with CF_4 reactive ion etching. Metal was deposited on the open regions, and only after it, the graphene was transferred to the sample. Therefore, the graphene in the contact region is on a metal layer, avoiding the over-etching under it. The top metal layer is used to ensure good resistance contact and to leave only the channel area exposed.

A new sample was fabricated using the MGM contact structure. 1 nm of tin was deposited in half of the sample's devices to verify if it could act as an adsorption site and increase sensitivity. Experiments with ethanol, acetone, benzene, and oxygen were performed. Changes in the low-frequency noise were observed only for oxygen (appearance of RTS). No conclusive difference was observed between the devices with and without tin. Likely, the tin formed a film covering the graphene (instead of nanoparticles). As a result, the number of adsorption sites (and device sensitivity) could not be increased. Lastly, from the results with oxygen, there is good evidence that the width of the GNR must be considered. Therefore, the effect of gases on the graphene's low-frequency noise may be increased with further device optimization.

Keywords: Suspended graphene, Random telegraph signal, Low-frequency noise, Oxygen adsorption, Gas sensor.