Urea Sensor used hydrogen-terminated polycrystalline diamond

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The urea sensor used hydrogen-terminated (H-terminated) polycrystalline diamond has been introduced for the first time. We used the electrolyte-solution gate diamond field effect transistor (SGFET)[1] as urea sensor.

The diamond SGFET meets the requirements as biosensors and chemical sensors because of its physical/chemical stability, wide potential window, high mobility, high response and biocompatibility, etc. The FETs have a structure where channel surface immobilized urease is directly exposed to urea solution and drain, source electrode are covered with epoxy resin.

The fabrication process of Si based urea sensor is complicated, because it needs at least doping process, gate thin oxide process, LOCOS process for isolation, passivation (Si_3N_4) layer deposition and so on. However the process of diamond is very simple. The doping process, oxide process and deposition of passivation layer process are unnecessary.

So far, we have reported that the threshold voltage of the H-terminated diamond surface is insensitive to pH solutions [1]. Otherwise the H-terminated diamond surface is sensitive to chloride (Cl^-) ion [2]. The threshold voltages of SGFETs are shifted about 30 mV/decade as Cl^- ion's concentration. This means that the upper bending band of H-terminated diamond surface is enhanced in the Cl^- ionic solutions. And it leads to the increase of the surface carrier density.

The as-grown CVD diamond surface terminated by hydrogen exhibits the surface p-type conductivity, which is used in p-channel SGFET. The H-terminated diamond surface layer is modified chemically to become pH sensitive and immobilize proteins such as uease. Urease is immobilized partially on the diamond surface channel of the SGFETs, which is sensitive to pH values. The diamond SGFETs of urea sensor have a structure where urease immobilized surface channel is directly exposed to urea solution and drain, source electrode are covered with epoxy resin.

Urea sensitive diamond SGFETs are based on the biocatalyzed decomposition of urea by urease. Although the two decomposition products affect oppositely the pH at the surface channel, the dissociation of $NH_4^+OH^-$ is higher than that of carbonic acid, resulting in the pH increase.

$$(NH_2)_2CO + 2H_2O + H^+ \longrightarrow 2NH_4^+ + HCO_3^-$$

We have checked the change in the drain-source current and the threshold voltage of SGFETs to examine the sensitivity of urea on the diamond surface channel. As urea density increases, the absolute value of the drain-source current increases at about 5 μA/decade as shown in Fig. 1 and the threshold voltage decreases at about 30 mV/decade in a FET with 500 μm gate length as shown in Fig. 2.

It is expected that the sensitivity of urea on polycrystalline diamond surface can be increased by the miniaturization of gate length. The 5 μm gate SGFETs exhibit more sensitivity by 50 times in the chloride ion detection of the 500 μm gate SGFET.

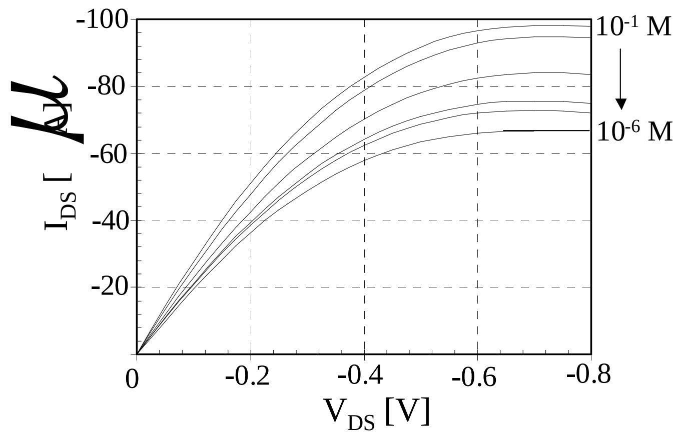

Fig. 1 I_{DS}-V_{DS} characteristics as urea density

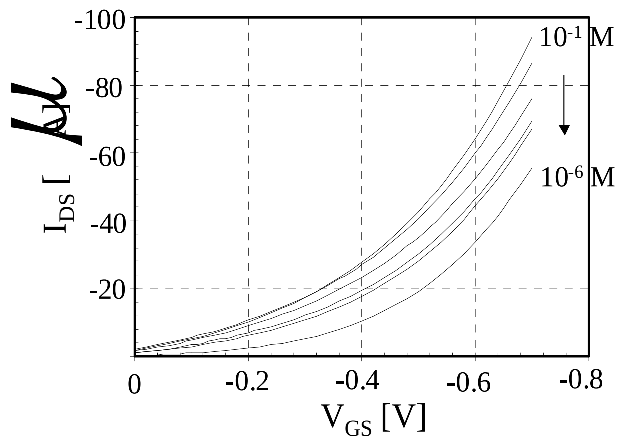

Fig. 2 I_{DS}-V_{GS} characteristics as urea density

1. H.Kawarada, et al., Phys. Status Solidi A 185 (2001) 79.
2. T. Sakai, H. Kanazawa, Y. Araki, H. Umezawa, M. Tachiki, H. Kawarada. Jpn. J. Appl. Phys. 48 (2002) 2595.