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# A Novel FET-type Hydrogen Gas Sensor with Pd-decorated Single-Walled Carbon Nanotubes by Electroplating Method

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## Abstract

In this work, we investigate the hydrogen ($H_2$) gas sensing performance in a *p*-type FET sensor having a floating-gate (FG) and a control-gate (CG) placing each other. Single-walled carbon nanotubes (SWNTs) are formed between the CG and FG by an inkjet-printing method to be used as a sensing layer. Then, SWNTs are decorated with palladium (Pd) by an electroplating method. The $H_2$ gas responses are studied by measuring the transfer characteristics ($I_D$-$V_{CG}$) and transient currents ($I_D$) with different $H_2$ concentrations under various CG biases ($V_{CG}$s). As the $H_2$ concentration increases from 0.02% to 1%, the sensitivity of $H_2$ gas increases and then starts to saturate regardless of operation region of FET-type sensor. The saturation is caused by a decrease in work-function, resulting from the diffusion of $H_2$ and the generation of $H_2O$.

**Keywords:** $H_2$ gas sensor, FET, SWNTs, Pd, electroplating

## Device fabrication

The structure of the fabricated sensor is shown in the cross–sectional schematic views and the optical microscopic image of the device shown in Fig. 1(a) and (b), respectively. Here, the key fabrication processes of the sensor are explained. A *n*–type Si (100) wafer is used as a substrate and the active area is formed by LOCOS process. After the gate oxide is thermally grown on the channel, formation of an *n*+ doped polysilicon FG is followed by O/N/O stack. Then a Cr/Au CG is formed. The FG and CG face each other in the form of interdigitated pattern. SWNTs as a sensing layer are formed in the area where the O/N/O stack covering the FG and the CG are interdigitated by an inkjet-printing method. Then, SWNTs are decorated with Pd by an electroplating method, which is carried out by using $PdCl_2$ as a precursor under -1 V of potential for 20 sec.

## Material characterization

Fig. 2 shows the energy dispersive X-ray spectroscopy (EDS) spectrum of the sensing layer (Pd-SWNTs). It shows X-ray peaks that indicate the constituent elements of the sensing layer. Pd Lα and Lβ peaks are observed at 2.838 keV and 2.990 keV, which are similar to those of theoretical values. Table in Fig. 2 show the atomic and weight concentrations of each element.

## Results

Gas sensing characteristics of the fabricated sensor is measured at room temperature (25 ℃) in an enclosed chamber. Fig. 3(a),(b) show the transfer characteristics ($I_D$-$V_{CG}$) of the fabricated FET-type sensor obtained by DC and pulsed measurements, respectively. In Fig. 3(b), the ambience is air and $H_2$ gas, and pulse scheme for pulse measurement is shown in the inset. As the $H_2$ concentration increases from 0.05% to 1%, the transfer curve is shifted to the left. When the sensor is exposed to $H_2$ gas, $H_2$ molecules are dissociated on the Pd surface. Then, H atoms are adsorbed on the Pd surface and quickly diffuse to the Pd/CNT interface, resulting in decreasing the work-function of CNTs. Also, $O_2$ in air ambience is reacted with H atom to form a hydroxyl (OH) group. OH group finally causes the generation of $H_2O$ with extra H atom [1]. Then, the work-function of CNTs decreases, because $H_2O$ is known as electron donor. In the higher $H_2$ concentration, however, excessive $H_2O$ causes the Grotthuss chain reaction [2], and it suppresses increase of sensitivity. Fig. 4 (a)-(f) show the transient responses ($I_D$) with different $H_2$ concentrations in the subthreshold and linear regions of the sensor. As the $H_2$ concentration increases from 0.02% to 1%, sensitivity ($\Delta I_D/I_D \times 100$) of $H_2$ gas increases and starts to saturate around $H_2$ concentration of 0.1% regardless of operation region of FET-type sensor. It is shown that these results coincide with Langmuir isotherm model [3].

## References

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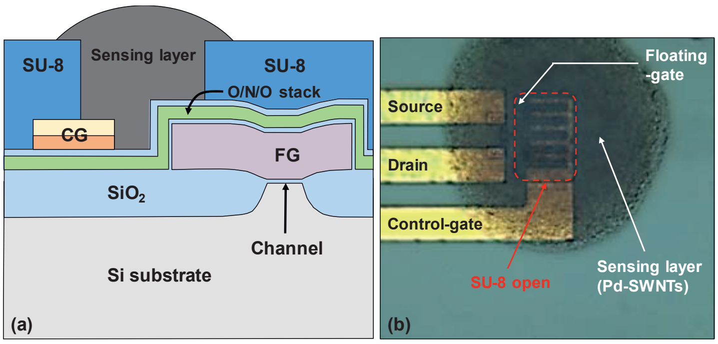


Fig. 1. (a) Cross-sectional schematic view cut along the channel width direction and (b) top optical image of the fabricated sensor.

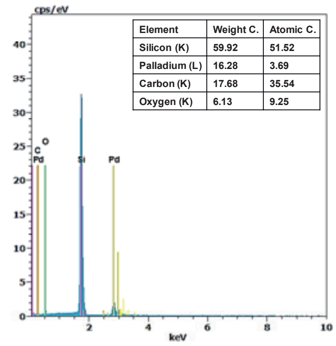


Fig. 2. EDS spectrum of the sensing layer (Pd-SWNTs).

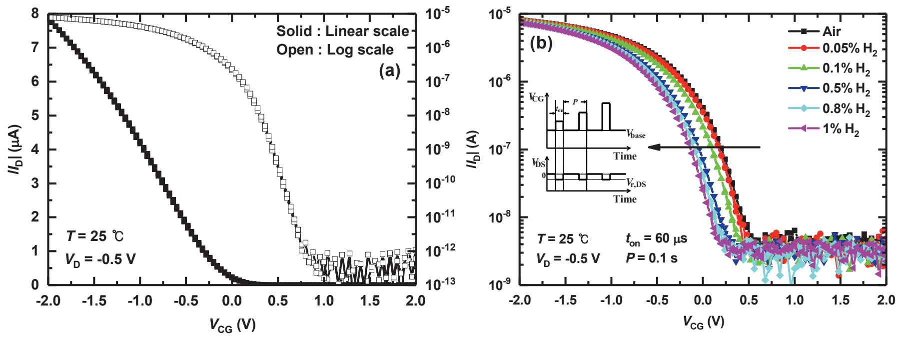


Fig. 3. (a) Transfer characteristics ($I_D$-$V_{CG}$) of the fabricated FET-type sensor obtained by DC measurement. (b) $I_D$-$V_{CG}$ curves as a parameter of $H_2$ gas concentration obtained by pulsed measurement (Reference : air).

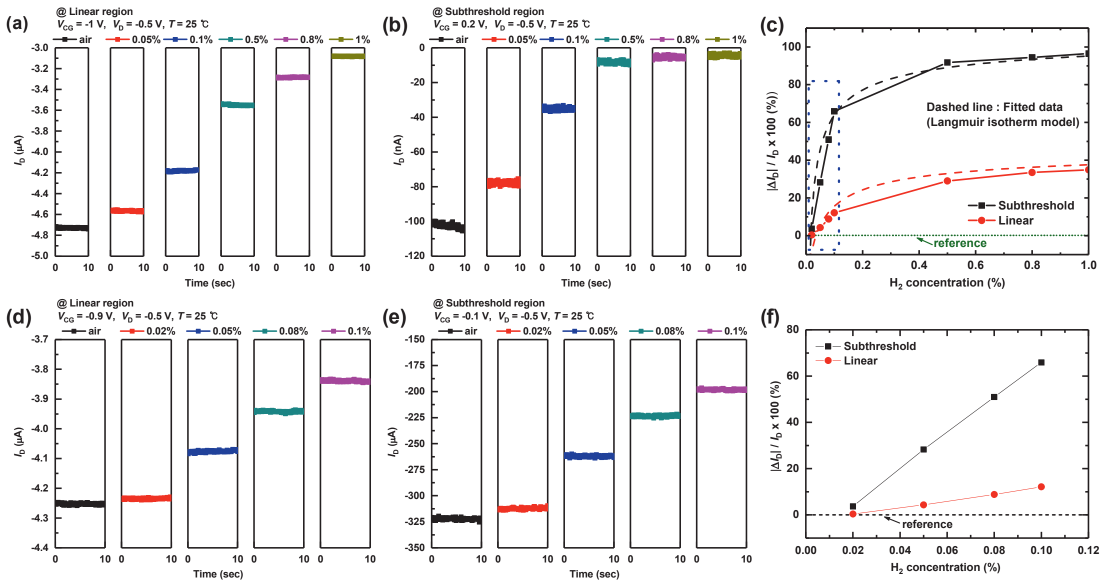


Fig. 4. (a) Transient ($I_D$) behaviors of the fabricated FET-type sensor as a parameter of $H_2$ concentration from 0.05% to 1% in linear region and (b) subthreshold region. (c) $H_2$ gas sensitivities versus $H_2$ concentration from 0.02% to 1%. Dashed lines are fitted lines by Langmuir isotherm model. (d) Transient ($I_D$) behaviors of the fabricated FET-type sensor as a parameter of $H_2$ concentration from 0.02% to 0.1% in linear and (e) subthreshold regions. (f) Magnified plot of blue dotted rectangle (0.02% ~ 0.1% $H_2$) in (c). Measurements are carried out by applying pulses to the control-gate. (Reference : air)

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