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Ammonia Gas Sensor based on Surface Modified Poly-Si Nanowires Field Effect Transistor

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Abstract

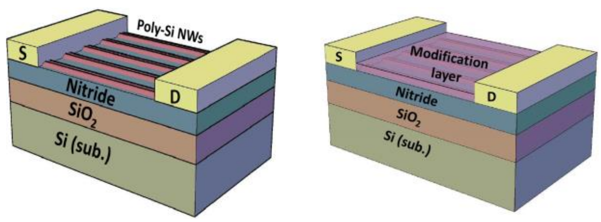
The noninvasive ammonia gas sensor based on the poly-Si nanowires field effect transistors (*p*-Si NWs FETs) was fabricated. The NW surface was further modified by imide group containing materials to enhance the low-concentration ammonia gas sensing ability. The experiment results showed that the surface modified *p*-Si NWs FETs by thalidomide have 30% and 10% enhancement at 2.0 and 0.5 ppm, respectively. The high sensitivity property of modified *p*-Si NWs FETs are able to be applied for biomedical detection in the liver disease.

1. Introduction

The development of diagnostic breath system is important for modern medical analytical tools. Some specific diseases, indeed, can be diagnosed by human breath [1]. Ammonia (NH_3), for example, contenting in human breath is a typical symptom for the liver cirrhosis patient. The ammonia concentration can be higher (0.997 ppm) than the healthy people (0.278 ppm) [2]. In this study, poly-Si nanowires field effect transistor (NWs FETs) as the ammonia gas sensor was fabricated. The device has several attractively properties, such as miniature size, simple processes, low cost, low power consumption and short response time. Moreover, the nano-scale device has geometry structure of large surface-volume ratio [3-4], which property is greatly suitable for the gas sensor. Beside, in order to enhance sensing sensitivity and selectivity for ammonia gas, we modify the poly-Si NWs surface by imide group compounds. The imide group compound has chemical adsorption which can help ammonia gas molecular to absorb on the modification layer surface. Through the ammonia gas molecular adsorption, the electric properties of device will vary that can achieve sensing purpose.

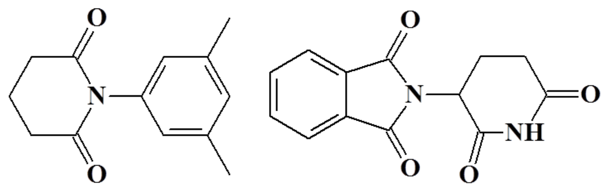
2. Experiment

The N-type poly-Si NWs FETs is a bottom gate FET which is shown in Fig.1 (a). Each poly-Si NWs FETs consists of ten nanowires (NWs) with channel length (l) and width (w) are 2 μm and 80 nm, respectively [5]. The organic compound was spun on the NW surface for testing their sensing ability, as shown in Fig.1 (b). N-(3, 5-dimethylphenyl) glutarimide (Compound-1) and (±)-Thalidomide (Compound-2), purchased from Sigma Aldrich, were selected to test the sensitivity enhancement. Their chemical structures are shown in Fig. 2 (a) and (b). The 0.01 wt. % solution was prepared in tetrahydrofuran (THF). The thin film thickness was controlled at 3 nm with spin rate at 5000 rpm for 40 sec. The experiment was conducted in the airtight chamber and controlled under pressure at 500 torr with relative humidity at 20%. The specific ammonia gas concentration was injected by mass flow controller (MFC). The electrical characteristic of Poly-Si NWs FETs was measured by Keithley 2636 chip analyzer.



(a) (b)

Fig. 1 Schematic of the poly-Si NWs FETs (a) normal device (b) modified device



(a) (b)

Fig. 2 Chemical structure of (a) N-(3, 5-dimethylphenyl) glutarimide (compound-1); and (b) Thalidomide (compound-2)

3. Result and Discussion

The compound 1 and 2 are selected due to their electronegativity atoms (e.g., O atom, N atom.) These functional groups might enhance the ammonia molecular absorbed on the modification layer. The I_D-V_G curves of the normal device under various ammonia gas concentrations are shown in Fig. 3. The drain current was slightly increased with the ammonia concentration increased. It was found that the grain boundary defect was minimized by trapping ammonia molecules [6]. As a result, the drain current was increased.

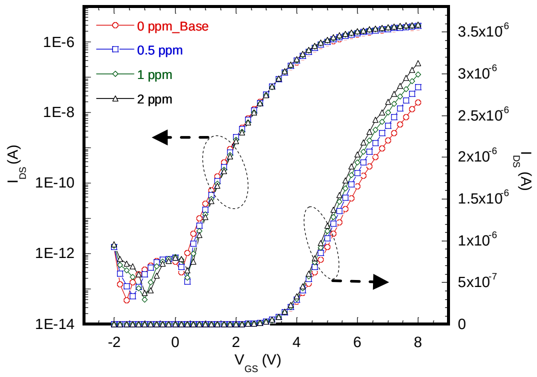
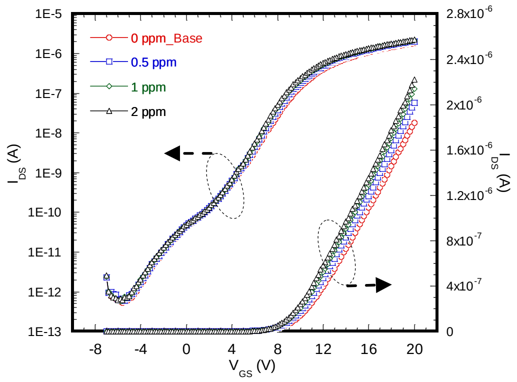
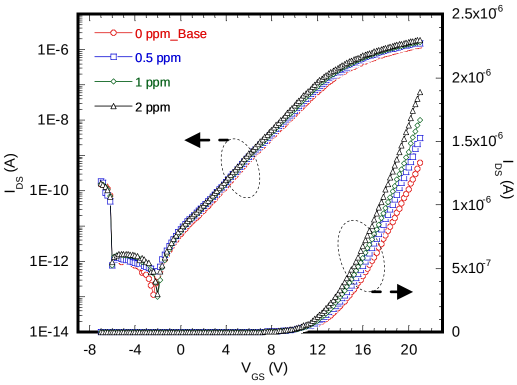


Fig. 3 The I_D-V_G curve of Poly-Si NWs FETs under specific ammonia concentration.

The I_D-V_G curves of the surface modified Poly-Si NWs FETs are shown in Fig. 4. From Fig. 4 (a) and (b), the drain current of modified devices greatly increase with ammonia concentration from 0 ppm to 2 ppm. When the modification layer was absorbed by ammonia molecular which can induce the surface charge to enhance electric fields, the electrical property of Poly-Si NWs FETs are improved.



(a)



(b)

Fig. 4 The I_D-V_G curve of surface modified Poly-Si NWs FETs under ammonia concentration by (a) Compound-1; and (b) Compound-2.

To quantify the sensing ability of poly-Si NWs FETs for ammonia gas, the drain current ratio can be expressed the standard of sensing ability, which is defined as eq. (1).

$$Current \quad Ratio \equiv \left. \frac{I_{D(NH_3)}}{I_{D(base)}} \right|_{Vg.\,fixed} \qquad (1)$$

where $I_{D(NH_3)}$ and $I_{D(base)}$ were measured under the environment of specific ammonia concentration and no ammonia concentration, respectively.

Table I. Current ratio of each modified Poly-Si NWs FETs

	0.5 ppm	1.0 ppm	2.0 ppm
Bare NWs	1.05	1.11	1.14
Compound-1 modified	1.09	1.16	1.20
Compound-2 modified	1.15	1.26	1.42

The current ratio of the surface modified poly-Si NWs FET is higher than bare one under various ammonia concentrations. The strong polar functional groups attracted ammonia molecules may be the major reason. Interestingly, the Thalidomide modified poly-Si NWs FETs has higher current ratio than N-caped glutarimide. The hydrogen bond of the N-H group from Thalidomide may be responsible for the enhancement. Comparing with the bare NW, the thalidomide modified poly-Si NWs FETs has 30% and 10% enhancement at 2.0 and 0.5 ppm, respectively. As the result, the strong polar attraction of hydrogen bond may be the future design for the surface modification layer.

4. Conclusions

The low-concentration ammonia poly-Si NWs FETs gas sensor which can detect as low as 0.5 ppm was fabricated. In particular, the NW's surface modified by thalidomide enhanced ammonia sensitivity by 30% at 2.0 ppm. The results provide a noninvasive monitor for liver cirrhosis of biomedical.

Acknowledgements

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