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The Selectivity of Nitric Oxide and Ammonia Gas Sensor based on Surface Modified Poly-Si Nanowires FETs

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Abstract

The poly-Si nanowires field effect transistors (*p*-Si NWs FETs) are able to detect very low concentration volatile organic compounds (VOCs) of ammonia (NH_3) and nitric oxide (NO). The surface modified NWs with S,S-dioxide oligofluorens enhanced the gas bonding ability. In particular, the current ratio of ammonia increased 80% from surface modified *p*-Si NWs FETs, but not the gas of nitric oxide. Our result suggested that the surface modified NW with correct material is able to enhance the selectivity.

1. Introduction

Many researches have revealed specific VOCs existing in human breath that associated to certain diseases. For example, the specific nitric oxide (NO) concentration corresponding to the acute asthma patients is over 25 ppb. On the other hand, the ammonia (NH_3) breath concentration over 0.50 ppm (ie. 500 ppb) is a typical symptom in the liver cirrhosis patients. [1-2] Various studies have been devoted to high precision measurements. However, it is less to mention the selectivity of gas sensing ability. We have developed the poly-Si nanowires field effect transistor (NWs FETs) as gas sensors which possess several advantages, such as small dimensions, high surface-to-volume ratio, low power consumption, and operating at room temperature. [3-4] The NWs FETs have been demonstrated as the gas sensor. [5] In this study, we reported our first attempt to enhance the selectivity between NO and NH_3 gases using surface modified NWs FETs. The S,S-dioxide functional group in oligo-fluoren served as media to promote the selectivity of the NW devices.

2. Experiments

The N-type poly-Si NWs FETs is prepared by bottom-gate method which is shown in Fig.1 (a). Ten polycrystalline silicon nanowires are arranged on the surface of devices. Each nanowire channel length (l) and width (w) of 2 μm and 80 nm. [6] NWs surface was modified with organic material by spin coating to enhance the selectivity of the device, as shown in Fig.1 (b).

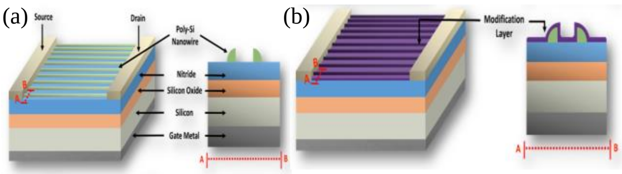

Fig. 1 Scheme of the poly-Si NWs FETs (a) bare device; and (b) surface modified device

The 3,7-Bis[7-(9,9-di-n-hexylfluorenyl-2,7-diyl)]-9,9-di-n-hexylfluoren-2-yl] dibenzothiophene - S,S-dioxide (abbreviated as "S-dioxide" in the following text) was purchased from American Dye Source. The S-dioxide was prepared at 3 nm thin film by spin coating on the NWs. The entire measurements were controlled under a pressure of 500 torr with 40% relative humidity in the airtight chamber. The desired concentrations of NO and NH_3 gases were precisely controlled by mass flow controller injecting into the chamber for measurement. The electrical properties were measured by a Keithley 2636 sourcemeter.

3. Result and Discussion

The I_D-V_G curves of the bare devices under different NO and NH_3 concentration are shown in Fig 2. The drain currents of the bare devices are different under NO and NH_3. It is due to the NO molecule and the NH_3 molecules are considered as electron acceptor and donor that cause differences in the drain current of NW device. As a result, the drain current would decrease along with increasing NO gas concentration. In contrast, the drain current would increase gradually when the NH_3 gas concentration rise.

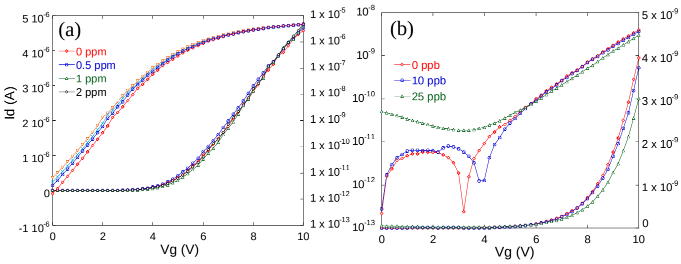

Fig. 2 The I_D-V_G curve of poly-Si NWs FETs under different (a) NH_3 and (b) NO concentrations.

The I_D-V_G curves of the surface modified S-dioxide and poly-Si NWs for NH_3 gas sensing as shown in Fig 3. The drain current of the device modified with S-dioxide increased visibly under increasing the NH_3 gas concentration. The NH_3 gas molecules could be attracted on the surface of S-dioxide modified NW device, which increase current due to the high electronegativity of S=O groups.

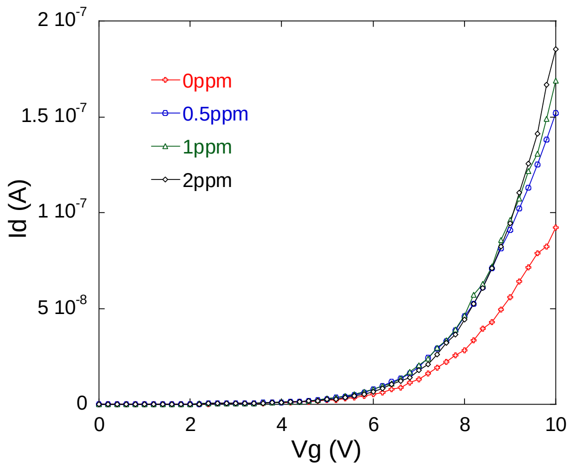

Fig. 3 The I_D-V_G curve of surface modified S-dioxide poly-Si NWs FETs under different NH_3 concentration.

The I_D-V_G curves of the surface modified S-dioxide poly-Si NWs for NO gas sensing are shown in Fig 4. The NO molecule and the S=O group on the oligo-flurene are both considered as electron acceptor. Besides, the thin film may also impede the charge transfer from NO molecule to the NWs. Therefore, the current of the surface modified NW device decrease slowly when increasing the concentration of NO gas.

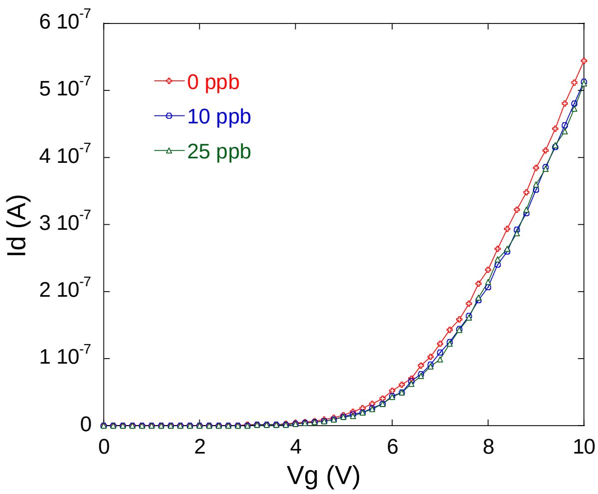

Fig. 4 The I_D-V_G curve of surface modified S-dioxide poly-Si NWs FETs under different NO concentration.

The drain current ratio was selected as parameter to quantize the sensing ability of poly-Si NWs FETs. The current ratio can be expressed sensing ability as defined in eq. (1)

$$Current\ Ratio = \frac{I_{D(\mathrm{NH3\ or}\ NO)}}{I_D(base)}\Big|_{V_G=10\ v} \quad \text{.......eq. 1}$$

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

40%RH	NH_3 (0.5 ppm)	NO (25 ppb)
Bare device	1.02	0.76
S-dioxide modified	1.82	0.93

For NH_3 gas sensing at 0.5 ppm, the bare NWs device showed barely 2% increase. The surface modified with S-dioxide NW device, on the other hand, shows 82% increase. The NO gas sensing on the bare device shows 24% decrease of current ratio. The surface modified with S-dioxide NW device, in contrast, shows only around 7% decrease. Accordingly, the S-dioxide has significantly improvement on the NH_3 gas sensing properties but not in the NO gas. The surface modified S-dioxide oligomers can be used to distinguish between NH_3 and NO gases.

4. Conclusions

In this study, we have investigated the gas sensing properties of a surface modified N-type poly-Si NWs FETs. Our results suggested that the surface modified NW device with S,S-dioxide oligofluorens is able to distinguish two different types of gases successfully. The current ratio can increase 80% at 0.5 ppm of NH_3 comparing to the bare NW devices but not in the 25 ppb NO gas. The large difference in current ratio is able to distinguish these two different gases.

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