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Enhancing Nitric Oxide Gas Sensitivity of p-Si NWs FETs with Antioxidant Surface Modification

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Abstract

The poly-Si nanowires field effect transistors (p-Si NWs FETs) have been shown sensitivity towards nitric oxide (NO) gas. In the study, antioxidant materials, L-Glutathione reduced form and S-Hexylglutathione, were selected as chemical modification layer on the NW surface. The modification layer is able to enhance the low-concentration nitric oxide (NO) gas sensing ability. The experimental results suggested that p-Si NWs FETs with antioxidant modification reaching approximately 10% and 17% enhancement at 10 ppb and 25 ppb nitric oxide, respectively.

1. Introduction

Nitric oxide (NO) concentration in the exhaled breath has been revealed strongly associated with the airway inflammatory disorders such as asthma. The higher NO concentration in breath can be found in the asthmatic patients (25~50 ppb) than the breath of healthy people (< 25 ppb.) Furthermore, five times NO concentration (100 ppb) more than its normal concentration level can be detected several hours before acute asthma attack. [1] In this study, poly-Si nanowires field effect transistor (p-Si NWs FETs) as the nitric oxide (NO) gas sensor was fabricated. Field effect transistor based gas sensors have been reported to detect gas molecules and possess several attractive properties: such as miniature size, label free, and low cost. [2] The nano-scale FETs are suitable for the gas sensor due to their large surface to volume ratio. [3, 4] Nitric oxide (NO) is a known radical molecule. As a result, we selected the antioxidants, L-Glutathione reduced form and S-Hexylglutathione, as modification materials for poly-Si NWs surface in order to enhance the sensing ability towards low-concentration nitric oxide (NO) gas. L-Glutathione reduced form and S-Hexylglutathione are antioxidants which means these two chemicals are prone to capture radicals. Therefore, the electrical properties of the device are able to be altered when low level of NO accumulated on the modification surface.

2. Experiments

An n-type poly-Si NWs FET consists of ten poly-Si NW channels, as shown in Fig.1 (a). The dimension of each channel is 80 nm in width and 2 μm in length. [5] The organic modified thin film layer was prepared by the vacuum thermal coating on the NWs surface for enhancing the sensing properties, as shown in Fig.1 (b). Both S-Hexylglutathione and L-Glutathione reduced form were purchased from Sigma Aldrich. Their chemical structures are shown in Fig. 2. The modification film thickness was controlled at ~3 nm. The thin film thickness was verified by Atomic Force Microscope (AFM-D3100). Electrical characteristics of Poly-Si NWs FETs were measured by Keithley 2636 semiconductor analyzer. The experiment was conducted in the airtight chamber and controlled under a pressure of 500 torr with relative humidity 40%. The specific NO gas concentration was injected by mass flow controller (MFC).

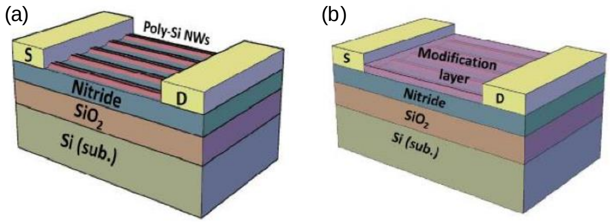

Fig. 1 Schematic of the poly-Si NWs FETs
(a) normal device; (b) modified device

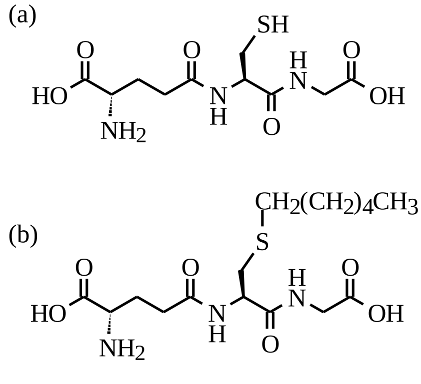

Fig. 2 Chemical structure of (a) L-Glutathione reduced form; and (b) S-Hexylglutathione

3. Results and Discussion

The $I_{DS} - V_{GS}$ curves of the normal device under different NO concentrations from 0 to 25 ppb are shown in Fig. 3. The curve chart shows that the drain current declines slightly as the NO concentration rises. This attributes to the NO molecule considered being the electron acceptor on the surface grain boundaries of poly-Si NWs.

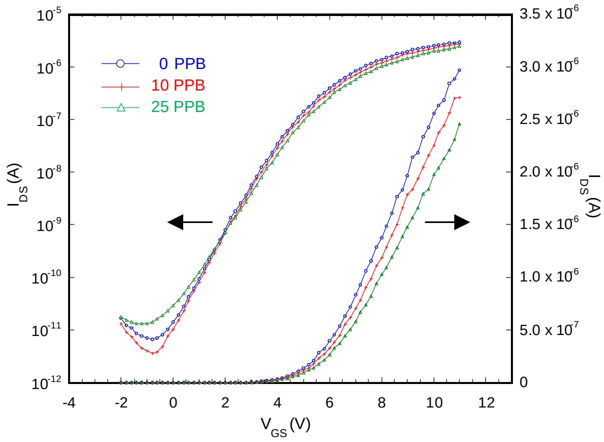

Fig. 3 The I_{DS} – V_{GS} curve of Poly-Si NWs FETs under different NO concentrations.

L-Glutathione reduced form is selected because of antioxidant ability in the biological system. It is interesting to compare the S-Hexylglutathione and L-Glutathione reduced form because the –SH group is chemically modified with alkyl group. The I_{DS} – V_{GS} curves of the surface modified poly-Si NWs FETs are shown in Fig. 4 (a) and (b). ,

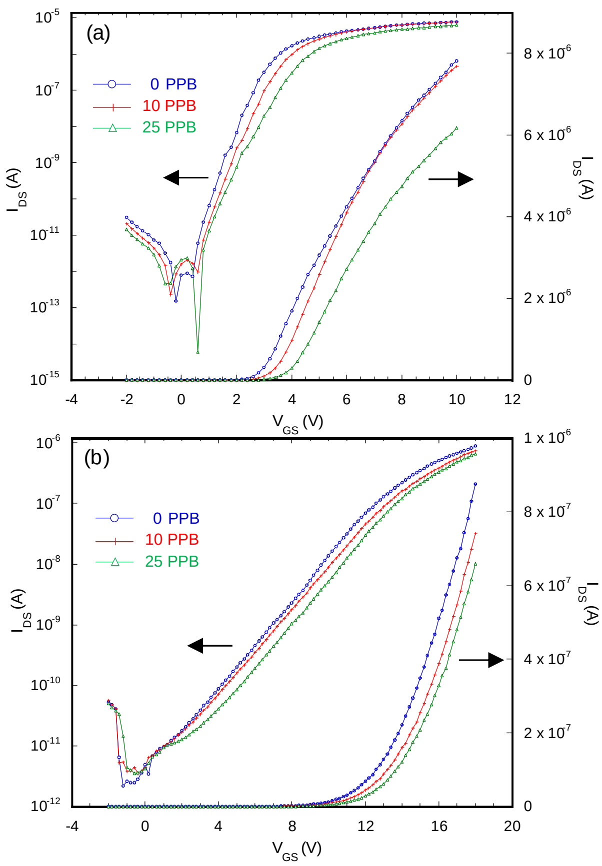

Fig. 4 The I_{DS} – V_{GS} curve of surface modified poly-Si NWs FETs under different NO concentration in the (a) L-Glutathione reduced form; and (b) S-Hexylglutathione

According to the curve charts, the surface modified devices have great improvement on the NO sensitivity. It is because when NO molecules encountered the modification film, they were reduced by the antioxidant materials and caused charges to transfer from gate channel to the modification layer.

To quantify the NO sensing ability of poly-Si NWs FETs, we defined the drain current ratio as the standard of the sensing ability, which is shown in Eq. (1):

$$\text{Current Ratio} = \frac{I_{DS(NO)}}{I_{DS(Base)}} \Big|_{V_{GS(fixed)}} \qquad \text{Eq. (1)}$$

Table 1. Current ratio of each modified Poly-Si NWs FETs

RH=40%	0 ppb	10 ppb	25 ppb
Normal	1	0.91	0.87
L-Glutathione reduced form	1	0.91	0.76
S-Hexylglutathione	1	0.81	0.70

The current ratio of each modified poly-Si NWs FETs are summarized in Table 1. The current ratio merely decreased approximately 13% at 25 ppb for normal poly-Si NWs FETs. However, L-Glutathione reduced form and S-Hexylglutathione modified device presented around 24% and 30% declination at 25 ppb, respectively. As the results, these two antioxidant materials have significantly improved the NO gas sensing ability at controlled environment.

4. Conclusions

In this study, antioxidant thin layer was proposed to enhance poly-Si NWs FETs' sensing ability toward low-concentration nitric oxide (NO) gas. Our experimental results indicated that the current ratio decreased significantly due to the charges interaction between NO molecules and the surface modified antioxidant thin film at controlled environment. The current ratio of surface modified S-Hexylglutathione device, as an example, declines 30% at 25 ppb, which is nearly 17% improvement comparing to the un-modified device.

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References

[1] Raed A. Dweik *et al*., American Journal of Respiratory and Critical Care Medicine. 184 (2011) 602-615.

[2] B. Timmer *et al*., Sens. Actuators, B.107 (2005) 666.

[3] C. Y. Hsiao *et al*., Biosens and Bioelectron. 24 (2009) 1223.

[4] M. Z. Dai *et al*., Anal. Chem. 85 (2013) 3110.

[5] H. C. Lin *et al*., IEEE Electron Dev. Lett. 53 (2006) 2471.