

Controlled decoration of double junction $n^+/n^-/n^+$ polysilicon nanobelt device with platinum for hydrogen gas sensor application

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Abstract

Double junction $n^+/n^-/n^+$ polysilicon nanobelt selectively modified with platinum has been studied for hydrogen sensor application. The selective modification of the devices is performed by the combination of localized ablating of a resist and lift-off process of e-beam evaporation of catalyst material. The coverage of Pt layer on n^- is precisely controlled by adjusting the Joule heating pulse bias and length. The fast response has been observed for hydrogen with the limit of detection of only 5 ppm on devices with Pt fully cover n^- region.

1.Introduction

Hybrid hydrogen systems have found increasing application due to the abundant and environmental friendly characteristics of H_2 . Hydrogen is highly flammable even at low concentration (~4%). This gives rise to the studies of numerous types of H_2 sensors in which palladium (Pd) and platinum (Pt) are widely used as catalyst. For H_2 sensor application, Pt has some advantages over Pd because it has higher diffusion coefficient and is not suffer from the blister [1, 2] or fracture [3] while exposed to H_2 . Besides, Pt also showed better limit of detection (LOD) and faster response time compare to Pd [4].

In this paper, we report on the application of double junction $n^+/n^-/n^+$ polysilicon nanobelt as H_2 sensor. Localized Joule heating and lift-off process have been used to deposit a layer of Pt with controlled area on the n^- region of the nanobelt. The coverage of Pt over the n^- region strongly affects hydrogen sensing behavior: the device with the entire n^- region covered with Pt shows fast responses to H_2 with LOD in the ppm range.

2.Experimental

Details on the device fabrication were described in previous work [5]. The sizes of the nanobelts are 13 μm (length), 0.5 μm (width) and 59 nm (thickness). The nanobelt consists of three sections: two heavily doped regions ($3 \times 10^{15} \text{ cm}^{-2}$) with equal length were separated by a lightly doped region ($2.5 \times 10^{14} \text{ cm}^{-2}$) of 2 μm length. The doping profile along the nanobelt enables the confine of heat in the n^- region of the device that can be applied as a mask-free technique for selective deposition of the hydrogen catalytic material.

The Pt decoration process is described below: a 50-nm layer of poly(methyl methacrylate) (PMMA) was applied on the device by spinner at 8000 rpm in 30 s. Localized Joule heating was then carried out by Agilent 4155B Pulse Generator. By adjusting the pulse bias length and magnitude, the ablated area of PMMA can be controlled. Atomic force microscope (AFM) (Jeol SPM-5200) was used to observe the devices at different steps of the decoration process. The area of the ablated PMMA was estimated by WSxM program [6]. The remained PMMA served as a mask for the selective deposition of 5-nm Pt layer by e-beam evaporation. Finally, the samples were immersed in acetone to lift-off the resist.

After lift-off of the resist, the device was bonded to a printed circuit board for H_2 testing. Sensor measurements were conducted at room temperature and atmospheric pressure. Pure N_2 was used as carrier gas while H_2 was pre-mixed with pure N_2 before entering the flow cell. Gas flow rate was monitored by mass flow controller while the device bias and current were controlled by Labview program. The sensitivity of the device was defined as the ratio of the relative current change due to hydrogen and the baseline. The response time (T_{90}) was calculated as the time to reach 90% of the steady state response and the recovery time (T_{10}) was the time to reach 90% of the baseline.

3.Results and discussion

Fig. 1 shows the ablated area of PMMA at n^- region with square of pulse voltage at 30 ms, 60 ms and 30 s pulse length. The area of the opening PMMA almost linearly increases with the square of pulse voltage, showing that power dissipation at the n^- region follows the Joule's law.

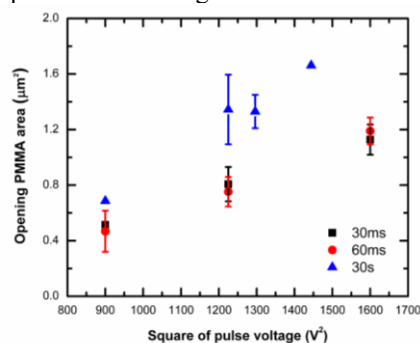


Fig. 1. Ablated area of PMMA layer at low doped region of the devices with applied power.

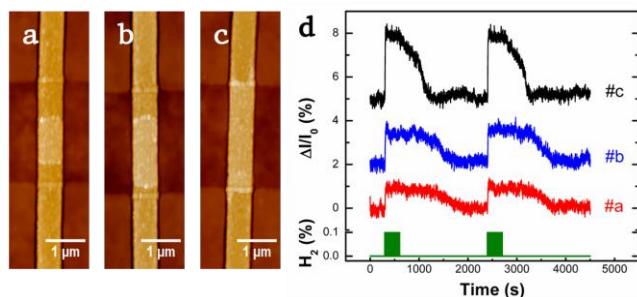


Fig. 2. Effect of Pt coverage area on the response of the devices to hydrogen: (a) devices with Pt area of $0.5 \mu\text{m}^2$, (b) devices with Pt area of $0.8 \mu\text{m}^2$, (c) devices with Pt area of $1 \mu\text{m}^2$ and (d) $\Delta I/I_0$ responses of these three devices to two pulses of 0.1% hydrogen at room temperature.

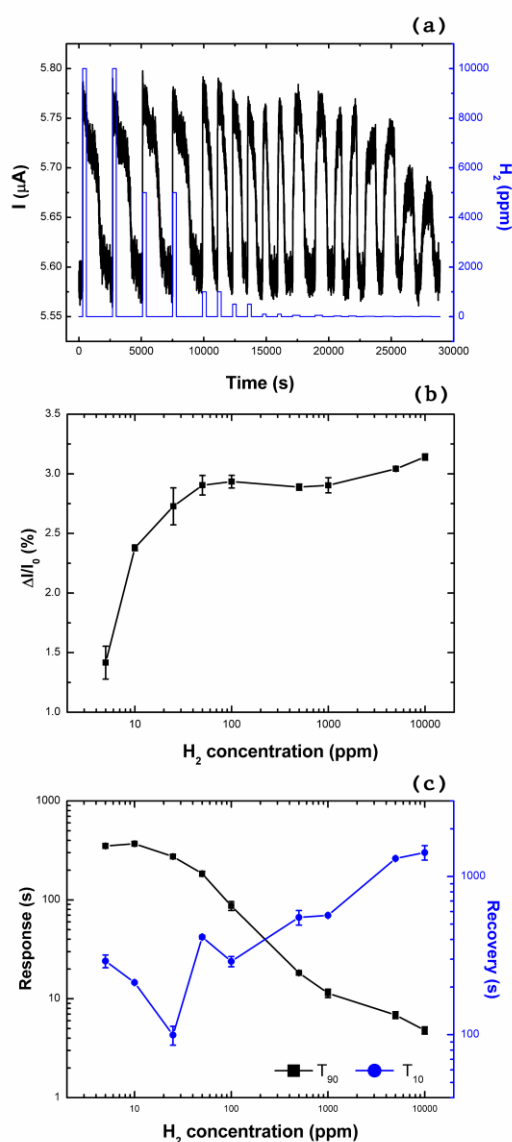


Fig. 3. Hydrogen sensing of $1 \mu\text{m}^2$ Pt coverage device: (a) real time responses to various H_2 concentrations at room temperature: 1%, 0.5%, 0.1%, 0.05%, 0.01%, 50 ppm, 25 ppm, 10 ppm, and 5 ppm, each concentration with two pulses; (b) sensitivity; (c) response and recovery times.

Fig. 2 shows how the coverage of Pt layer affects the responses of the devices to H_2 . AFM images in Fig. 2a, b, c show the devices with different Pt coverage areas on the n^- region. The areas of these Pt layers are estimated to be 0.5 , 0.8 and $1 \mu\text{m}^2$, respectively. Real time responses of these devices with 0.1% H_2 (Fig. 2d) reveals that sensitivity is improved with increasing Pt coverage. Device with Pt layer fully cover n^- region (i.e. $1 \mu\text{m}^2$) shows the highest sensitivity and fastest recovery times compared to two other smaller coverage devices. In H_2 ambient, currents through the devices increase due to the decrease of work function caused by H_2 adsorption on Pt surfaces.

Fig. 3 represents the responses of the $1 \mu\text{m}^2$ Pt decorated device with various hydrogen concentrations at room temperature. The device shows responses to H_2 concentrations ranging from 5 ppm to 1%. Response time is accelerated while recovery time is retarded with increasing H_2 concentration. The response time is just several seconds at 1% hydrogen and expands to just over a minute at 100 ppm. The recovery rate, especially at high concentration, is relatively slow. The LOD of this device is on the order of 5 ppm.

4. Conclusion

We have described the controlled decoration of a polysilicon $n^+/n^-/n^+$ double junction structure by localized Joule heating. Devices decorated with Pt have been applied in hydrogen sensing. The study results show that device with $1 \mu\text{m}^2$ Pt coverage over the n^- region was optimum to obtain the best sensitivity and recovery time to hydrogen at room temperature. The device responses rapidly with H_2 in N_2 ambient and is capable to detect hydrogen with concentration as low as 5 ppm.

References

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