Poster

POLYCRYSTALLINE SILICON NANOWIRE SENSING DEVICES

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Introduction

Recently nano-devices based on silicon nanowire (SiNW) structures have drawn much attention. SiNWs are particularly attractive as sensors because their critical dimension is comparable to the size of chemical and biological species. Due to its high surface-to-volume ratio, the NW's sensitivity is greatly enhanced when the signal is effectively transduced. More recently, we have investigated the use of polycrystalline silicon (poly-Si) NW field-effect-transistors (FETs) [1, 2]. With its easy preparation, low-cost, and compatibility with various substrates, poly-Si NW device is favorable for many applications. However, poly-Si suffers from inherent defects in inter/intra grains that impede carrier transport. This could potentially hinder poly-Si from sensor applications because of sensitivity degradation issue. In this work, we show that such concern is alleviated as long as the operation is carried out in an aqueous solution. Finally, the sensing capability of poly-SiNW device for detection of pH-value and biomolecules is also presented.

Experimental

Key fabrication steps of poly-SiNW devices are briefly described. First, a 90nm-thick amorphous Si was deposited on thermally-oxidized Si wafers. After doping of source/drain (S/D) regions with phosphorus dopants, wafers were annealed at 600^{o}C for re-crystallization and dopant activation purposes. Next, poly-SiNW channels and S/D regions were simultaneously formed by e-beam lithography and subsequent dry-etching steps. Wafers were then capped with an oxide layer except for NW channels and S/D contact regions. To execute measurement in aqueous environment, a polydimethylsiloxane (PDMS) microfluidic structure was used to enclose the device, as shown in Fig. 1.

Results and Discussion

Fig. 2 shows that poly-SiNW operating repeatedly in alternate dry and wet (de-ionized water, DI water) ambients displays two distinct behaviors. Specifically the performance, in terms of carrier mobility, threshold voltage (V_{th}) and subthreshold swing (S.S.), is significantly enhanced when the device is operating in wet ambient. As re-plotted in Fig. 3, dramatic performance improvement as well as much better stability is found in wet-ambient operation. Such improvement is mainly attributed to H^+ and/or OH^- passivation effects [3]. These electrical parameters are closely related to the reproducibility, conductivity and sensitivity of a device required for sensing applications. It is also worth noting that the S.S. is reduced to 0.2 V/dec in wet ambient (c.f., 0.9 V/dec in dry ambient), which is very comparable to that of monocrystalline SiNW (e.g., 0.174-0.649 V/dec) [4]. This implies that poly-SiNWs in aqueous environment actually behave on a par with the single-Si devices. This finding is very important because biologic and chemical sensing is usually performed in aqueous solutions. In this regard, the unique enhanced behavior of poly-SiNW in aqueous ambient thus lend itself nicely to sensing applications.

To study the electrical response to pH value, surfaces of poly-SiNWs were functionalized with 3-aminopropyltriethoxysilane (APTES) to produce amino groups on the NW surface which act as receptors of hydrogen ions (H^+). The change of surface charge state on the SiNWs will in turn modulate the NW conductance. Since our NW device is operating as n-type FET, more positive charges on NW surface will induce more carriers for transport, and therefore higher conductance with lower pH value. As shown in Fig. 4, the poly-SiNW device indeed shows strong dependence of conductance on pH value.

For the purpose of biological detection, the poly-SiNW's surface is modified in sequence with APTES and goat mouse-IgG biomolecules, as illustrated in Fig. 5. When the NW is immersed in goat α-rabbit-IgG solution, the conductance is slightly higher than that in the buffer. This is ascribed to some ionic effect as α-rabbit-IgG is not supposed to react with mouse-IgG. However, huge drop in conductance is observed when anti-mouse-IgG (0.69 mg/ml) is injected into the microfluidic chamber. This indicates that the charge state over the NW surface has changed, as a result of the bonding of anti-mouse-IgG to the modified NW surface (Fig. 5(a)).

Conclusions

In this paper, the feasibility of poly-SiNWs for sensing applications is reported. We found that the performance of poly-SiNWs is significantly boosted by water passivation effect. This finding is important as it suggests that poly-SiNWs can be cleverly operated in aqueous solutions to take advantage of the performance improvement. By functionalizing specified receptor on its surface, poly-SiNWs exhibit good sensibility and selectivity for ionic and biologic detection. Our finding, coupled with simple preparation method, makes poly-SiNWs very promising for future sensor device fabrication in terms of good integrity and reduced cost.

Acknowledgment

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References:

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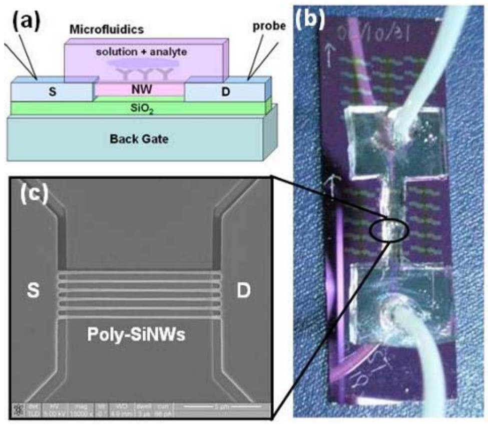

Fig. 1 (a) Schematic diagram of poly-SiNW device with back-gate, (b) photo of the device enclosed with PDMS flow chamber, (c) top-view scanning electron micrograph of poly-SiNW device showing NWs with 10 µm long, 70 nm wide and 90 nm thick.

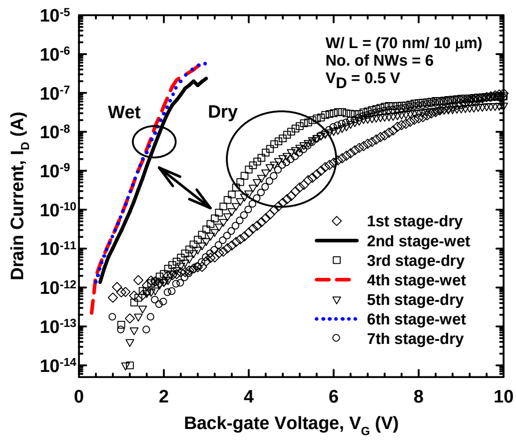

Fig. 2 Current-voltage characteristics of poly-SiNW device in several stages of exposure to alternate dry and wet ambients, also showing the reproducibility of water passivation effects.

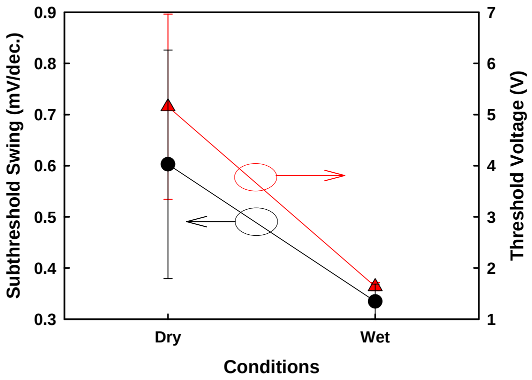

Fig. 3 Plot of subthreshold swing (S.S.) and threshold voltage (V_{th}) extracted from the seven stages in Fig. 2. Much smaller variation and better stability of electrical characteristics in wet ambient can be observed besides lower S.S. and V_{th}.

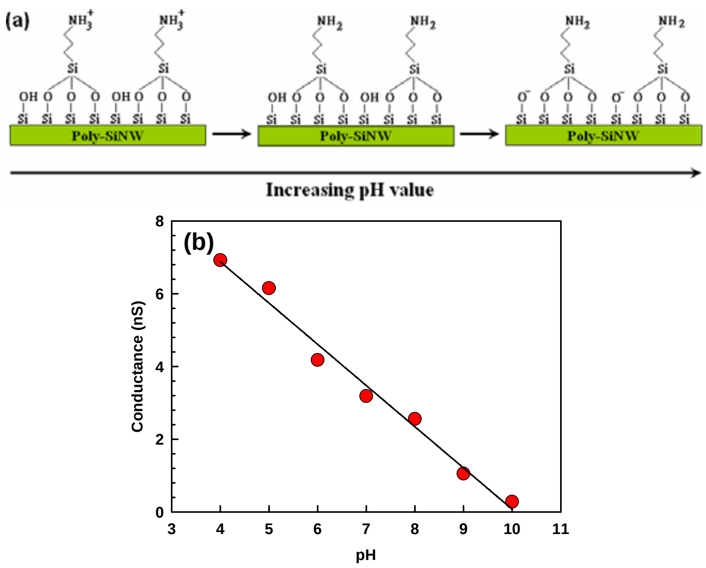

Fig. 4 (a) APTES-modified SiNW surface illustrating changes in the surface charge state with pH values, (b) conductance response as a function of pH value.

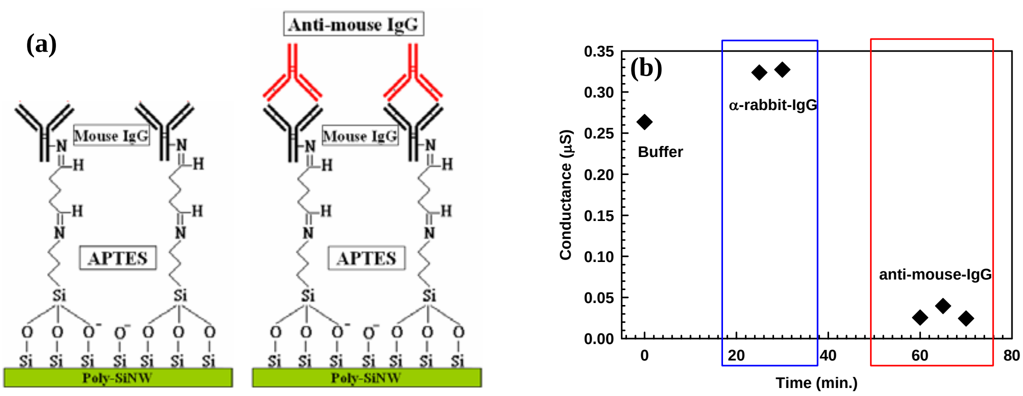

Fig. 5 (a) Schematic diagram illustrating a mouse-IgG modified SiNW (left) and subsequent binding of anti-mouse-IgG to the SiNW surface (right), (b) electrical responses of the modified poly-SiNWs to buffer, α-rabbit-IgG, and anti-mouse-IgG, respectively.