Electronic Supplementary Material (ESI) for Nanoscale.

Supporting Information

Direct ultrasensitive electrical detection of prostate cancer biomarker with CMOS-compatible n- and p-type silicon nanowire sensor arrays

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Uniformity of the fabricated SiNWs

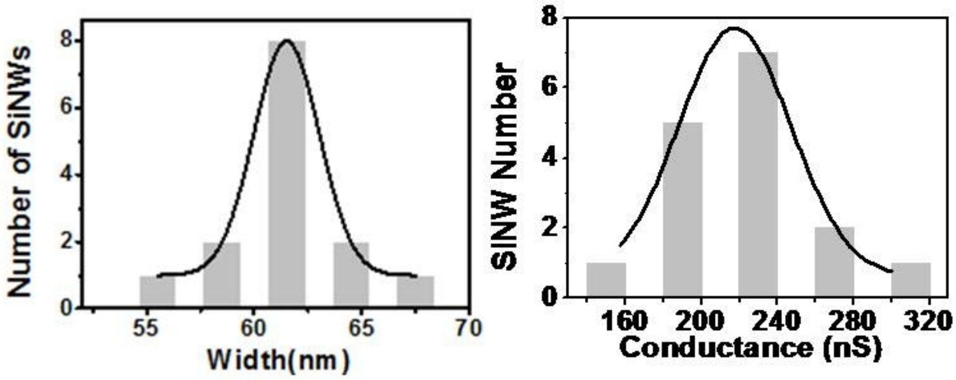

Figure s1 The uniformity of the fabricated SiNWs.(a) Distribution of the width of a batch of SiNWs was shown in columns. The anticipative width of the SiNWs is 60 nm, and 14 SiNW is counted in total. (b) Column plot of the conductance of different fabricated SiNWs. 16 SiNWs were measuredin total. The length and width of the SiNWs were 6 μm and 100 nm, respectively. p-type and boron-doped nanowires were used in the experiments.

Electrical characterization

The SiNW was characterized by using a Cascade probe station in conjunction with HP parameter analyzer (HP-4156), which controls gate potential and source/drain bias voltage. To verify the quality of the SiNW devices before real-time detection was performed, SiNWs were characterized. The transfer characteristic of an as-made SiNW device was measured, with varying gate and source/drain voltage, to evaluate the gate control capability. For simplicity, the silicon substrate was used as the back gate, and I/V measurements were implemented through the SiNW accordingly. Generally, in the measurement of the I_{DS}/V_{DS} curve, the source-drain current was measured for varying V_{GS} (0 to 20 V, $\Delta V = 2$ V for n-type device and 0 to -20 V, $\Delta V = -2$ V for p-type device) while sweeping the V_{DS} from -5 V to 5 V for n-type device and from 5V to -5 V for p-type device to test the performance of SiNW FET. Generally, in the measurement of the I_{DS}/V_{GS} curve, I_{DS} was measured at constant voltage ($V_{DS} = 1$ V for n-type device and $V_{DS} = -1$ V for p-type device) while sweeping the gate potential (V_{GS}) to determine the sensing parameters.

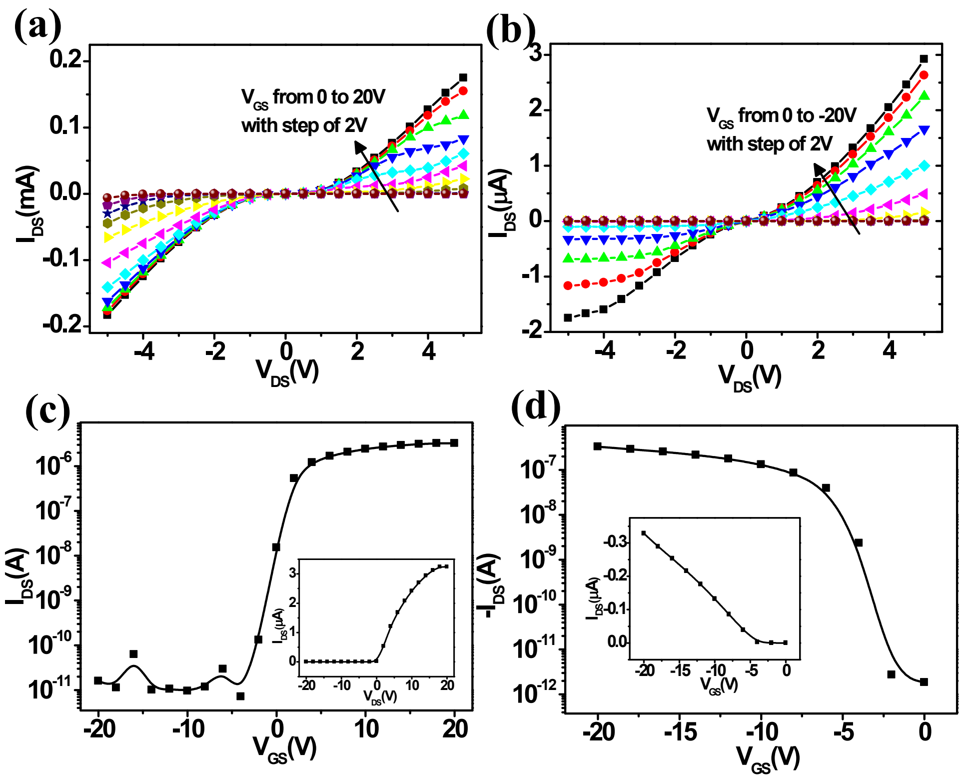

Figure S2 (a) (b) I_{DS}-V_{DS} curve for varying V_{GS} of (a) n- and (b) p-type SiNW devices. (c) I_{DS}-V_{GS} curve in log scale and linear scale (inset) for V_{DS} = 1 V of an n-type nanowire with length of 3 μm. (d) I_{DS}-V_{GS} curve in log scale and linear scale (inset) for V_{DS} = -1 V of a p-type nanowire with length of 3 μm.

The quality of manufactured SiNWs was verified by electrical characterization of both p- and n-type nanowire FET devices. As seen in Figure S1, the source-drain current (I_{DS}) versus source-drain voltage (V_{DS}) dependence for varying gate-source voltage (V_{GS}) and the I_{DS}-V_{GS} curve for a constant voltage were measured. The I_{DS}-V_{DS} curve of the SiNW shows saturation as the increase of V_{DS} which yielded typical n-type accumulation mode behavior (Figure S1a). Similarly, the transfer curve in Figure S1b yields typical gate modulation of p-type devices. The I_{DS}/V_{GS} curve for V_{DS} = 1 V (Figure S1c) of n-type device in log scale and linear scale shows excellent transfer characteristic, demonstrating the sensing parameter for practical biochemical applications. Similarly, Figure S1d shows I_{DS}/V_{GS} curve for p-type device and reveals the sensing parameter. The device shows almost no electronic hysteresis indicating a small density of trapped charges inside the structure. Electrical characterization verifies that this fabrication approach produces devices with high controllability and high quality.

Influence of Debye Screening on PSA sensing

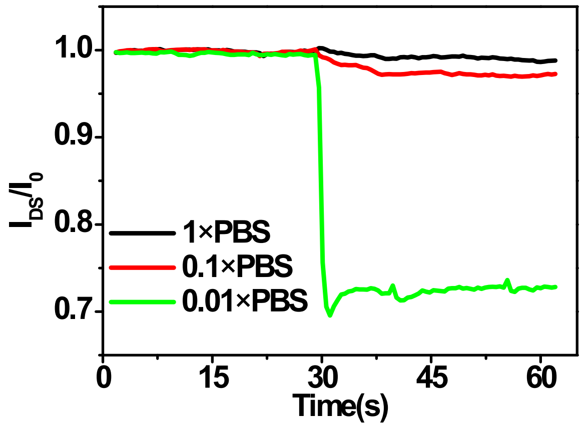

Figure S3 Response of anti-PSA functionalized SiNW biosensor to 100 fg/ml PSA in varying buffer ionic strengths.

The Debye screening length, the distance over which significant charge separation can take place, is an important parameter challenging device performance[1, 2]. A longer Debye length is expected to ensure fewer charges screened by using a dilute buffer solution with low electrolyte concentrations. Here, we demonstrate the effect of increasing buffer ionic strengths on device sensitivity for recognition by real time measurement of 100fg/ml PSA in 1× PBS, 0.1× PBS, and 0.01× PBS at pH 7.4 using a n-type device (Figure S2). A SiNW-FET device was functionalized with anti-PSA capture antibodies, and after establishing a baseline current in PBS 100fg/ml PSA was added in the same buffer. As shown in Figure 8, the addition of PSA in 0.01× PBS resulted in a sharp decrease in current, whereas addition of PSA in 1×PBS just gave rise to a slight current drop and a moderate current change was observed upon the injection of PSA in 0.1× PBS. When referencing the formula of the Debye screening length, the ionic strength of 0.01× PBS yields a Debye length of ~7.3 nm, thus the majority of the charge is unscreened at the SiNW-FET surface. A 10-fold increase in the ionic strength of the buffer (0.1× PBS, ~2.3nm) partially screens PSA's intrinsic charge, and a further 10-fold increase in buffer ionic strength (1× PBS, ~0.7 nm) effectively screens almost all of the PSA's charge, returning the current approximately to its baseline value.

References

1. E. Stern, R. Wagner, F. J. Sigworth, R. Breaker, T. M. Fahmy and M. A. Reed, Nano Letters, 2007, 7, 3405-3409.
2. A. Vacic, J. M. Criscione, N. K. Rajan, E. Stern, T. M. Fahmy and M. A. Reed, Journal of the American Chemical Society, 2011, 133, 13886-13889.