Thin Film Polycrystalline Silicon Nanowire Biosensors

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SUPPLEMENTARY INFORMATION

A. NANOWIRE DIMENSION CONTROL

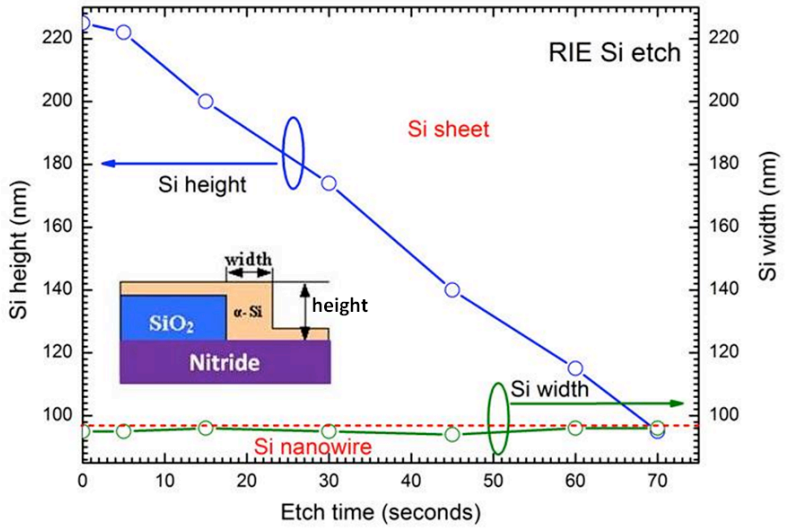

Figure S1: *α-Si spacer height and width as a function of etch time. The etch was done in a Plasmalab 80+ RIE system with 12 sccm O_2, 12 sccm SF_6 flow at 160 W RF input power, with a plate temperature of 20 ºC.*

The nanowire definition technique uses a non-lithographic spacer etch along the sidewall of a pre-fabricated oxide pillar structure (inset in Figure S1). The nanowire material (α-Si) is deposited by LPCVD and a special anisotropic dry etch process is used in an OIPT Plasmalab 80+ RIE system, with gas flows of 12 sccm O_2 and 12 sccm SF_6 at 160 W RF input power. Figure S1 shows the α-Si height and width as a function of etch time. An approximately

linear reduction of α-Si height can be observed with time, whereas no reduction of the α-Si width is seen. This indicates that this etch is highly anisotropic and hence gives excellent control of the nanowire width. The etch rate was measured to be 1.4 nm/sec. With this process, the nanowire height is primarily determined by the oxide pillar height and the nanowire width by the deposited α-Si thickness and the etch time. This nanowire fabrication method process has the advantage over bottom-up self-assembly that nanowires are created in defined locations on a substrate. Furthermore, it is a very low cost technology due to the use of mature top-down microelectronics technology (linewidths of >3 μm) and thin film display technology. This approach therefore offers a credible route to the mass production of disposable sensor kits on glass substrates.

B. NANOWIRE FUNCTIONALISATION

The polysilicon nanowires were converted into sensors for inflammatory biomarker detection by attaching antibodies to the nanowire surface. The functionalisation of the nanowire surface was performed in three steps.

(i) Nanowire silanisation

The surface was functionalised with 3-aminopropyltriethoxysilane (APTES) by oxygen-plasma cleaning the wires, then exposing the wires to APTES vapour overnight at 25 °C, followed by drying in an oven for 2 hours at 70 °C to complete the silane cross-polymerisation. During this process, the typical silanol group (-OH) terminating a bare silicon nanowire is substituted by an amino group ($-NH_2$), as shown in Figure S2a.

Figure S2b shows the nanowire current/voltage characteristics before and after APTES treatment, for measurements in a phosphate buffer solution with pH=7. The APTES treatment decreases the nanowire conductivity by a factor of 7-8 due to the presence of the amino group that is protonated at pH=7 (pK_a=9). Consistent with other reports on nanowire behaviour, for both bare and APTES functionalised nanowires, a change in the solution pH caused a change in the conductance (data not shown): a higher pH produced a higher nanowire conductance. The H^+ ions in the double layer at the nanowire surface increase the positive charge at the surface which decreases the local concentration of holes (carriers) in the p-type nanowire. The APTES treated nanowires showed real-time conductance changes with pH with an average sensitivity $(\Delta G/G)/(\Delta pH)$ of approximately 1.4%, similar to data reported for nanowires fabricated using other top-down processes (reference 11, main paper).

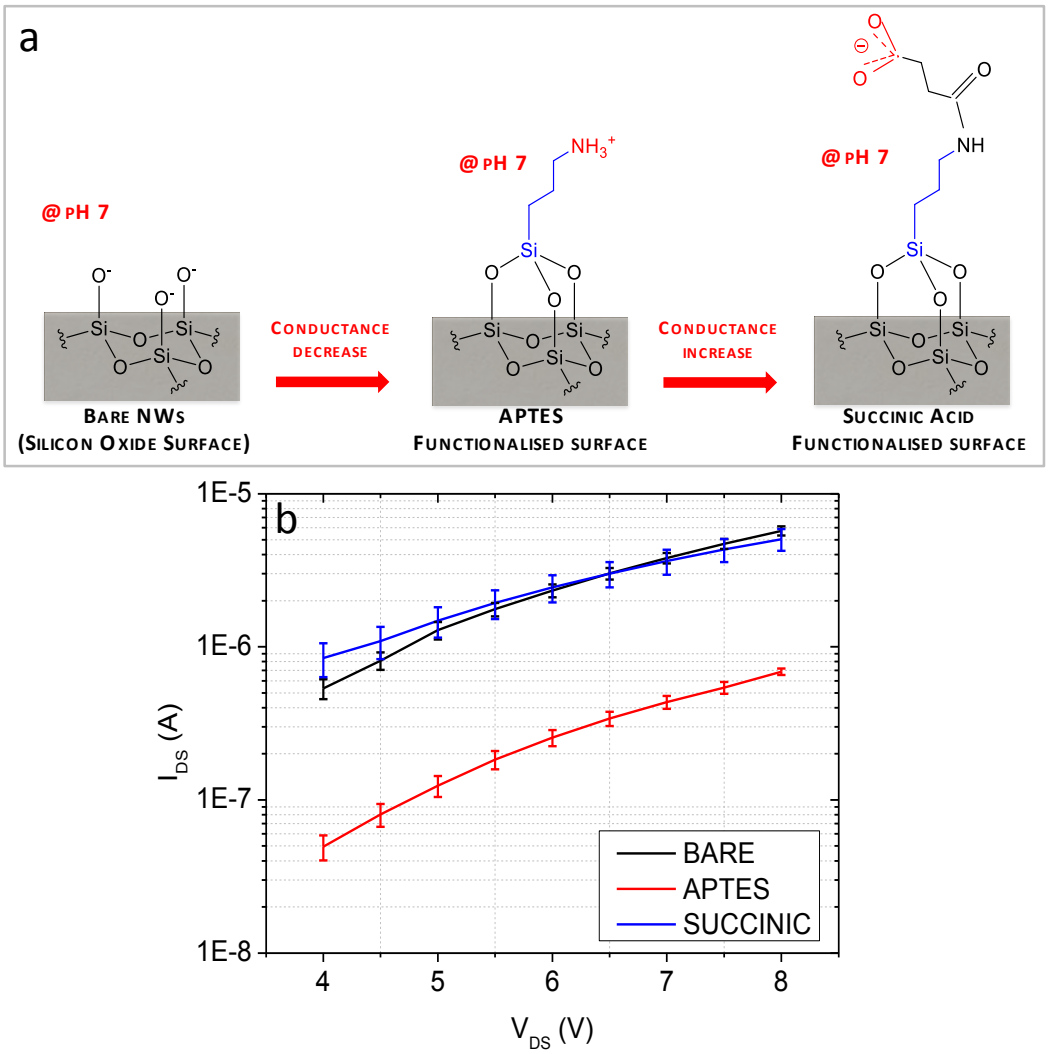

Figure S2: *Functionalisation of the nanowire surface; a) schematic illustration of functionalisation steps; b) nanowire current/voltage characteristics at a back-gate bias of -10 V before functionalisation (bare surface), after APTES treatment and after succinic acid treatment.*

(ii) Succinic acid coupling

The nanowire surface was activated with succinic acid, as shown in Figure S2a. This was done by exposing the nanowires for 2 hours at 25 °C to a solution of 1-ethyl-3-(3-dimethylaminopropyl)carbodiimide hydrochloride (EDC-HCl), N-hydroxysulfosuccinimide (Sulfo-NHS) and succinic acid in phosphate buffer with pH=8. The terminal group in this case is the carboxyl group (pK_a=5.0). Figure S2b shows the current/voltage characteristics of polysilicon nanowires after succinic acid treatment and indicates that the conductance is higher after succinic acid treatment than after APTES treatment. This is as expected, since the carboxyl group (pK_a=5) deprotonates at pH=7, increasing the conductivity.

(iii) Antibody coupling

The nanowires were functionalised with two different antibodies, anti-TNF-α (from ELISA kit human-TNF-α, Duoset R&D) or anti-IL-8 (ELISA kit human IL-8 CytoSet, Biosource Invitrogen), as shown in Figure 2c,d (main paper). The antibodies were covalently bound to the nanowires by first activating the surface by exposure to EDC-HCl and Sulfo-NHS for 2 hours at 25 ºC in a phosphate buffer with pH=6. Coupling of the antibodies was achieved by overnight incubation at 4 ºC in a phosphate buffer with pH=8. Finally, the nanowires were treated for 30 min with 200 mM ethanolamine to reduce non-specific binding.

IL-8 has a pI value of 9.1, which means that the molecule will be positively charged at pH=7. This implies that the conductivity of the nanowire should decrease with increasing molecular coverage, contrary to observation (Fig. 2c, main paper). However, De Vico *et al.* (reference 26, main paper) demonstrated for streptavidin and nucleocapsid that the overall charge of the protein can only be used to predict the nanowire response if the protein is positioned entirely within the Debye length. Our detection system uses a buffer with a Debye length of 11 nm. From crystal structures of an antibody and of IL-8 (PDB entry 1HZH and 1IKL) it is clear that the antibody-bound IL-8 cannot be positioned entirely within the Debye length. Moreover, the net charge on the antibody-antigen complex changes when the antigen binds. Consequently, the electrical signal change is not only due to the presence of the cytokine at the surface but also to the net charge of the antibody-antigen pair contained within the Debye length. These considerations can explain why we measure a change in the net charge at the nanowire surface in the presence of the IL-8 antibody-antigen pair as an increase in the conductivity of the nanowires. A similar argument applies to TNF-α (Fig. 2d, main paper).

C. NANOWIRE ELECTRICAL CHARACTERISATION

The electrical signal from the nanowires during cytokine binding (Figure 2c and 2d) was affected by a systematic drift. This drift was subtracted from an average of the slope of the signal, and the processed data are shown in Figure 2c and d (main paper). The detection of different concentrations of cytokines gives a series of conductance steps between different levels of constant conductance (steady states). The steady state corresponding to the different concentrations of detected cytokines was used to create the titration curves for the antibody-cytokine reaction (black squares in Figure 3a and 3b).