Reliable Si nanowire FETs defined by lithography for pH sensing and ultrasensitive detection of protein

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Recently, field effect transistors (FETs) based on nanowires (NW) and nanotubes are emerging as powerful, general platforms for ultrasensitive and label free detection of a wide-range of biochemical species, presenting a new paradigm for biosensing. For example, label-free detection of protein at 2-10 femtomolar (fM) concentration has been demonstrated by both chemically synthesized nanowires [1] and lithographically defined nanowire FETs [2]. However, for this type of nano-sensor to eventually be useful for *in vitro* diagnostics using clinical samples, important reliability issues must be addressed which have been largely overlooked. In address this issue, we employ a set of techniques to achieve highly reliable NW-FETs for ultrahigh sensitivity in biosensing.

In this work, we present our recent work on the fabrication of Si nanowire FETs defined by lithography and selective detection of proteins at concentrations of 1fM or less. In our process, SiNWs were defined by e-beam lithography in hydrogen silses quioxane (HSQ) resist, followed by a unique two-step Si etch process. The two-step etching is designed to improve the process reliability and controllability by avoiding the degradation of buried oxide during the Si etch. SiNW FETs of 20-100 nm in width, 10-30 nm in thickness, 5-90 μm in length have been successfully fabricated on Si on insulator (SOI) substrates. Later the devices were undergone thermal oxidation followed by annealing to stabilize the fixed charges and to reduce the surface dangling bonds. Silicon nitride was sputtered to passivate metal contacts, to avoid the electrochemical reaction. These SiNW FET devices have shown excellent scalability (Fig. 1a), high uniformity and consistency (Fig. 1b) and high performance (sub-threshold slope ~80 mV/dec, On/Off ratio>10^7). The good device stability under dry and wet (salty solutions) conditions was demonstrated, showing surprisingly better performance in salty solution than in ambient condition (Fig. 1c). These devices were then functionalized using silane based surface chemistry for biosensing experiments. Reliable sensing of pH with excellent linearity (Fig. 2a) and selective detection of 1fM protein: bovine serum albumin (BSA) with anti-BSA coated SiNW FETs (Fig. 2b) has been achieved. We will report systematic study of the device reliability and biosensing in the paper.

[1] Patolsky, F., Zheng, G and Lieber, C.M, *Nat.Protocols* 1, 1711-1724 (2006)
[2] Stern, E., et al. *Nature* 445, 519-522 (2007)

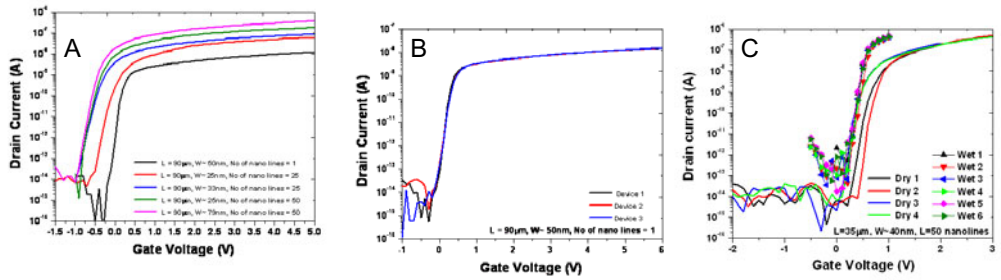

Fig. 1: I-V characteristics of Si nanowire FETs made by e-beam lithography: A) Five SiNW devices with different widths showing good scalability; B) Consistency of three different SiNW FETs with same dimensions (W=50 nm); C) Stability of a single SiNW FET during repeated tests in air (dry) and in salty buffer solution of pH=7.4 (wet).

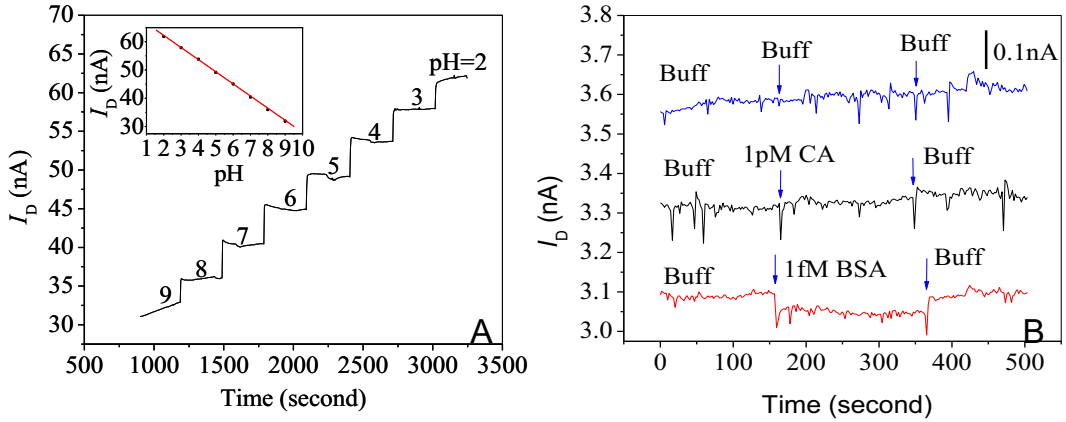

Fig. 2: A) pH sensing with a n-channel SiNW FET device treated with APTES monolayers. The inset is the correlation between drain current and solution pH, showing nice linearity. B) Ultrasensitive protein sensing at 1fM level using anti-BSA modified SiNW FETs. Injection of buffer without proteins would not change the nanowire current (blue curves); 1pM carbonate anhydrase that has similar charge as BSA does not change current (black curve), indicating no current change due to non-specific binding or adsorption at this concentration. 1fM BSA protein yields stable current change (red curve).