SOI based Nanowire Field-Effect Transistor Biosensors with Diamond-Like Carbon Modification

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Silicon Nanowire Field-Effect Transistors (NW FETs) are widely considered as a promising technology for next-generation biosensors due to their advantages of low-cost fabrication, rapid response time and label-free detection. However, they often encounter difficulties in preserving long-term stability and sensitivity when operating in complex biological fluids [1]. In this work, diamond-like carbon (DLC) films with nanometer-scale thicknesses, ranging from 1 nm to 14 nm, were introduced to modify the surface characteristics of low-defect-density silicon dioxide (SiO_2) layers, aiming to enhance their long-term stability. The capacitance–voltage (C–V) characteristics and stability time-domain measurements of structures with various DLC thicknesses were systematically examined to estimate the evolution of the flat-band voltage (V_{fb}) during prolonged operation in different biological liquid environments (Fig.1). The experimental results indicate that incorporating a DLC layer enables the system to reach equilibrium more rapidly whilst improving electronic performance in liquid. Owing to its highly dense structure, DLC exhibits excellent chemical constancy over extended periods, which is essential for maintaining biosensor functionality in physiologically relevant solutions [2]. Furter impedance spectroscopy measurements reveal that the improved stability of DLC-covered structures is determined by suppressed ion penetration and reduced diffusion transport through the high-quality diamond-like layer (Fig.2). As a result, the optimized structures demonstrate enhanced long-term performance, including shorter V_{fb} stabilization time, better stability compared with bare SiO_2-covered ones, and optimized sensitivity in various liquid environments. Experiments conducted in solutions with varying pH concentrations confirm that DLC-modified structures are well applicable for biological signal detection and monitoring.

To verify the functionality of DLC-covered structures for direct biosensing, silicon NW FETs with a DLC protective layer were fabricated using a complementary metal–oxide–semiconductor (CMOS)-compatible process [3] and functionalized with C-reactive protein (CRP) aptamers. Biomedical studies of CRP solutions show that the DLC-protected NW FET devices achieve a sensitivity of approximately 100 mV per the decade concentration change (Fig.3), demonstrating their functionality as stable highly sensitive biosensors. This study provides valuable insight into the design of dielectric-layer-based structures and the surface modification of SiO_2 at liquid–solid interfaces in FET biosensing systems. Moreover, the results highlight the importance of DLC protective layer engineering for the development of highly stable SOI-based device structures, including reliable field-effect transistor (FET) biosensors.

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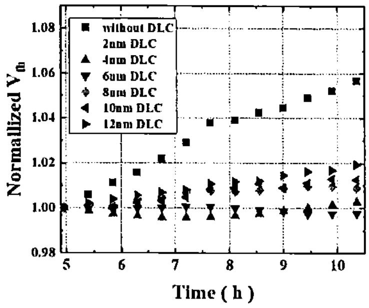

Figure 1. Normalized V_{th} time traces for the reference sample, covered with SiO_2 (black points) in comparison with DLC-covered samples of different thicknesses: 2 nm, 4 nm, 6 nm, 8 nm, 10 nm, 12nm.

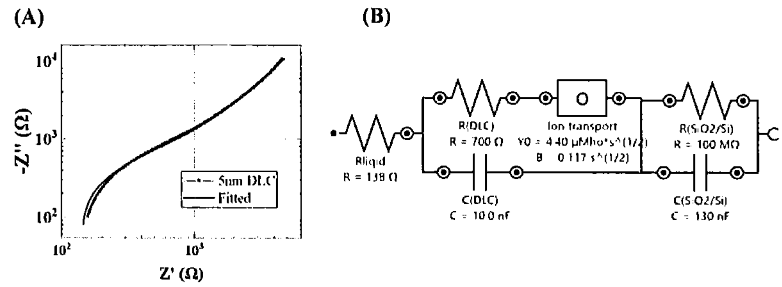

Figure 2. (A) Nyquist curve for the 5 nm DLC-covered sample; (B) Equivalent circuit diagram for the 5 nm DLC-covered sample.

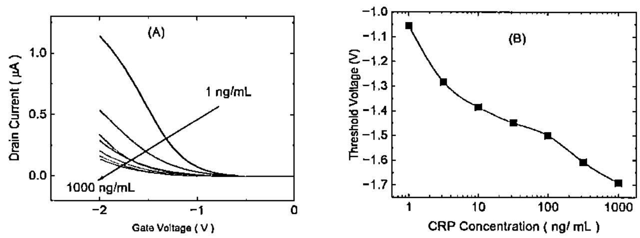

Figure 3. (A) Typical transfer characteristics of a liquid-gated Si NW FET biosensor studied with increasing CRP-containing biological solutions of different concentrations (ng/mL): 1, 3, 10, 32, 100, 316, 1000; (B) Threshold voltage, extracted using data of Figure 3A, as a function of CRP concentration.

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