

Unchallenging the Debye Challenge in Field-Effect Biosensors

Gil Shalev^{1,2}

¹ School of Electrical Engineering, Ben-Gurion University of the Negev, POB 653, Beer-Sheva 8410501 Israel

² The Ilse-Katz Institute for Nanoscale Science and Technology, Ben-Gurion University of the Negev, POB 653, Beer-Sheva 8410501, Israel
glshalev@bgu.ac.il

Summary:

The Meta-Nano-Channel (MNC) bioFET performs specific, label-free, and real-time quantitative sensing of C-reactive protein (CRP)—a key biomarker for inflammation and tissue damage. This sensor operates using tiny, 0.5 μL unprocessed samples of blood and sweat, successfully overcoming significant screening effects in environments with Debye lengths of 0.7 nm and 2.3 nm, respectively

Keywords: sweat, blood, bioFET, antigen-antibody, Debye length

Background, Motivation and Objective

While Biological field-effect transistors (bioFETs) are highly promising for the future of point-of-care and home diagnostics, they face a significant hurdle: Debye screening. In unprocessed physiological fluids, high ionic concentrations result in a Debye length of less than 1 nm, theoretically making bioFETs "blind" to any molecular interactions occurring further from the sensor surface [1] [2]. Traditionally, this limitation was thought to rule out the use of antibody-based receptors, as their large physical dimensions (typically 10–15 nm) would place the binding event far beyond the sensitive zone. This has sparked an intensive search for smaller, "short" receptors to bring the target interaction closer to the surface. However, recent findings suggest this may not be entirely necessary; observations of adsorbed antibodies show they often tilt sharply toward the surface, allowing binding events to occur much closer to the sensing area than previously expected.

Description of the New Method or System

This study utilizes the Meta-Nano-Channel (MNC) bioFET, a platform specifically engineered to overcome traditional interface challenges such as molecular gating and solution gating. The MNC bioFET's unique multi-gate architecture allows for the excitation of various conducting channels that differ in size, shape, and spatial orientation. This diversity ensures that each channel is uniquely coupled to the potential variations at the sensing area, which are

often non-uniform due to the irregular distribution of molecular interactions. Furthermore, the device enables the switching of these channels between off and on states while preserving the electrochemical equilibrium of the solution and surface-bound biomolecules—a critical factor for accurate real-time measurements.

Results

The device achieves a limit of detection (LoD) of 100 fg/mL in blood and 10 fg/mL in sweat [3]. Across both mediums, the sensor demonstrates a remarkably wide dynamic range of eight orders of magnitude, characterized by exceptional sensitivity and high linearity. This study presents the first direct bioFET measurement of antibody-antigen interactions in raw physiological samples, achieved without any preprocessing or washing steps. The findings challenge the long-held "Debye screening" dogma within the bioFET community. The standard assumption—that surface-bound antibodies stand in a rigid, upright ("Fab-up") position—has led many to prematurely dismiss the possibility of sensing in physiological fluids. This work argues that such a view is an oversimplification of the complex sensing interface. By demonstrating exceptional performance in environments with physiological Debye lengths, this study proves that target molecules must interact in much closer proximity to the surface than previously thought, perhaps even involving direct interaction with the surface chemistry itself. Consequently, this research reaffirms that antibodies, with their superior specificity, remain the gold standard for bioFET receptors.

References

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