Field-effect transistors for rapid on-site disease diagnostics

A. Tarasov,[1,2] M.-Y. Tsai,[1] D. W. Gray,[3] N. Shields,[3] N. Creedon,[4] A. Montrose,[4] P. Lovera,[4] E. M. Flynn,[1] C. A. Joiner,[1] R. C. Taylor,[1] P. M. Campbell,[1] A. O'Riordan,[4] M. H. Mooney,[3] and E. M. Vogel[1]

[1]*School of Materials Science and Engineering, Georgia Institute of Technology, Atlanta, GA 30332, USA*
[2]*BioMed X Innovation Center, Im Neuenheimer Feld 515, 69120 Heidelberg, Germany*
[3]*Institute for Global Food Security, School of Biological Sciences, Queen's University Belfast, Belfast, Northern Ireland, BT9 5AG, United Kingdom*
[4]*Nanotechnology Group, Tyndall National Institute, University College Cork, Cork, T12R5CP, Ireland*

tarasov@bio.mx, alexey.tarasov@mse.gatech.edu

Abstract

Field-effect transistors (FETs) based on large-area graphene [1, 2] and other two-dimensional (2D) materials such as MoS_2 [3, 4] and WSe_2 [5] can potentially be used as highly sensitive, low-cost and flexible biosensors in future point-of-care (POC) diagnostic devices. However, there have been few attempts to use these devices for quantifying molecular interactions and to compare their performance to established sensor technology. Here, gold-coated graphene FETs are used to measure the binding affinity of a specific protein–antibody interaction. [6] Having a gold surface gives access to well-known thiol chemistry for the self-assembly of linker molecules. The results are compared with potentiometric silicon-based extended-gate sensors and a surface plasmon resonance system. The estimated dissociation constants are in excellent agreement for all sensor types as long as the active surfaces are the same (gold).

Furthermore, using the model pathogen Bovine Herpes Virus-1 (BHV-1) this study employs an extended-gate field-effect transistor (FET) for direct potentiometric serological diagnosis.[7] BHV-1 is a major viral pathogen of Bovine Respiratory Disease (BRD), the leading cause of economic loss ($2 billion annually in the US only) to the cattle and dairy industry. To demonstrate the sensor capabilities as a diagnostic tool, BHV-1 viral protein gE was expressed and immobilized on the sensor surface to serve as a capture antigen for a BHV-1-specific antibody (anti-gE), produced in cattle in response to viral infection. The gE-coated immunosensor was shown to be highly sensitive and selective to anti-gE present in commercially available anti-BHV-1 antiserum and in real serum samples from cattle with results being in excellent agreement with Surface Plasmon Resonance (SPR) and ELISA. The FET sensor is significantly faster than ELISA (<10 min), a crucial factor for successful disease intervention. This sensor technology is versatile, amenable to multiplexing, easily integrated to POC devices, and has the potential to impact a wide range of human and animal diseases.

Finally, tunneling field-effect transistors based on vertical stacks (heterostructures) of 2D materials will be discussed.[8] These band-to-band tunneling devices have a fundamentally different working principle, and can overcome the thermionic turn-on limit (or subthreshold swing) of conventional field-effect transistors,[9] which can potentially enable fast und ultra-sensitive biosensors.

References

[1] W. Fu, C. Nef, O. Knopfmacher, A. Tarasov, M. Weiss, M. Calame and C. Schönenberger *Nano Lett.* **11** (2011) 3597-600

[2] W. Fu, C. Nef, A. Tarasov, M. Wipf, R. L. Stoop, O. Knopfmacher, M. Weiss, M. Calame and C. Schoenenberger *Nanoscale* **5** (2013) 12104-10

[3] A. Tarasov, P. M. Campbell, M.-Y. Tsai, Z. R. Hesabi, J. Feirer, S. Graham, W. J. Ready and E. M. Vogel *Adv. Funct. Mater.* **24** (2014) 6389-400

[4] A. Tarasov, S. Zhang, M.-Y. Tsai, P. M. Campbell, S. Graham, S. Barlow, S. R. Marder and E. M. Vogel *Adv. Mater.* **27** (2015) 1175-81

[5] P. M. Campbell, A. Tarasov, C. A. Joiner, M.-Y. Tsai, G. Pavlidis, S. Graham, W. J. Ready and E. M. Vogel *Nanoscale* **8** (2016) 2268-76

[6] A. Tarasov, M.-Y. Tsai, E. M. Flynn, C. A. Joiner, R. C. Taylor and E. M. Vogel *2D Mater.* **2** (2015) 044008

[7] A. Tarasov, D. W. Gray, M.-Y. Tsai, N. Shields, N. Creedon, A. Montrose, P. Lovera, A. O'Riordan, M. H. Mooney and E. M. Vogel *Biosens. Bioelectron.* **79** (2016) 669–78

[8] P. M. Campbell, A. Tarasov, C. A. Joiner, W. J. Ready and E. M. Vogel *ACS Nano* **9** (2015) 5000–8

[9] D. Sarkar, X. Xie, W. Liu, W. Cao, J. Kang, Y. Gong, S. Kraemer, P. M. Ajayan and K. Banerjee *Nature* **526** (2015) 91-5