

Toward Rapid Water Quality Monitoring: QCM-Guided Bio-interface Engineering of Graphene SGFET Biosensors for *Escherichia coli* Detection

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Summary:

This work presents a QCM-guided biointerface engineering strategy for graphene SGFET biosensors dedicated to rapid *Escherichia coli* detection in water. The bio-functionalization process is optimized using Quartz Crystal Microbalance to ensure controlled antibody immobilization while preserving graphene electrical properties. The optimized protocol is successfully transferred to SGFET devices, enabling concentration-dependent Dirac point shifts upon bacterial exposure.

Keywords: graphene biosensor, SGFET, *Escherichia coli*, QCM, water quality

Title

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Introduction

Microbial contamination of coastal waters represents a major public health and socio-economic challenge for coastal territory management. It directly impacts both the sanitary safety of shellfish production and the opening of recreational bathing areas, which rely on monitoring bacterial indicators such as *Escherichia coli* [1,2]. Increasing contamination events associated with human activities and climate-driven environmental variability have strengthened the demand from public authorities and economic stakeholders for rapid microbial risk assessment tools. Current surveillance frameworks, based on laboratory culture analyses requiring extended processing times, limit monitoring frequency and delay decision-making.

In addition, graphene has emerged as an attractive material for biosensing applications due to its atomically thin structure, high surface-to-volume ratio, and accessible π -electron system. These properties make graphene well suited for surface-dominated transduction schemes, including field-effect transistors [3,4], and mass-sensitive platforms such as quartz crystal microbalance (QCM) devices [5]. In this context, this

work aims at functionalizing graphene for *E. coli* detection in water.

Methods

In this work, we developed a non-covalent bio-interface engineering strategy based on a novel tripodal structure that enable robust and stable antibody immobilization (see Fig. 1). The bio-functionalization was first optimized using QCM to ensure efficiency and reproducibility prior to device integration. The optimized protocol was then transferred to graphene SGFET devices and used for bacterial detection.

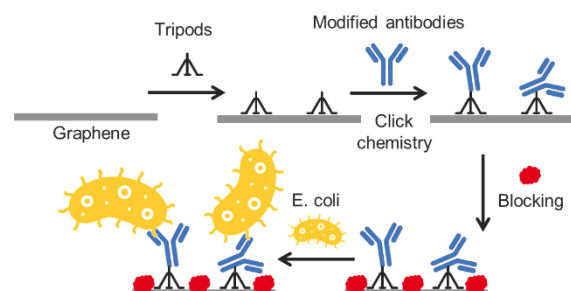


Fig. 1. Schematic representation of the graphene biofunctionalization steps.

Results

The biofunctionalization strategy was validated using QCM where each functionalization step induced reproducible and well-defined frequency shifts (see Fig. 2) confirming successful and stable layer-by-layer assembly. In particular, no

antibody desorption was observed, and the bacterial binding step induces a significant frequency shift, proportional to bacterial concentration in sample. The initial deposition of the tripodal linker on graphene, performed prior to QCM measurements, was independently confirmed by Raman spectroscopy.

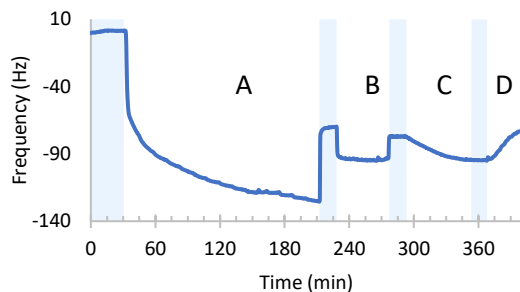


Fig. 2. QCM frequency response (third harmonic) during biofunctionalization and detection steps: (A) modified antibody immobilization, (B) blocking, (C) *E. coli* exposure (2.5×10^7 CFU/mL), and (D) water rinsing. Intermediate blue regions correspond to buffer rinsing steps.

The optimized biofunctionalization protocol was successfully transferred to graphene SGFETs. Upon exposure solutions of *E. coli* in aqueous media, systematic Dirac point shifts were observed, demonstrating reliable bacterial detection (see Fig. 3).

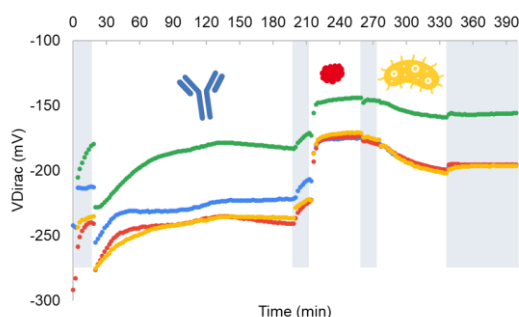


Fig. 3. Dirac point tension during functionalization and exposure to 10^7 CFU/mL solution of *E. coli* on 4 SGFET replicates. Intermediate blue regions correspond to buffer rinsing steps.

Conclusion

This work demonstrates an effective graphene biofunctionalization strategy enabling specific bacterial capture while preserving its electronic properties. The successful transfer of a QCM-optimized protocol to SGFET devices highlights the robustness and reproducibility of the approach. The observed electrical responses upon *E. coli* exposure show promising potential toward bacterial detection, paving the way for the development of rapid graphene-based biosensors for water quality monitoring.

References

- [1] R. F. Vaccaro, M. P. Briggs, C. L. Carey, B. H. Ketchum, Viability of *Escherichia coli* in Sea Water, *American Journal of Public Health and the Nation's Health* 40, 1257–1266 (1950)
- [2] F. Petronella, D. De Biase, F. Zaccagnini, V. Verina, S.-I. Lim, K.-U. Jeong, S. Miglietta, V. Petrozza, V. Scognamiglio, N. P. Godman, D. R. Evans, M. McConney, L. De Sio, Label-Free and Reusable Antibody-Functionalized Gold Nanorod Arrays for the Rapid Detection of *Escherichia coli* Cells in a Water Dispersion, *Environmental Science: Nano* 9, 3343–3360 (2022); doi: 10.1039/D2EN00425K
- [3] A. Béraud, M. Sauvage, C. M. Bazán, M. Tie, A. Bencherif, D. Bouilly, Graphene Field-Effect Transistors as Bioanalytical Sensors: Design, Operation and Performance, *Analyst* 146, 403–428 (2021); doi: 10.1039/D0AN01661F
- [4] S. K. Krishnan, N. Nataraj, M. Meyyappan, U. Pal, Graphene-Based Field-Effect Transistors in Biosensing and Neural Interfacing Applications: Recent Advances and Prospects, *Analytical Chemistry* 95, 2590–2622 (2023); doi: 10.1021/acs.analchem.2c03399
- [5] P. Hampitak, et al., A Point-of-Care Immunosensor Based on a Quartz Crystal Microbalance with Graphene Biointerface for Antibody Assay, *ACS Sensors* 5, 3520–3532 (2020); doi: 10.1021/acssensors.0c0164