



Guide

Enhancing precision at the nanoscale

How advanced nanomaterials drive higher
sensitivity in electrochemical biosensors

Introduction

Electrochemical biosensors have the potential to greatly improve diagnostics by enabling rapid, quantitative detection of biomarkers at ultra-low concentrations.

Sensitivity is the critical performance factor, determining whether devices can detect disease indicators or contaminants at the femtogram-per-millilitre level in complex samples. Achieving this demands electrode materials that maximise analyte capture, accelerate electron transfer and maintain stable performance in challenging real-world matrices.

Nanomaterials such as graphene and carbon nanotubes offer these advantages through their vast surface areas and exceptional conductivity. They do, however, have their own challenges of scalability and reproducibility that stand in the way of commercial integration. Fortunately, recent advances in nanomaterials have combined research-grade sensitivity with the scalability and reproducibility required for commercial use. These innovations are moving biosensors beyond the limits of traditional noble metals, closing the gap between laboratory performance and industrial deployment.

The importance of sensitivity in biosensing

High sensitivity in electrochemical biosensors is the key metric for the detection of biomarkers at extremely low concentrations, sometimes down to femtogram-per-millilitre. This is what provides the capability of early diagnosis and reduced sample preparation to greatly benefit applications like POC diagnostics. Improving sensitivity also helps reduce false negatives, enables faster readings and broadens point-of-care applicability.

Here are some real-world examples:

- Early-stage disease detection relies on detecting biomarkers present at <10 pg/mL
- Food safety monitoring requires identifying contaminants before they reach harmful levels
- Environmental testing demands quantification of trace pollutants in complex matrices

Where nanomaterials come into play to drive sensitivity

Achieving ultra-low detection limits and rapid response times in electrochemical biosensors hinges on the properties of the electrode material itself. This is where nanomaterials play a key role by offering a suite of structural and electronic advantages that directly enhance every stage of the sensing process. Examples include **graphene**, **carbon nanotubes** (CNTs) and **noble metal nanostructures**.

Surface area to maximise analyte capture

Whether in the form of flat graphene sheets, nanotubes or metal nanoparticles, the central advantage of nanomaterials is their large surface-to-volume ratio. This directly increases the number of available binding sites for capture molecules, raising the probability that an analyte molecule in solution will encounter its target on the sensor surface.

Improving electron transfer kinetics

High conductivity in graphene, CNTs and noble metals supports faster electron transfer at the electrode-electrolyte interface. In impedance-based sensors, this results in larger, more easily measurable changes in charge transfer resistance upon analyte binding. In voltammetric sensors, it can translate into higher faradaic currents for a given analyte concentration.

Lowering detection limits

The combined effects of greater analyte binding density and efficient charge transport mean that smaller amounts of bound analyte can produce detectable signal changes. Traditional graphene and CNT-based sensors have achieved detection limits in the low picogram-per-millilitre range for various biomarkers whereas noble metal-based electrodes have similarly pushed sensitivities far beyond those possible with conventional bulk electrodes.

The barriers in the way of traditional nanomaterials in electrochemical biosensors

For all their technical strengths, the nanomaterials of graphene and noble metals come with their own limitations when viewed through the lens of commercial biosensor development.

- **Scalability** remains a major hurdle. Producing high-quality CVD graphene requires specialised infrastructure, and transferring the delicate monolayers onto device substrates without introducing defects is a non-trivial engineering problem. Graphene oxide and rGO are easier to manufacture in bulk, but batch-to-batch variations in flake size and defect density make it difficult to guarantee consistent sensor performance. CNT production suffers from similar variability in morphology and purity, whereas noble metal nanostructures are costly and subject to geopolitical supply risks.
- **Reproducibility** is another major challenge. For regulated diagnostics, electrode materials must deliver consistent electrochemical properties across thousands or millions of units. In nanomaterials derived from processes with innate variability involved, maintaining tight performance tolerances is difficult.
- Finally, **sustainability** is becoming a defining concern. Noble metals carry environmental burdens in extraction and processing, whilst some graphene synthesis methods rely on toxic reagents or high-energy steps. For biosensor manufacturers under increasing pressure to meet environmental, social, and governance (ESG) criteria, these factors can weigh heavily against otherwise attractive materials.

How advanced carbon nanomaterials are changing sensitivity and scalability at the same time

The shortcomings of traditional graphene, CNTs and noble metals have created a clear demand for electrode materials that combine the performance benefits of nanocarbon systems with the scalability, reproducibility and sustainability required for commercial biosensing.

Fortunately, advances in material science have delivered a new class of advanced carbon nanomaterials designed to meet these demands. These materials are engineered from the ground up for high-volume manufacture and stable electrochemical performance whilst preserving the high surface area, conductivity and functionalisation flexibility that make nanocarbons so effective.

How these advanced nanomaterials are overcoming scalability

Advanced carbon nanomaterials are engineered with manufacturing in mind, ensuring they can move from laboratory demonstrations to high-volume production without a drop in performance. Key advantages include:

- 🟠 **Direct-on-substrate synthesis:** Avoids transfer steps, preventing defects and contamination.
- 🟠 **Batch-to-batch uniformity:** Tightly controlled pore size, defect density and surface chemistry for reproducible electrochemical behaviour.
- 🟠 **Lower production costs:** No need for precious metal catalysts, high-vacuum systems or extreme temperatures.
- 🟠 **Sustainable fabrication:** Reduced energy consumption and free of toxic chemical oxidants and environmentally damaging raw materials.

This balance of manufacturability and material quality makes them inherently suited for regulated, large-scale biosensor deployment.

And how they're driving higher sensitivity at the same time

Beyond manufacturing strengths, these materials also match or even outperform traditional nanomaterials in detection performance thanks to their engineered structure and chemistry. Ultra-low detection limits like femtogram-per-millilitre sensitivity are achievable even in complex fluids like whole blood or saliva, along with a list of other benefits/features.

- 🟠 **Three-dimensional porous architecture:** Massively increases accessible surface area for bioreceptor immobilisation.
- 🟠 **Multiplexing potential:** Different regions can be functionalised for simultaneous detection of multiple biomarkers.
- 🟠 **Rapid electron transfer:** Conductive framework ensures binding events in the material still produce strong, immediate signals.

By combining these sensitivity benefits with industrial viability, advanced carbon nanomaterials close the gap between research-grade and commercially-ready biosensors.

Closing the gap between sensitivity and scalability with **Gii**

Advanced carbon nanomaterials are transforming electrochemical biosensing by combining ultra-high sensitivity with the scalability and reproducibility required for real-world deployment, closing the gap between the performance achieved in research labs and what's needed in commercial manufacturing.

Gii is this material, engineered with direct-on-substrate synthesis for defect-free production and a three-dimensional porous structure that boosts surface area and achieves femtogram-per-millilitre detection. This makes it a reliable and sustainable choice for high-performance biosensors at scale and is one of the only products that has multianalyte capabilities.

If you're looking to take your biosensor development to the next level, our team can help you leverage Gii's unique advantages from concept through to market.

Get in touch today to see how it can power your next innovation.





Choosing the right material for your biosensing application

With its unique combination of performance and scalability, Gii enables the development of next-generation multi-analyte biosensors that are not only technically sophisticated but also commercially viable. To find out more about this innovative material, contact a member of our team today.

[Get in touch today](#)

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