



Comparing Biosensor Materials

Nanomaterials vs. Graphene vs. Noble Metals

Introduction

Biosensors play a crucial role in modern diagnostics and industrial applications, offering precise, real-time detection of biological markers with ever-increasing efficiency.

As biosensing technology continues to evolve, material selection has become a defining factor in determining sensor performance. Engineers need to carefully navigate the trade-offs between different materials to optimise their sensors for specific applications, whether in medical diagnostics, environmental monitoring or industrial quality control.

Among the various materials available, noble metals such as gold and platinum have long been the industry standard due to their unmatched electrochemical stability and conductivity. These materials have been used in biosensors for decades, but their high cost and limited flexibility pose challenges, particularly in emerging applications requiring miniaturisation and wearable formats. Emerging alternatives, including graphene and other advanced nanomaterials, are pushing the boundaries of what biosensors can achieve. But while graphene offers the potential for high conductivity and surface area, it unfortunately suffers from fabrication difficulties and batch-to-batch reproducibility.

For engineers to make an educated and informed decision on biosensor material, they need a clear understanding of the key performance metrics of each, including sensitivity, cost, scalability and biocompatibility.

An introduction to each biosensing material

Noble metals

Gold and platinum have long been the standard for biosensing applications due to their electrochemical stability and conductivity. They enable highly sensitive detection of biomolecules, making them ideal for applications such as enzyme-based glucose sensors and immunosensors. However, these materials are often susceptible to surface fouling and are costly, making large scale production difficult.

🟡 **Strengths:** High conductivity, chemical stability, established methodologies

🟡 **Limitations:** Susceptible to surface fouling, expensive, limited adaptability for flexible sensors

Graphene

Graphene, a single layer of carbon atoms arranged in a hexagonal lattice, offers great electrical conductivity and a high surface area, making it a strong contender for biosensing applications. Its 2D structure allows for rapid electron transfer, which is particularly beneficial for electrochemical biosensors. That said, graphene suffers from batch-to-batch variability and is challenging to fabricate.

🟡 **Strengths:** High surface-to-volume ratio, good conductivity

🟡 **Limitations:** Oxidises easily, inconsistent batches, needs functionalisation for biomolecule use

Other nanomaterials

Nanomaterials, such as carbon nanotubes (CNTs), quantum dots and metal nanoparticles, provide additional avenues for biosensor development. They offer tunable properties, including enhanced fluorescence (quantum dots) and targeted surface chemistry (nanoparticles), which allow for multi-modal sensing capabilities. But like noble metals, these materials are often expensive to manufacture at scale and also present potential toxicity concerns.

🟡 **Strengths:** Diverse functional properties, enhanced signalling, tunable optics and electronics.

🟡 **Limitations:** Stability concerns, potential cytotoxicity, often expensive to manufacture at scale

Cost considerations Balancing performance with affordability

Cost is a crucial factor in biosensor development, particularly for point-of-care diagnostics and large-scale deployment.

Noble metals

Gold and platinum are among the most expensive materials and also face fluctuating costs based on geo-political events. As a result, this can significantly increase the cost of biosensor fabrication.

Graphene

While graphene is relatively affordable, high-quality synthesis methods such as chemical vapour deposition (CVD) are costly, making mass production challenging.

Nanomaterials

Costs vary widely depending on the type. Quantum dots and some nanoparticles require complex synthesis, whereas carbon-based nanomaterials, like CNTs, can be more economical but face production consistency issues.

Scalability Bringing biosensors to market

For biosensor technology to move beyond research labs and into widespread commercial use, scalability is paramount. The material choice directly affects the ease of manufacturing, reproducibility, and cost-effectiveness at scale. Biosensors must be produced in large volumes with consistent quality while maintaining their performance in real-world applications.

Noble metals

The established use of noble metals in biosensors means that existing fabrication methods, such as screen-printing and electrodeposition, allow for relatively consistent production. However, the high material costs and supply chain limitations pose scalability challenges.

Graphene

Whilst CVD-fabricated graphene offers high conductivity for biosensors, its batch-to-batch reproducibility remains a major hurdle. Variability in growth conditions and the transfer process lead to inconsistencies in layer quality, defect density and electrochemical performance, limiting its scalability.

Nanomaterials

Nanomaterials vary in scalability potential. Carbon-based nanomaterials, such as CNTs and graphene derivatives, offer promising avenues for flexible and wearable biosensors. However, metal nanoparticles and quantum dots require precise synthesis techniques, limiting their scalability for commercial applications.

Biocompatibility Ensuring safe and effective biosensing

For biosensors intended for medical diagnostics, biocompatibility is a critical factor for the safety of patients and to reduce interference from biological elements during assays.

Noble metals

Generally biocompatible, particularly gold, which is widely used in implantable and wearable biosensors. However, long-term stability and surface degradation need to be considered.

Graphene

Shows promise due to its chemical versatility, but concerns over oxidative stress and potential cytotoxicity require further investigation.

Nanomaterials

The biocompatibility of nanomaterials varies. Some nanomaterials exhibit cytotoxicity, particularly at high concentrations, whereas CNTs have been scrutinised for their potential to cause inflammation in biological tissues.

Biofouling Ensuring long-term stability

Biofouling occurs when biomolecules accumulate on sensor surfaces, blocking active sites and reducing sensitivity and specificity. In biosensing, this can lead to signal degradation, false readings and decreased long-term performance, especially in complex biological fluids.

Noble metals

Gold and platinum are severely prone to biofouling, requiring antifouling coatings and other preventative measures to maintain signal integrity.

Graphene

Biofouling is a key challenge for graphene as its hydrophobicity leads to significant protein deposition.

Nanomaterials

Carbon nanotubes and metal nanoparticles experience significant fouling, often needing polymer or chemical coatings for stability.

The future of electrochemical biosensors through a novel nanomaterial

Traditional biosensing materials suffer in at least one key area when it comes to mass-scale production. However, emerging nanomaterials like Gii have demonstrated exceptional promise in electrochemical biosensing in each of these areas. With its ability to address the limitations of traditional biosensor materials, Gii is set to revolutionise electrochemical biosensing, paving the way for more accessible, high-performance detection technologies.



Sensitivity

Gii's high surface area and advanced conductivity properties enable more efficient electron transfer, allowing for lower detection limits and more reliable biosensing outcomes.



Cost

Unlike noble metals, which are expensive and prone to supply chain fluctuations, Gii offers a more affordable alternative without compromising performance.



Scalability

The production of Gii is highly reproducible, overcoming many of the challenges faced by graphene and other nanomaterials when transitioning from lab-scale to mass production.



Biocompatibility

Gii's biocompatibility makes it ideal for medical diagnostics and implantable biosensors.



Anti-fouling properties

Gii's inherent resistance to biofouling maintains sensor sensitivity and specificity without requiring extensive surface modifications.



Choosing the right material for your biosensing application

Each biosensor material has unique strengths and trade-offs. Noble metals provide reliability and sensitivity but come at a high cost. Graphene offers versatility, yet production challenges persist. Other nanomaterials bring innovative functionality but may present biocompatibility or scalability issues.

The choice of biosensor material ultimately depends on the specific application, required performance metrics, and commercial viability. Emerging solutions, such as Gii, are set to redefine biosensor development, making high-performance, cost-effective, and scalable biosensors a reality.

For those seeking to balance sensitivity, cost, and scalability, novel carbon-based nanomaterials like Gii provide a compelling alternative to traditional noble metals, overcoming many of their limitations. If you are developing biosensing technologies and looking for the optimal material, now is the time to explore these next-generation solutions.

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