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Review Article

Shaping the next-generation of fused deposition modeling three-dimensional-printing-based electrochemical (bio)sensing: Drawing a realistic horizon

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The emergence of three-dimensional (3D)-printing as a fabrication tool has revolutionized the development of customized electrochemical (bio)sensors, offering exceptional design flexibility, cost-effective and rapid prototyping. Among the additive manufacturing technologies, fused deposition modeling (FDM) stands out for its affordability, ease of use, and the growing availability of conductive filaments, providing a new approach to produce tailored electrodes with enormous analytical potential and capabilities. This perspective presents a critical overview of the current opportunities and limitations of FDM-3D-printing as a technology for the design and development of electrochemical (bio)sensors, addressing material formulation, electrode architecture, surface modification strategies, analytical performance, and emerging applications. Current challenges and directions to overcome them are identified and discussed, drawing a realistic horizon for the next generation of FDM-3D-printed electrochemical (bio)sensors.

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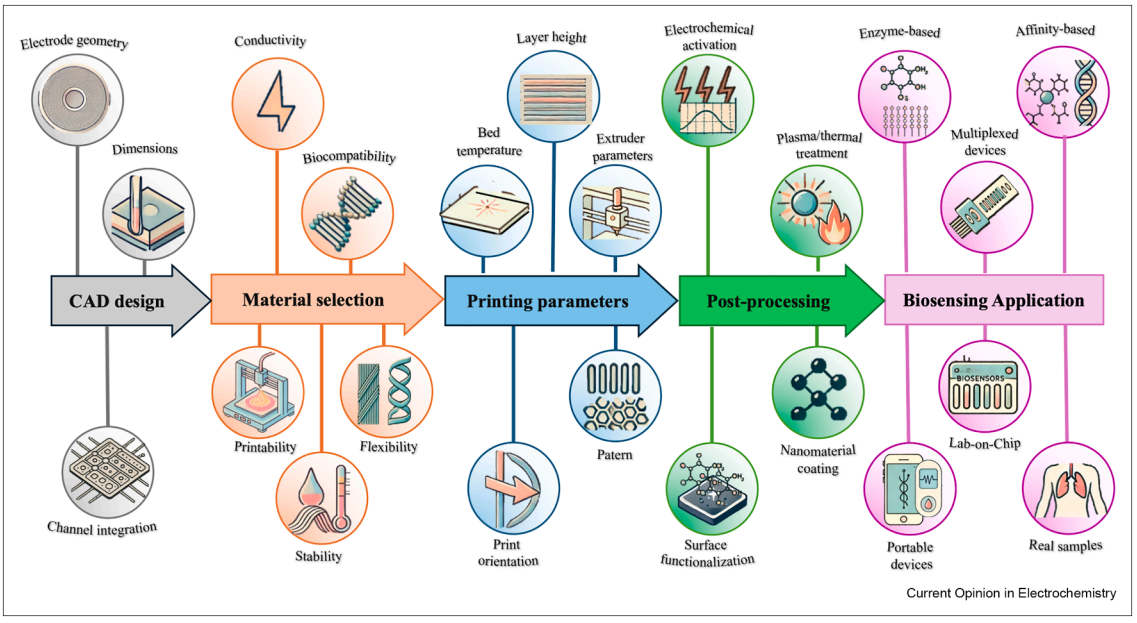
Fused deposition modeling in the three-dimensional-printing map

The emergence of three-dimensional (3D) printing, particularly through additive multimaterial approaches, has deeply transformed various scientific fields, with electrochemistry being one of the most impacted [1]. As a distinctive feature compared to other low-cost manufacturing methods, 3D-printing enables a layer-by-layer deposition of materials. Thus, 3D-printing offers exceptional design flexibility, and rapid prototyping [2], which are invaluable for the development of 3D-printed electrochemical (bio)sensors, with enormous potential for (bio)analytical, biomedical, and environmental applications [3–5].

Among the different 3D-printing techniques, fused deposition modeling (FDM), based on the melting, extrusion, and deposition of filaments, is the preferred approach in electrochemistry, as it allows the integration of conductive and nonconductive materials in monolithic structures. In addition, its affordability, ease of use, and the growing availability of conductive filaments render FDM-3D-printing as an optimal approach for the development of a new generation of electrochemical (bio)sensors [6]. From a structural perspective, FDM-3D-printing is an excellent option to tailor the architectures of the electrodes, allowing optimization surface area and mass transport, which in turn enhance overall electrochemical performance of the device [7,8].

At present, technical challenges still need to be addressed; being the most important being the improvement of the electrochemical performance due the poor conductivity of as-printed electrodes. This is due to their composition, based on conductive particles that are partially embedded or encapsulated within an insulating thermoplastic matrix. Post-treatment, mostly using (electro)chemical activation protocols is therefore required to remove as much of the insulating phase as possible, altering the surface composition by exposing a

Figure 1



Workflow integrating the main fabrication steps of FDM-3D-printed electrochemical (bio)sensors, divided in five stages: **(i) computer-aided design** (CAD) of the (bio)sensor, involving electrode geometry, dimensional control, and channel integration (optional); **(ii) material selection**, with key features including electrical conductivity, biocompatibility, printability, flexibility, and stability; **(iii) printing parameters**, such as layer height, temperature control, infill patterns, and print orientation; **(iv) postprocessing**, including electrochemical activation, thermal or plasma treatments, nanomaterial coatings, and surface (bio)functionalization, in connection with **(v) biosensing application**, including the development of enzymatic and affinity-based platforms, integration into multiplexed and LoC devices, and testing in real samples. FDM, fused deposition modeling; LoC, Lab-on-a-Chip.

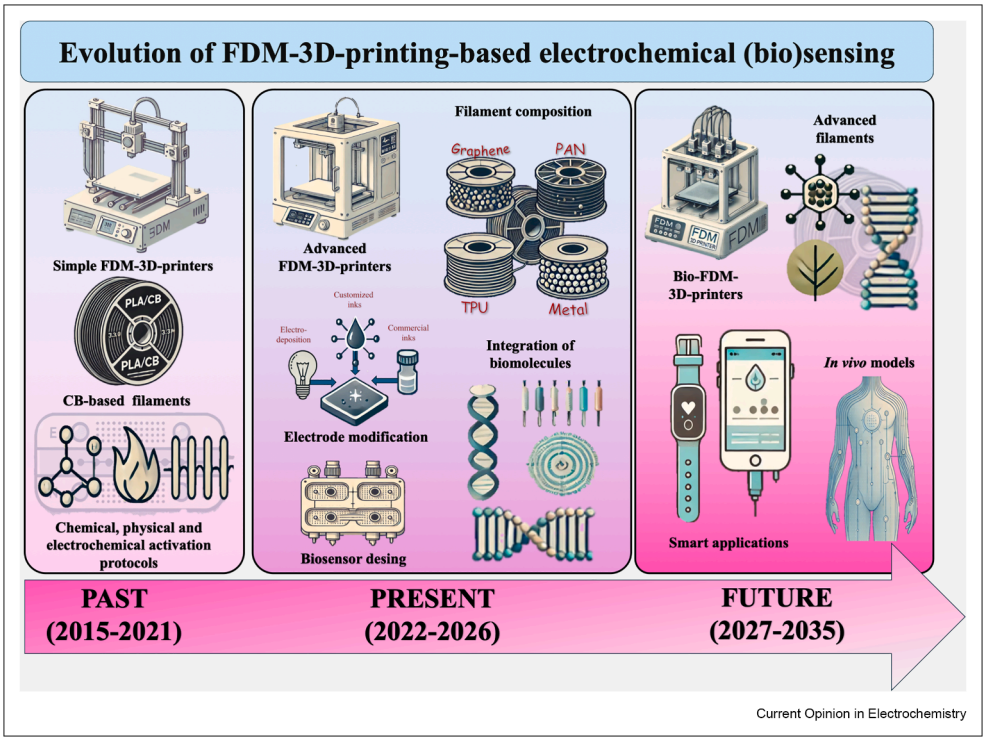
larger proportion of the conductive material. As an alternative, the electrodes may also be coated directly with conductive inks [9].

Figure 1 shows a workflow of the key steps to design and fabrication of functional (bio)sensors via FDM-3D-printing: (i) computer-aided design (CAD), (ii) material selection, (iii) printing parameters, (iv) post-processing, and (v) surface (bio)functionalization for the target (bio)sensing applications. Surface modification implicates not only the improvement in the filament electrical conductivity, acting as electrochemical transducer, as specific challenge in FDM-3D-printing, but also the integration of a biological recognition element on the filament (enzymes, antibodies, nucleic acids, or cells). Succeeding in this step solely through filament printing is nearly impossible; therefore, a seamless incorporation of biorecognition components into the (post-)printing process is essential to obtain (bio)sensors with optimal functionality [10]. The illustrated framework also highlights the versatility of FDM-3D-printing technology for the fabrication of completely tailored electrochemical (bio)sensors. The potential of FDM-3D-printing in electrochemical (bio)sensing has clearly been identified and deeply discussed, as reflected in excellent reviews focused mainly on printing methods, design constraints, and postprocessing modifications [11–17].

Figure 2 shows the chronological evolution of electrochemical (bio)sensors developed by this manufacturing approach. The earliest devices (2015–2021) relied on basic desktop FDM-3D-printers and carbon-black-filled polylactic acid (CB/PLA) filaments, which imposed constraints on electrode miniaturization and electrical performance. Over roughly the past three years (2022–present), the field has progressed rapidly thanks to (i) high resolution, multimaterial printers, (ii) new conductive filaments incorporating (nano)materials, (iii) screen-printable inks integrable with printed architectures, and (iv) biofunctional materials that can be included in a single manufacturing workflow. Building on these advances, forthcoming research (2027 onwards) is expected to focus on bio-FDM-3D platforms, smart/connected (bio)sensing formats and new biocompatible filaments.

Currently, one major limitation of FDM-3D-printing is the restricted availability of commercial conductive filaments that meet electrochemical and (bio)analytical requirements. Although the latest and most innovative ones, integrating other carbon-based nanomaterials

Figure 2



Chronological evolution of electrochemical (bio)sensors produced by FDM-3D-printing. Early work used basic printers and low-conductivity CB-based filaments that required heavy postprocessing for electrochemical activation. Today, the field benefits from higher-resolution printers, tailored inks, improved filaments (graphene-, PAN-, metal-, or TPU-based), and hybrid approaches that embed biomolecules into complex device architectures. Looking ahead, Bio-FDM-3D-printing promises to produce biofunctional materials, enabling the fabrication of wearables and implantable biosensors for real-time *in vivo* monitoring. The time frames delineating the past, present, and future have been established based on a comprehensive survey of the literature. FDM, fused deposition modeling; 3D, 3-dimensional; CB, carbon-black;

(graphene, graphite, and carbon nanotubes) or metal (nano)particles as additives, exhibit enhanced conductivity compared with the long-standing CB/PLA, it still falls short the electrochemical performance offered by traditional metallic electrodes [9,18].

Another subject of ongoing debate is the resolution of FDM-3D-printing. Typical values, range between 100 and 400 µm (both in width and height dimensions), are markedly lower than those achieved with stereolithography (SLA) 3D-printing approach (resolutions below 50 µm). Although this level of resolution cannot be considered a drawback for the development of electrochemical (bio)sensors, FDM-3D-printing resolution is an inherent limitation that must be borne in mind during the development of devices with the potential for use in microscale applications. Here is worth to mentioning another key value of the FDM-3D-printing as a clean-room-free technology.

While only preliminarily explored, a promising way to bypass the resolution of FDM-3D-printing is to adopt a hybrid workflow including the SLA approach where SLA prints the rigid structure, including, if desired, microchannels, and FDM step lays carbon- or metal-filled filaments that form embedded electrodes and contact pads. Thus, fine feature fidelity of SLA is combined with the material versatility and conductivity of the FDM approach, enabling the fabrication of devices integrating microfluidic precision and electrochemical functionality. Unfortunately, there are currently no commercial 3D printers that combine both technologies within a single machine [17,19].

Reproducibility is further affected by small variations in printing parameters like extrusion temperature, nozzle speed, infill pattern, or layer height. Drift on the values may alter filament crystallinity and thus the number of conductive pathways, so two nominally identical prints could present important differences in charge-transfer resistance and conductivity [20–25].

At present, even with these limitations, FDM-3D-printing is considered a transformative technology for

developing electrochemical (bio) sensing platforms. Extensive and smartly guided research is essential for ensuring its scalability and reliability as a manufacturing approach and will pave the way for its widespread adoption in the fabrication of the next generation of electrochemical (bio)sensors.

Fused deposition modeling-three-dimensional-printing-based electrochemical biosensors

Firstly, selected works that address the improvement of the electrochemical properties of the filament-based transducers are discussed. Then, the studies presenting (bio)sensors where the electrodes are fabricated through FDM-3D-printing, will be presented.

The electrical conductivity (and thus the electrochemical response) exhibited by FDM-3D-printed electrodes is specially affected by: (i) the parameters selected for the 3D-printing fabrication, (ii) the intrinsic composition of the conductive filament, and (iii) the surface modifications conducted.

The overall characteristics of the (bio)sensor, from its structural integrity and mechanical properties to its electrochemical performance, are strongly influenced by the parameters established during the FDM-3D-printing fabrication. Thus, appropriate parameter selection, including base temperature, layer height, print orientation, and extruder configuration, directly enhances the percolation pathways within the matrix of the filament, thereby improving its overall electrical conductivity. The orientation of the layers have been deeply study, reveling that it critically affects the mechanical and piezoresistive properties of the material [26]. Modifying the CB/PLA conductive/binder ratio, the improvement of the electrochemical performance has also been demonstrated [27–29]. Despite the growing range of conductive filaments available, CB is still the predominant conductive filler for three reasons: (i) combines good conductivity with low-cost production, (ii) it disperses uniformly in thermoplastics, allowing smooth and clog-free extrusion, and (iii) its use as nanomodifier in 2D-screen-printed electrodes, improving their electrochemical performance, is largely demonstrated, accelerating the optimization of fabrication protocols based on FDM-3D-printed (bio)sensors [30,31].

Surface modification with (nano)materials represents a convenient approach to enhance the interfacial electrochemical properties. Their incorporation on 3D-printed platforms can be achieved through several well-established strategies (e.g. drop casting, homemade inks, (electro)deposition). In addition to CB [32], a variety of (nano)materials, comprising carbon nanotubes and graphene [33], MXenes [34], and gold nanoparticles [35] are starting to be explored, showing promising results. These nanomaterials accelerate interfacial electron transfer kinetics (higher k_0), minimize the charge-transfer resistance (R_{ct}), and enlarge the electroactive area. However, these improvements are confined to the very outer microns of the electrode surface (filament/electrolyte interface). For example, gold-decorated CB/PLA-printed electrodes exhibit a ten-fold rise in k_0 after the introduction of the nanomaterial, yet their peak-to-peak separation remains quasi-reversible, as $\sim$50 Ω of series resistance is contributed by the printed conduction path itself [36]. Thus, it must be recognized that nanomaterials do not fundamentally change the low intrinsic conductivity of the bulk filament due its composition, which results in high ohmic resistance along the electric contact, irrespective of surface modifications, which is a limitation in constructing electrochemical sensors using FDM-3D-printing.

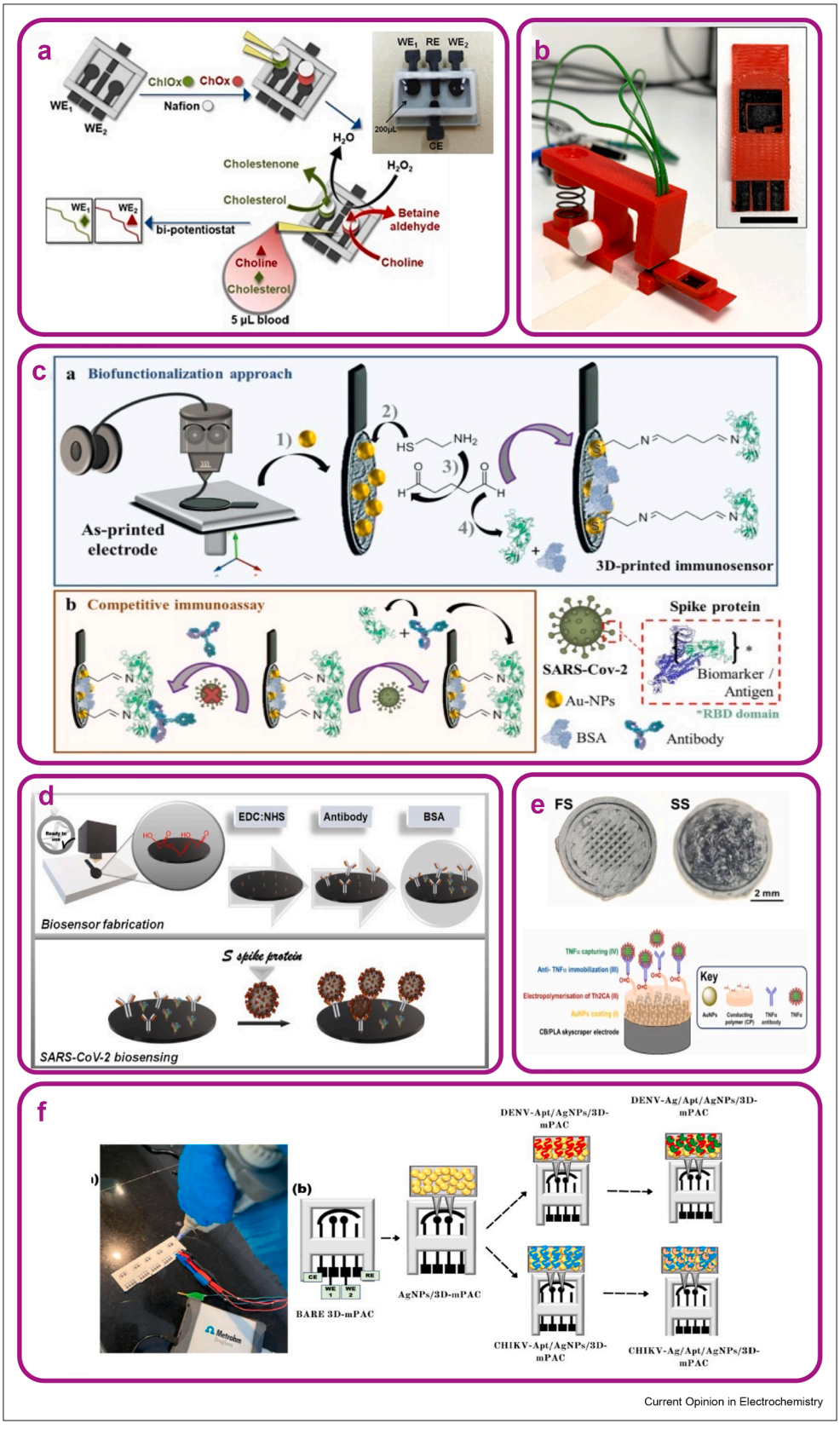
Beyond these approaches focused on improving inherent filament conductivity and active surface area through (nano)materials, emerging works are also emphasizing the need for advanced surface functionalization strategies and the direct incorporation of biological elements as another fundamental issue in the development of (bio)sensors. However, surface functionalization strategies are still an unexplored in FDM-3D-printed electrochemical (bio)sensors. While conventional electrodes often rely on well-established protocols for surface modification, the intrinsic characteristics of FDM-3D-printed conductive filaments, including heterogeneous composition, roughness, and lower conductivity, faces unique challenges that require adapted or entirely new approaches. Particularly, achieving robust and reproducible immobilization of biorecognition elements demands a deeper understanding of physicochemical properties of the filament, as well as the development of specific functionalization chemistries tailored to these substrates.

The incorporation of biorecognition elements during or immediately after FDM-3D-printing could yield fully integrated, more stable biosensors, but success hinges on overcoming two majors obstacles: (i) ensuring biological compatibility with the thermoplastic conductive matrix, and (ii) preserving biomolecular activity throughout the manufacturing process.

However, there is no question that the advantages of FDM-3D printing have opened a new landscape for the development of highly customized and compact enzymatic and affinity biosensors. Outstanding examples, recently reported, are discussed in the following paragraphs.

With respect to enzymatic biosensors, a FDM-dual cholesterol and choline electrochemical biosensing platform is presented in Figure 3a [37]. The device is

Figure 3


a
ChlOx
ChOx
Nafion
WE1
WE2
RE
CE
200µL
H2O
H2O2
Cholestenone
Cholesterol
Betaine aldehyde
Choline
bi-potentiostat
5 µL blood
b
c
a Biofunctionalization approach
1)
2)
3)
4)
HS
NH2
As-printed electrode
3D-printed immunosensor
b Competitive immunoassay
Spike protein
SARS-Cov-2
Au-NPs
BSA
Antibody
Biomarker / Antigen
*RBD domain
d
EDC:NHS
Antibody
BSA
Biosensor fabrication
S spike protein
SARS-CoV-2 biosensing
e
FS
SS
2 mm
TNFα capturing (IV)
Anti- TNFα immobilization (III)
Electropolymerisation of Th2CA (II)
AuNPs coating (I)
CB/PLA skyscraper electrode
Key
AuNPs
Conducting polymer (CP)
TNFα antibody
f
(b)
BARE 3D-mPAC
AgNPs/3D-mPAC
DENV-Apt/AgNPs/3D-mPAC
DENV-Ag/Apt/AgNPs/3D-mPAC
CHIKV-Apt/AgNPs/3D-mPAC
CHIKV-Ag/Apt/AgNPs/3D-mPAC
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composed of a miniaturize vessel and four integrated electrodes, two of which host a specific enzyme reaction, allowing the simultaneous sensitive determination of cholesterol and choline with limits of detection of 0.8 μM and 0.6 μM, and linear ranges of 1−100 μM and 1−200 μM, respectively. Moreover, the device shows rapid response times (<5 s), good repeatability (RSD <4 %), and high recoveries in serum samples (96−102%). Another dual biosensing approach for glucose and dopamine is illustrated Figure 3b [38]. Glucose is detected through glucose oxidase immobilization, while dopamine is sensed by its inherent electroactivity in the printed electrodes, which are physically and electrochemically activated prior to use. The integrated multimaterial platform achieves good results for both dopamine and glucose determination, with linear ranges of 50 μM−1 mM for dopamine and 1−12 mM for glucose. Calabria et al. have proposed the use of a custom carbon black-doped polylactic acid-based filament to enhance electrochemical performance through conductive nanomaterials [39]. Through an innovative design, this study presents a smartphone-integrated, FDM-3D-printed electrochemiluminescence biosensor for reagentless glucose detection in artificial serum samples. The biosensor demonstrates remarkable analytical capabilities for glucose detection (LOD of 60 μM, and a linear range up to 5 mM).

These FDM-3D-printing biosensors employed efficient well-known enzyme immobilization strategies, which include drop-casting, hydrogel entrapment, and polymeric coating techniques (*nafion*, gelatin-glutaraldehyde matrices, and agarose gels), ensuring reliable enzyme attachment while preserving biocatalytic activity. This demonstrates the compatibility of integrating established methodologies onto the FD-3D printing platform, confirming the versatility of 3D-printing for the construction of biosensors as well.

Affinity biosensors-based FDM-3D-printing have also been elegantly developed. One of the earliest works, consisted of a 3D-printed graphene-based electrode for Covid 19 antigen detection (Figure 3c) [40]. Janegitz's group designed an immunosensor using CB-enriched filaments that provide adequate electrochemical responses without activation protocols, enabling detection of the SARS-CoV-2 spike protein receptor in the 5−75 nM range, with a LOD of 1.36 nM (Figure 3d) [41]. Another example using affinity biosensors-based FDM-3D printing consist of a nucleic acid-based biosensor, which employs a capture DNA oligonucleotide immobilized on a gold-modified 3D-printed graphene electrode. Viral cDNA hybridizes with the probe; the event is transduced into an electrochemical signal [42]. Other examples include immunosensors for detecting critical biomarkers like tumor necrosis factor alpha (TNF-α) and viruses such as dengue (DENV) and chikungunya (CHIKV). The TNF-α immunosensor integrates an FDM-3D-printed electrode with covalently immobilized anti−TNF-α antibodies on a conductive polymer; the binding of TNF-α can be detected through changes in impedance spectroscopy measurements or recorded current using voltammetric techniques (Figure 3e) [43]. Viral antigens from DENV and CHIKV have also been detected in a dual electrochemical immunoassay, smartly combining FDM-3D-printed electrode with a paper-based electrode enhanced by silver nanoparticles, amplifying the electrochemical signal in response to bound viral proteins (Figure 3f) [44].

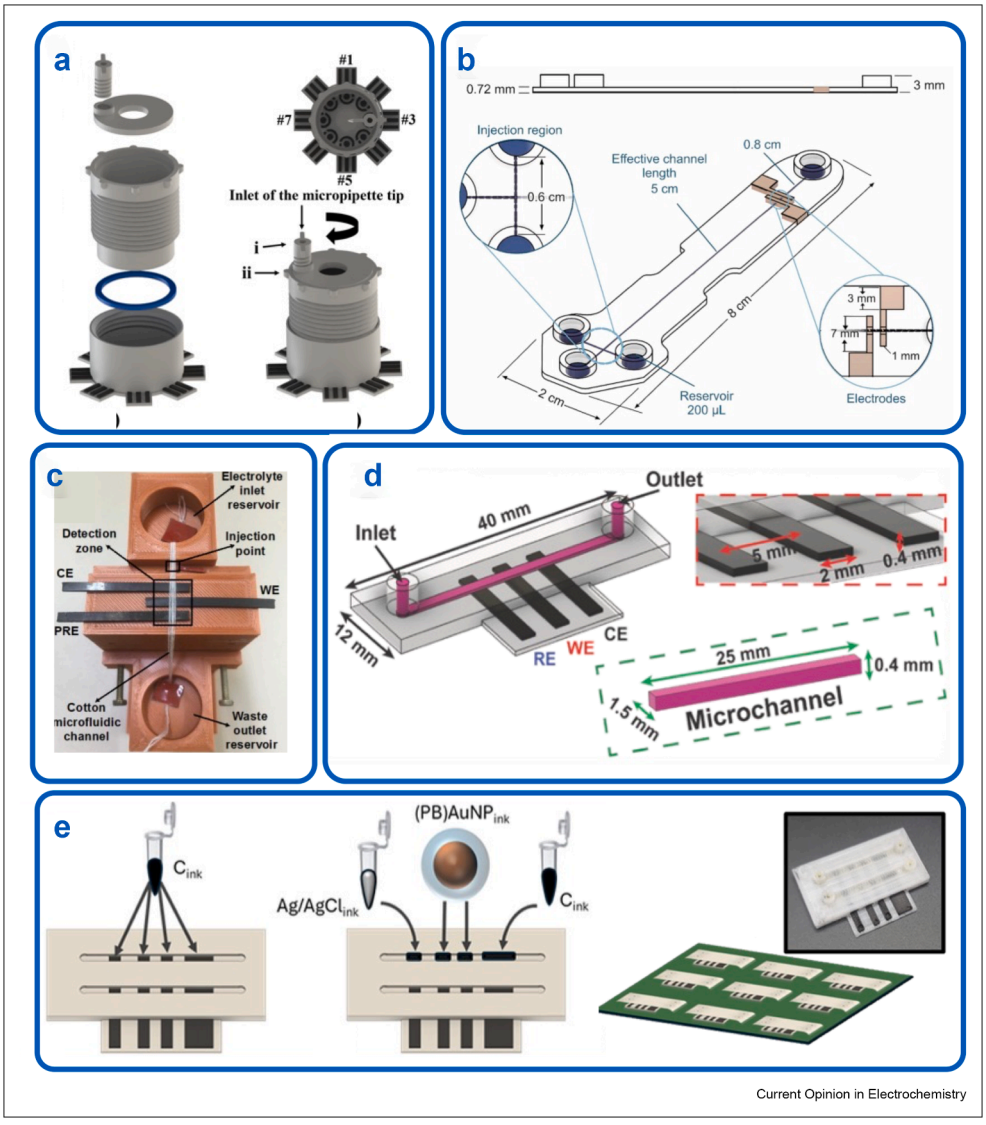
Having surveyed representative electrochemical biosensors, this section closes by examining recent publications in which FDM-3D-printing unifies microfluidic channels and embedded electrodes within a single manufacturing step, thereby contributing to the development of fully integrated, miniaturized, and reproducible Lab-on-a-Chip (LoC) devices.

Interestingly, FDM-3D-printing fabrication allows to use thermoplastic and conductive materials to produce both the microfluidic channels and electrochemical cell with embedded electrodes, in a single fabrication workflow, enabling one-step construction of (ultra)-miniaturized flow-through (bio)sensors. This approach combines rapid prototyping, low cost, and straightforward multimaterial printing, while eliminating the clean-room requirements of conventional microfluidics fabrication protocols. As a result, FDM-3D-printing is an excellent approach for the fabrication of innovative LoC devices that demand seamless integration of flow channels and electrochemical transducers to achieve reliable, sensitive, and reproducible (bio)sensing performance [45].

While many studies employ FDM-3D-printing in certain stages of device construction, few report truly

Selection of electrochemical biosensors fabricated using FDM-3D-printing technology, illustrating diverse device architectures, functionalization, and target detection. Figures have been adapted with permission from the following sources: **(a)** 3D-printed enzymatic microchip for multiplexed electrochemical biosensing (2021) *Anal. Chim. Acta.* 1186, 339114; **(b)** integrated multimaterial portable 3D-printed platform for electrochemical detection of dopamine and glucose (2022) *Analyst.* 147(20), 4598−4606; **(c)** 3D-printed COVID-19 immunosensors with electronic readout (2021) *Chem. Eng. J.* 425, 130599; **(d)** new conductive filament ready-to-use for 3D-printing electrochemical (bio)sensors: Towards the detection of SARS-CoV-2 (2022), *Anal. Chim. Acta.* 1191, 339372; **(e)** 3D-printed skyscraper electrochemical biosensor for the detection of tumor necrosis factor alpha (TNFα) in faeces (2024), *Sens. Actuators B Chem.* 410,135694; and **(f)** next-generation point-of-care diagnostics: Silver nanoparticle-enhanced 3D-printed multiplex electrochemical biosensor for detecting dengue and chikungunya viruses (2023), *ACS Appl. Bio. Mater.* 6(2), 1234−1245. FDM, fused deposition modeling; 3D, 3 dimensional.

Figure 4



Representative examples of flow-through miniaturized devices with integrated electrochemical functionality. Figures have been adapted with permission from the following sources: **(a)** 3D-printed electrochemical platform with multipurpose carbon black sensing electrodes (2022) *Microchim. Acta.* 189(6), 235; **(b)** using multi-FDM for one-step FDM-3D-printing of microfluidic capillary electrophoresis with integrated electrodes for capacitively coupled contactless conductivity detection (2022) *Sens. Actuators B Chem.*15(365), 131959; **(c)** exploring the coating of 3D-printed insulating substrates with conductive composites: a simple, cheap, and versatile strategy to prepare customized high-performance electrochemical sensors (2022) *Anal. Methods* 14(34), 3345–3354; **(d)** electrochemical fluidic fused filament fabricated devices (eF^4D): In-channel electrode activation (2023) *Sens. Actuators B Chem.* 15(393), 134206; **(e)** FDM-3D-printed dual-channel flow-through miniaturized devices with dual in-channel electrochemical detection (2024) *Anal. Chem.* 97(5), 2667–2677. FDM, fused deposition modeling.

monolithic systems in which conductive electrodes and flow-through structures are integrated. Furthermore, most of the recent studies have addressed critical aspects of device fabrication such as (i) the optimization of structural dimensions, as exemplified in Figure 4a–c [46–48], (ii) the fabrication of fully 3D-printed electrochemical microfluidic monolithic devices compatible with postprinted in-channel electrode activation strategies for enhancement of electrochemical performance (Figure 4d) [49], (iii) the integration of customized conductive filaments, [50] and (iv) the surface bioreceptor functionalization [51]. In the latest work, the well-established glucose/glucose oxidase chemistry has driven pioneering using a FDM-3D-printed microfluidic-integrated electrochemical sensing platform by customizing drop-casted electrode

surfaces with carbon ink, a Prussian Blue (PB) layer, and glucose oxidase biofunctionalization using hydrogel trapping, using CB/PLA for the conductive elements. By leveraging the selectivity of both the enzyme and PB toward hydrogen peroxide detection, and in connection with the improved electrochemical response from ink-based electrode, a microfluidic FDM-3D-printed biosensor was successfully developed. Dual-channel flow-through miniaturized devices with dual electrochemical detection, integrating two working electrodes each in an in-channel configuration and with customized surfaces prepared by drop-casting hybrid nanoparticles PB-shell AuNP-core for PB-based hydrogen peroxide detection in cell culture systems, have also recently been reported, revealing the potential of FDM-3D printing for design and development of more complex electrochemical cells (Figure 4e) [35]. These recent studies are compelling examples of how the synergy between FDM-3D printing and other well-established technologies can be utilized to enhance both sensitivity and selectivity.

Collectively, these advancements demonstrate the growing versatility of FDM-3D-printing technology for constructing functional, flow-based miniaturized electrochemical devices suitable for bioanalytical applications, removing the need for clean-room facilities and establishing 3D-printing as an exceptional asset in modern biosensor development.

Fused deposition modeling-three-dimensional-printing: current limitations, ongoing directions, and horizons

Throughout this opinion article, it becomes evident that FDM-3D-printing has progressed from pioneering works demonstrating the filaments as printed electrodes to versatile and creative sophisticated (bio) sensing approaches.

FDM-3D-printing's main advantages, such as rapid prototyping and easy customization, together with its low cost, compatibility with a broad spectrum of thermoplastics, conductive composites, and (nano)materials, allow the one-step fabrication of geometrically complex, fully integrated electrochemical (bio)sensing platforms. Another valuable feature of FDM-3D-printing is that is a cleanroom-free technology, which open new opportunities in the fabrication of electrochemical (micro)fluidics as well. These attributes have drawn attention to the analytical potential of FDM-3D-printing in a new biosensing landscape.

Nonetheless, despite its clear potential, the use of FDM-3D-printing in (bio)sensing fabrication remains at an early technological stage, and further research is needed to unlock its full capabilities. Indeed, FDM-3D-printing faces key challenges in manufacturing electrochemical (bio)sensors, related to material limitations, postprocessing, and interdevice fabrication reproducibility.

The conductive commercially available filaments, including those based on carbon nanomaterials or metal nanoparticles, often results in lower conductivities (one to three orders of magnitude) compared to both traditional metallic electrodes and screen-printed carbon inks, demanding extra processing steps. Consequently, FDM-3D-printed electrodes require additional postprocessing treatments such as thermal annealing, solvent polishing, (electro)chemical activation, or laser irradiation. These protocols are routinely applied to remove insulating polymer material, smooth ridges, and create electroactive nano-textures, improving conductivity. These materials can also exhibit inconsistent layer adhesion and surface roughness, contributing to variability in sensor performance. Poor interlayer fusion and high fraction of insulating polymer islands further degrade electron percolation, increasing ohmic drops.

Current directions seek to overcome these limitations by: (i) developing conductive filaments with superior electrical properties and biocompatibility to resolve existing issues in conductivity and mechanical durability; (ii) designing next-generation filaments that assemble (nano)materials, aiming to balance conductive functionality with the dielectric stability; (iii) achieving higher resolution and interdevice reproducibility by standardizing printing fabrication parameters, postprocessing routes, and metrics, to guarantee reproducibility across laboratories; (iv) accurately integration FDM-3D-printing and surface chemistry, including biorecognition; and (v) exploiting the synergy between FDM-3D-printing and other well-established technologies (as screen printing, stencil printing) improving control over (bio) sensor performance and thereby enhancing sensitivity and selectivity to expand their fabrication for real-world applications.

On these bases, a realistic horizon for the field can be charted by mapping short-, mid-, and long-term tasks. In the short term, establishing universally accepted protocols for characterizing surface morphology, electrical conductivity, and device-to-device reproducibility is essential to enable rigorous cross-study comparisons. In the mid-term, research should pivot toward formulating printable composites and refining multimaterial printing workflows to improve device assembly. In the long term, FDM-3D-printing is poised to converge with the latest technologies, allowing the fabrication of user-friendly platforms for real-time and multiparametric monitoring in the field of personalized health. Indeed, the integration of FDM-3D-printing with digital and portable technologies is set to revolutionize proof-of-concept

(PoC) technologies for real-time monitoring of critical biomarkers, supporting early disease detection and remote patient management, particularly in resource-limited settings.

Achieving this trajectory will demand sustained, interdisciplinary collaboration to move beyond PoC demonstrations and deliver robust, economical, and customizable electrochemical (bio)sensors ready for widespread clinical and industrial deployment.

FDM-3D-printing has emerged as an innovative technology for the development of a new generation of electrochemical biosensors, encompassing all its working modes within a landscape that is as exciting as it is rapidly evolving.

Author contributions

M.C.: conceptualization, writing original draft, review and editing, visualization. FA.: conceptualization, review and editing, visualization. A.E.: conceptualization, writing review and editing, supervision, funding.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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