

Application of 2D MoS₂-Based Nanocomposites

Subjects: Electrochemistry

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The 2D molybdenum disulfide (MoS₂) nanosheets have unique and complementary properties to those of graphene, rendering them ideal electrode materials that could potentially lead to significant benefits in many electrochemical applications. These properties include tunable bandgaps, large surface areas, relatively high electron mobilities, and good optical and catalytic characteristics.

Keywords: Molybdenum disulfide ; Functionalization ; Metal and metal oxide nanostructures ; Electrochemical sensors ; Biosensor ; Detection ; Nanosheets

1. Introduction

Layered materials have been studied for several years. Each layered material, when thinned to its physical limit, reveals novel properties different from its bulk counterpart. Therefore, at the physical limit, these materials are referred to as two-dimensional (2D) materials ^[1]. These 2D materials have received great attention due to the affluence of unusual physical characteristics that occur when charge and heat transports are confined to a plane ^[2]. Graphene is the most widely studied 2D material because of its exceptional properties. It is composed of a single layer of carbon atoms arranged in a 2D honeycomb lattice ^[3]. It is a fundamental building block for a range of well-known carbon materials such as three-dimensional (3D) graphite, one-dimensional (1D) carbon nanotubes, and zero-dimensional (0D) fullerene ^[3]. Since its isolation, it has inspired thoughtful research on other 2D materials. These materials are useful building blocks that can be restacked and incorporated into composites for a wide range of applications. Other than graphene, recent efforts have focused on other 2D materials (ranging from conductors to insulators). These materials include transition metal dichalcogenides (TMDs) as semiconductors involving a general chemical formula of MX₂, where M is a transition metal atom (M = Mo, W, Ti, Zr, Ta, Nb, Re, Ni, or V) and X is a chalcogenides atom (X = S, Se, Te), as well as black phosphorus (BP), transition metal oxides, and hexagonal boron nitride (hBN) as an insulator ^{[3][4][5]}. TMDs are now the key focus of many researchers because of their unique properties. Exfoliated 2D TMDs have properties that are complementary to (but yet distinct from) those of graphene, and they also have the advantages of tunable bandgaps ranging from 1–2 eV ^{[4][6][7]}. One of the most widely explored transition metal dichalcogenides is molybdenum disulfide (MoS₂) ^{[8][9][10]}. The electrical and optical properties of MoS₂ are layer-dependent. For instance, bulk MoS₂ is an n-type semiconductor with an indirect bandgap of about 1.3 eV, while a monolayer MoS₂ has a direct bandgap of 1.8 eV ^{[6][11]}. Moreover, monolayer MoS₂ exhibits carrier mobility of 200 cm²V⁻¹s⁻¹ at room temperature with a high on/off current ratio of ~10⁸ ^[12]. MoS₂ has a layered crystal structure formed by stacking covalently bound S-Mo-S monolayers through weak van der Waals interactions ^{[13][14]}. The van der Waals interlayer interaction between these monolayers allows for their separation leading to crystal exfoliation with approximately 0.65 nm of thickness (6.5 Å) ^{[12][15]}.

As a semiconducting analog of graphene, this material has recently been reported as promising in the application of sensors ^[13], photodetectors ^[16], transistors ^[12], flexible electronics ^[17], and fuel cells ^[18]. Although the use of MoS₂ nanosheets offers many advantages, poor conductivity (due to the large bandgaps) considerably limits their practical applications in sensors. Moreover, it has been reported that pristine MoS₂ nanosheets suffer from gradual degradation at ambient conditions, which are triggered by surface contamination and significant adsorption of oxygen in an air environment. This leads to instability and decreased electrical properties and sensing abilities ^{[19][20]}. Therefore, to obtain satisfactory results, pristine MoS₂ nanosheets need to be operated in an inert atmosphere. To overcome these limitations and extend the potential application of MoS₂ nanosheets, various approaches have been attempted, such as the substitution of the transition metal of MoS₂ with other elements ^[21], molecular physisorption of organic materials ^[22], changing interfacial chemistry ^{[23][24]}, solution-based chemical doping ^[25], and promoting structural phase transition (from semiconducting 2H phase to metallic 1T phase) ^{[26][27]}. However, some of these methods are complicated and time-consuming; some result in structural defects, reduced mobility, and unstable composites ^[28]. Furthermore, researchers noted that TMDs have a habit of being inert to chemical functionalization. Chalcogen atoms in the basal plane of TMD nanosheets are saturated and, therefore, are not highly reactive, whereas the metal sites in TMDs are embedded beneath

the chalcogen layer, all but eliminating them from being useful for functionalization [29]. Despite this, it is necessary to functionalize MoS₂ with chemical moieties, which can enable its interface with other nano- or micro-structures [15]. The synergetic effects resulting from MoS₂ composites can produce enhanced properties or improved performances. The large surface-to-volume ratio of 2D MoS₂ nanosheets presents an opportunity for the effective surface functionalization of the material with metal and metal oxide nanostructures (NSs). Compared with previously described methods of functionalization, interfacing 2D MoS₂ nanosheets with metal-based NSs is more simply carried out and offers an additional path for controlling the thermal, catalytic, magnetic, optical, and electrical properties. Based on theoretical calculations, it has been reported that the effective adsorption of different metal atoms on 2D MoS₂ is related to the number of d

-electrons, which can also effectively modulate the band structures of the material [30]. Most metal-based NSs have good stability and are resistant to environmental deterioration and oxidation, which make them ideal for the fabrication of nanocomposites. However, it is worth noting that the structures and properties of nanocomposites are dependent on the conditions of the composite synthesis and the control of the decorated location, morphology, and number density of the NSs [31]. Recently, metal and metal oxide nanocomposites have received a great deal of attention because of their excellent physical and chemical properties, which expanded their application in sensors [20][31], electrocatalysis [32][33], and optoelectronics [34]. Thus, it can be expected that 2D MoS₂ nanosheets decorated with metal-based NSs could potentially extend their applications as novel nanomaterials in sensors. For instance, 2D MoS₂ functionalized with metal and metal oxide NSs, such as nickel (Ni) [35], gold (Au) [36], and tricobalt tetraoxide (Co₃O₄) [37], to name a few, was reported to exhibit excellent catalytic sensing properties. The MoS₂-Ni nanocomposite demonstrated good reproducibility and excellent sensitivity toward glucose detection. The reported results showed that small Ni nanoparticles (NPs) on the surface of the MoS₂ nanosheet had more active sites, resulting in high electrocatalytic activity and a fast response time of less than 2 s. In addition, it was discovered that Ni NPs without MoS₂ support appeared to aggregate, which was detrimental to the electrocatalytic activity of the sensor [35]. The MoS₂-Co₃O₄ nanocomposites showed high sensitivity and fast response and recovery features for the detection of ammonia at room temperature. The sensing film was constructed on an interdigital electrode substrate using layer-by-layer self-assembly of MoS₂ nanosheets and Co₃O₄ nanorods. The layer-by-layer self-assembly not only efficiently prevented agglomeration but also provided many more active catalytic sites on p-type Co₃O₄ nanorods toward ammonia. The results indicated that the fundamental sensing mechanisms of the MoS₂-Co₃O₄ nanocomposite towards ammonia were attributed to the layered nanostructure, synergistic effects, and p-n heterojunction depletion layer formed at the interface of n-type MoS₂ and p-type Co₃O₄ [37]. These 2D-MoS₂/metal-NSs composite sensor films showed significant improvements in sensitivity in comparison with the 2D MoS₂ and metal/metal oxide nanostructure counterparts, suggesting that the large surface areas, high conductivity, and improved biocompatibility played significant roles in the resulting sensing outcome. Su et al. [10], also reported that MoS₂ stabilizes metallic NPs, such as platinum (Pt), Au, silver (Ag), and lead (Pd) to form hierarchical nanocomposites, and such 2D-MoS₂/metal-NSs composites possess the essential properties of pure metal NPs and MoS₂ nanosheets due to their synergistic effects, making the 2D MoS₂ and metal/metal oxide nanostructured composites exhibit excellent electrochemical properties for the fabrication of electrochemical sensors [13].

2. Synthesis of MoS₂ Nanosheets

Different methods for synthesizing 2D MoS₂ nanosheets have been proposed; these methods have also been used for tuning 2D MoS₂ electronic band structures. So this creates an opportunity to find new methods that are appropriate for sensing applications. Lately, MoS₂ nanosheets have been produced by either mechanical or chemical methods. In a standard mechanical exfoliation procedure, sufficient thin MoS₂ crystals are first peeled off from their bulk crystals, layer-by-layer, using adhesive Scotch tape and exerting normal force. By repeating this process multiple times, the bulk MoS₂ becomes thinner until it is reduced to a single sheet of MoS₂. The cleaved thin crystals are detached with devices, such as plastic tweezers, and are adsorbed onto the target substrate [38]. While this method can yield pristine and high-quality 2D MoS₂ nanosheets, poor scalability limits its practical application in general.

Chemical methods include:

1. lithium (Li) intercalation exfoliation, which involves an initial 48 h intercalation of Li ions between bulk MoS₂ in an inert gas atmosphere followed by a spontaneous ultrasonic-assisted exfoliation of the Li-intercalated MoS₂, which occurs through water reaction [39][40]. During the process, bulk MoS₂ is treated with an n-butyllithium solution to produce the intercalation product Li_xMoS₂. The reaction process is caused by the electron transfer from n-butyllithium to MoS₂ layers, which absorbs Li⁺ between the layers to balance the charge. When the intercalate, Li_xMoS₂, comes into contact with water, it reacts with the intercalated lithium, creating LiOH and H₂ gas. As a result, negatively-charged nanosheets repel each other, increasing interlayer distances and weakening van der Waals forces, resulting in a colloidal

dispersion of (nearly) entire single layers of MoS₂ [41]. The lithium intercalation reaction converts MoS₂ from the semiconductive 2H phase hexagonal structure to the metallic trigonal 1T phase [42], although the 1T phase MoS₂ is not suitable for optoelectronic devices, it is quite desirable for electrochemical catalysis.

2. Liquid-phase exfoliation involves exfoliation by sonication [43][44] or exposure of bulk MoS₂ to high shear rates using either a rotor–stator high shear mixer or a basic kitchen blender [45][46]. The bulk MoS₂ is exfoliated in the presence of stabilizing liquids, such as suitable solvents [43], surfactant solutions [46], or polymers [47]. Sonication-assisted exfoliation is triggered by hydrodynamic shear forces associated with cavitation, which is the formation, growth, and collapse of voids or bubbles in liquids due to pressure changes [44]. Following exfoliation, the inter-sheet attractive forces and interfacial tension between the sheets and the surrounding liquid are reduced, resulting in the dispersion of a single layer [44]. When using a high shear mixer or blender, exfoliation occurs as a result of revolving rotor–stator blades producing extremely high shear rates [45][46]. The shear rate generates full turbulence, resulting in viscous shear forces. The presence of dominant viscous shear forces increases collision and cavitation between bulk materials, leading to exfoliation [45][46]. During this process, the sheets are coated with an appropriate surfactant/solvent and stabilized by repulsive inter-sheet interactions [46]. This approach results in defect-free single or multilayered nanosheets that are stabilized against aggregation by liquid interaction. The liquid-phase exfoliation method, due to its simplicity and scalability potential, has an advantage over the lithium exfoliation method; it is also not an air-sensitive process and it does not require chemical reactions; thus, it provides high crystallinity for synthesized MoS₂ nanosheets [48].
3. Hydrothermal/solvothermal synthesis is essentially where the chemical reaction takes place in a closed system (autoclave) in which the solvent temperature is raised to its critical point (> 200 °C) by heating concurrently with autogenous pressure [49]. This approach involves direct crystallization from solutions, which often include crystal nucleation and subsequent growth [49]. The sample is rapidly precipitated from the reaction solution during the synthesis process, allowing for controlled homogeneity, as well as control over aging, particle size, and morphology [50]. The solvothermal synthesis is similar to the hydrothermal synthesis, except that in the synthetic method organic solvents are used instead of water [51]. MoS₂ nanosheets with good crystalline structure and morphology are produced by optimization of hydrothermal temperature and reaction time [50].
4. Chemical vapor deposition (CVD) has been used to synthesize high-quality graphene, and it was recently adopted for the synthesis of MoS₂ nanosheets. In a standard CVD procedure, molybdenum trioxide (MoO₃) and sulfur powders are common precursors used for the deposition of MoS₂ films on a silicon/silicon dioxide (Si/SiO₂) substrate; upon heating, MoO₃ reacts with sulfur vapor in the gas phase at a high temperature (> 650 °C) to give MoS₂ layers in a reducing atmosphere under ambient pressure [52]. The CVD process is capable of producing nanosheets of good quality with scalable size, controllable thickness, and excellent electronic properties. However, it is more difficult to obtain crystalline 2D MoS₂ nanosheets with a controlled number of layers by CVD as compared to graphene, because the structure, thickness, and crystallinity of graphene could be well controlled by an effective catalyst design but there is no catalyst involved in the growth of 2D MoS₂ nanosheets [52][53].

The important thing to realize is that due to the nature of the exfoliation method, many imperfections, such as surface defects, may occur. The usual defect positions that occur are sulfur vacancies on the surface or edges [54][55]; due to these defects, 2D MoS₂ nanosheets have low charge carrier mobility and density [55]. These defects were recognized as possible synthetic targets for the functionalization and modification of MoS₂ surfaces for various additional applications [54]. The functionalization of MoS₂ is important to adjust or add the required properties to the material, which can be utilized in the fabrication of sensors and catalysts. This is an advantage given that 2D MoS₂ offers abundant exposed edges that are known as the root of the catalytic activity [56][57].

3. Functionalization of MoS₂ Nanosheets with Metal and Metal Oxide Nanostructures

Metal and metal oxide NSs are known for their exceptional electrical and catalytic properties; hence, they are the most widely used nanomaterials. The application of these nanomaterials to medicine [58], energy storage, catalysts, sensors [59][60][61], and electronics [62] has led research into the development of synthetic pathways toward the formation of nanocomposites. The integration of these NSs on MoS₂ can effectively exploit the distinct qualities of both materials, which have already attracted considerable attention in the sensing field. The metal-based NSs can be distributed and significantly improved by the effective support matrix of MoS₂ nanosheets, where the synergistic effects of metal-based NSs and MoS₂ nanosheets can lead to greater catalytic efficiency and conductivity than plain MoS₂. Several factors play significant roles in the properties of metal and metal oxide NSs, such as crystal structure, size, shape, morphology, and surface chemistry [63]. Thus, structuring methods have been applied to obtain different sizes and shapes of NSs with promising properties, such as high sensitivity, faster electron transfer kinetics, low background currents, high surface areas, and high current densities [64]. Metal and metal oxide NSs have been used to modify electrodes for use as

electrocatalysts in sensors; hence, they play significant roles in diagnostic devices. The 2D-MoS₂/metal-NS composites utilize the optimum availability of the nanoscale surface area for electron transfer, and also enable mass transport of the reactants to the electroactive focal point on the electrode surface, resulting in a significantly improved electrochemical response [65][66].

The decoration of MoS₂ nanosheets with metal-based NSs is commonly carried out in two different ways: in situ or ex situ functionalization. These functionalization methods can be achieved by post immobilization of NSs on MoS₂ [65], hydro/solvothermal reaction [66], electrodeposition [13], or the chemical reduction method [35]. In these functionalization methods, the growth control of NSs on MoS₂ nanosheets is a prerequisite for tuning the shape, size, and morphology. This growth control however involves precise process monitoring of the experimental parameters, such as the concentration of the reactant, time and temperature of the reaction, pH solution, the surfactant used, and the type of metal salts [67][68]. For instance, in a chemical synthesis process, the size and shape of the NPs can be effectively controlled by the concentration of metal salts, reaction conditions, or the use of different surfactants. Moreover, through an electrochemical synthesis, the concentration of surfactants, growth temperature, and current density can be optimized to control the size and shape of the NPs [68]. Concerning the subject, a study was conducted where thionine (C₁₂H₁₀N₃S⁺)-MoS₂ was functionalized with AuNPs by a hydrothermal reaction for electrochemical immunosensing [69]. C₁₂H₁₀N₃S⁺ was used as a reducing agent and a surfactant to tune the resulting AuNPs structures on the surface of the MoS₂ nanosheets. The study demonstrated that various well-defined shapes of AuNPs were produced by adjusting the concentration of C₁₂H₁₀N₃S⁺ while the concentration of metal salt (HAuCl₄) remained constant. It was discovered that with an increasing concentration of C₁₂H₁₀N₃S⁺, the size of the NPs increased and the shape changed from spherical, triangle, and clover-like to flower-like shape. A significant finding was that C₁₂H₁₀N₃S⁺ could not facilitate the growth of AuNPs in the absence of MoS₂ nanosheets. This indicated that C₁₂H₁₀N₃S⁺ and MoS₂ had a synergistic effect on the formation of AuNPs and the growth of AuNPs was also promoted by the effective support matrix of MoS₂ nanosheets. The proposed mechanism was because C₁₂H₁₀N₃S⁺ is an electrochemical indicator, the growth of AuNPs on the surface of MoS₂ nanosheets could be due to the redox reaction among MoS₂, C₁₂H₁₀N₃S⁺, and AuCl₄⁻. C₁₂H₁₀N₃S⁺ was absorbed on the surface of MoS₂ nanosheets through a π - π

interaction and an electrostatic interaction due to its planar aromatics structure. Therefore, MoS₂/AuCl₄⁻ and C₁₂H₁₀N₃S⁺/AuCl₄⁻ formed two redox pairs, enabling the spontaneous transfer of electrons from MoS₂ and C₁₂H₁₀N₃S⁺ to Au ions, allowing the reduction of Au ions to AuNPs on the MoS₂ nanosheets [69][70][71].

Recently published reviews have reported on the synthesis and application of metal and metal oxide NSs [68][72]. The reviews included extensive information on the effects of structural morphology, size, and shape on the properties of NSs and their application in the field of electrochemical sensors. Interestingly, all studies clearly indicate that the shape and structural morphologies of NSs serve important roles in determining their resulting electrocatalytic properties, as the number of exposed catalytic active sites is specifically dependent on the shape of the NPs. That being said, it was also reported that a perfect shape-surface structure interaction is unrealistic and, even with a well-defined size and shape, its surface will be extremely complex. It consists of not only some ordered surface domains of different dimensions but also a defined number of defects, corners, edges, steps, and kink sites, all of which contribute to the resulting electrocatalytic activity [73].

Many methods for the preparation of size and shape-controlled metal-based NSs are now available in the literature. Various sizes, shapes, and structures can be synthesized, such as 0D NSs, which include structures, such as NPs, quantum dots, and nanospheres, as well as 1D NSs with high aspect ratios, such as nanorods, nanocombs, nanofibers, nanotubes, nanoneedles, nanoribbons, and nanowires. The 2D NSs are known as nanoplates, nanosheets, and nanopellets, while nanocrystals, multi-nanolayers, nanoflowers, and snowflakes are characterized as 3D NSs [72][74]. A comprehensive effort has been made to control the shapes and sizes of metal-based NSs in order to guarantee their efficient performances in electrochemical sensors. The synthesis of various forms of NSs not only enhances physical and chemical properties but also improves the biocompatibility and bioefficacy for the immobilization of biomolecules [68][72][75]. Moreover, due to the many active sites provided by particular NSs, a wide linear range and low detection limits have been achieved, resulting in NSs being ideal materials for the fabrication of biosensor devices. **Table 1** summarizes the various functionalization methods of MoS₂ nanosheets with different metal and metal oxide NSs, their resulting structural morphologies (size and shape), and their application in electrochemical sensors. The commonly used technique for making 2D-MoS₂/metal-NSs composites is in situ chemical growth.

Table 1. Functionalization methods of MoS₂ nanosheets with different metal and metal oxide NSs and their applications in electrochemical sensors.

	MoS ₂ -NS Composites	Method of Functionalization	Metal and Metal Oxides Structural Morphology	Size (Diameter)	Type of Sensor	Ref.
Ex situ functionalization	MoS ₂ -Au	Post immobilization	Nanoparticles	5 nm	Electrochemical biosensor	[65]
	TTR-MoS ₂ -Au	Post immobilization	Nanocrystals	-	Photoelectrochemical immunosensor	[76]
	MoS ₂ -PEI-Au	Post immobilization	Nanoparticles	12 nm	Electrochemiluminescence immunosensor	[77]
	CuO-MoS ₂	Post immobilization	Nanotubes	20 nm	Electrochemical sensor	[78]

	MoS ₂ -NS Composites	Method of Functionalization	Metal and Metal Oxides Structural Morphology	Size (Diameter)	Type of Sensor	Ref.
In situ functionalization	MoS ₂ -Au	Electrodeposition	Nanoparticles	10 nm	Electrochemical aptasensor	[13]
	MoS ₂ - MWCNT/Au	Electrodeposition	Nanoparticles	3–5 nm	Electrochemical sensor	[79]
	MoS ₂ -Au/Pt	Electrodeposition	Nanoparticles	100 nm	Electrochemical biosensor	[80]
	Cu-MoS ₂	Electrodeposition	Nanoflowers	-	Electrochemical biosensor	[81]
	ZnO-MoS ₂	Electrodeposition	Nanosheets	50 nm	Electrochemical sensor	[82]
	Ni-MoS ₂ -Naf	Chemical reduction	Nanoparticles	6 nm	Electrochemical sensor	[35]
	Au-MoS ₂	Chemical reduction	Nanoparticles	80 nm	Electrochemical sensor	[83]
	N/F/MoS ₂ -Ag	Chemical reduction	Nanoparticles	3 nm	Electrochemical sensor	[84]
	Au-Pd/MoS ₂	Chemical reduction	Nanoparticles	-	Electrochemical sensor	[85]
	TiO ₂ -MoS ₂ -Au	Chemical reduction	Nanoparticles	5–10 nm	Photoelectrochemical aptasensor	[86]
	Pt-MoS ₂	Chemical reduction	Nanoparticles	2.5 nm	Electrochemical biosensor	[87]
	PtNi-MoS ₂	Chemical reduction	Nanoparticles	1.35–6.26 nm	Electrochemical sensor	[88]
	Cu ₂ O-MoS ₂	Chemical reduction	Nanoparticles	6–18 nm	Electrochemical sensor	[89]
	PtW-MoS ₂	Chemical reduction	Nanocubes	10 nm	Electrochemical sensor	[90]
	Pd-MoS ₂	Chemical reduction	Nanoparticles	-	Electrochemical aptasensor	[91]
	PtPd-MoS ₂	Chemical reduction	Nanocubes	50 nm	Electrochemical immunosensor	[92]

MoS ₂ -NS Composites	Method of Functionalization	Metal and Metal Oxides Structural Morphology	Size (Diameter)	Type of Sensor	Ref.
Pt-MoS ₂	Chemical reduction	Nanoparticles	-	Electrochemical sensor	[93]
Ag-MoS ₂	Chemical reduction	Nanoparticles	5 nm	Electrochemical sensor	[94]
MoS ₂ -Pt	Chemical reduction	Clover-like nanoparticles	15.3–2 nm	Electrochemical sensor	[95]
Au-Pd-Pt/MoS ₂	Chemical reduction	Nanoflowers	14–26 nm	Electrochemical sensor	[96]
PdNi-MoS ₂	Chemical reduction	Nanowires	0.5–3 nm	Electrochemical sensor	[97]
MoS ₂ -Cu ₂ O-Au	Hydrothermal reaction	Nanocrystals	20–30 nm	Electrochemical immunosensor	[98]
NiO-MoS ₂	Hydrothermal reaction	Nanoparticles	38–72 nm	Electrochemical sensor	[99]
Fe ₂ O ₃ -MoS ₂	Hydrothermal reaction	Nanoflowers	-	Electrochemical sensor	[100]
Fe ₃ O ₄ -MoS ₂	Hydrothermal reaction	Nanospheres	20–30 nm	Electrochemical sensor	[101]
MoS ₂ -TiO ₂	Hydrothermal reaction	Nanorods	20 nm	Photoelectrochemical biosensing	[102]
Ag/MoS ₂ @Fe ₃ O ₄	Hydrothermal reaction	Nanospheres	50 nm	Electrochemical immunosensor	[103]
MoS ₂ -Cu ₂ O/Pt	Solvothermal reaction	Nanoparticles	15 and 3 nm	Electrochemical immunosensor	[66]
Cu-MoS ₂ -Naf	Solvothermal reaction	Nanoparticles	1–5 nm	Electrochemical sensor	[104]
NiCo ₂ O ₄ -MoS ₂	Solvothermal reaction	Nanorods	-	Electrochemical sensor	[105]

TTR; transthyretin, **PEI**; polyethylenimine, **CuO**; copper oxide, **MWCNT**; multiwalled carbon nanotubes, **Cu₂O**; cuprous oxide, **Cu**; copper, **ZnO**; zinc oxide, **Naf**; Nafion, **N/F**; nitrogen fluorine, **TiO₂**; titanium dioxide, **PtW**; platinum/tungsten, **NiO**; nickel oxide, **Fe₂O₃**, **Fe₃O₄**; iron (II, III) oxide, **NiCo₂O₄**; nickel cobaltite.

4. Properties

The 2D nanomaterials are known to have special properties, which are distinct from their 3D bulk counterparts. The 2D MoS₂ nanosheets with completely tunable properties can be synthesized successfully with various types of methods as discussed above. Due to changes in properties with a decrease in the number of layers, 2D MoS₂ nanosheets possess significantly distinctive electrical, optical, and chemical properties, which are known to play important roles in the fabrication of sensors. The exceptionally large surface areas of 2D MoS₂ nanosheets offer robust surface functionalization and provide new possibilities for functional devices based on 2D materials. MoS₂ has been reported to simply form nanocomposites with metal and metal oxide NSs [65][78], carbon nanomaterials [106][107], conductive polymers [108][109][110], and other 2D nanomaterials [111][112], which could be used as catalytic materials to significantly increase the electrochemical performance of sensors based on MoS₂-nanocomposites. The 2D MoS₂/metal-NS composites have the inherent properties of pure metal NSs and MoS₂ nanosheets due to their synergistic effects, which makes the 2D MoS₂/metal-NS composites exhibit outstanding electrochemical properties and improved sensitivity [13]. Through studying Zhang's review paper [8], one can find comprehensive insights into MoS₂ nanosheets used as building blocks or supports for the preparation of MoS₂ nanosheet-based composites with other materials.

5. Application of 2D MoS₂-Based Nanocomposites

5.1. Electrochemical Biosensors

Recently, significant progress has been made in the development of electrochemical sensors and their application in point-of-care diagnostics, environmental studies, food safety, drug screening, and security. Electrochemical sensing has proven to be a simple analytical technique for detection of various chemicals and biological molecules due to intrinsic advantages, such as high sensitivity and selectivity, real-time measurements, low-cost instrumentation, and the potential for miniaturized and portable devices. A standard electrochemical sensor has three components, namely, a recognition component that specifically binds the target analyte, a transducer where specific reactions occur and a signal is produced, and an electronic component that converts the obtained signal to a response [113]. The operating mechanism of an electrochemical sensor involves the interaction of the target analyte with the electrode surface coated with a catalyst, and producing the desired change in the signal as a result of a redox reaction [114]. The reaction results in electrical, thermal, or optical output signals that can be used to investigate the nature of the analyte species [115]. The active sensing materials could be biological or chemical compounds that function as catalysts for sensing specific analytes [115]. Sensitivity and selectivity are essential variables in electrochemical sensors. Thus, the surface modifications of electrodes by immobilization of specific chemical or biological recognition elements is an efficient technique used for obtaining optimal binding of the target analyte. Commonly used biorecognition elements include enzymes [65], antibodies and antigens [66][92], aptamers [91], proteins [116], etc., for high catalytic activity and excellent selectivity of the target analytes. Even so, the resulting signal from biorecognition molecules is not strong enough to achieve the ultra-sensitive detection of biomolecules required for early and rapid diagnosis of diseases [117]. Biorecognition molecules have therefore been integrated into nanomaterials to address this limitation, and to significantly improve the overall performance of the biosensor [118]. The 2D MoS₂ nanosheets are among the nanomaterials that have become incredibly popular for sensing applications. They have been reported to be good electrode materials for electrochemical sensing; hence, there is an increasing number of publications addressing their integration into sensors [65][104]. Although 2D MoS₂ has low electrical conductivity compared to graphene due to its large band gap limiting its use as a pristine material, 2D MoS₂ has tunable properties that depend on the crystal structure, nanosheet size, and surface defects [119][120][121], as already discussed in detail earlier. This gives researchers the opportunity to explore the electrocatalytic properties of non-functionalized 2D MoS₂ for the detection of biological molecules. In a study presented by Wang et al. [122], an electrochemical sensor based on non-functionalized MoS₂ nanosheets was fabricated for detection of DNA. The reported results indicated that the bulk MoS₂ had no electrocatalytic effect due to the low electronic conductivity that resulted from the poor interlayer electron transport. However, the exfoliated MoS₂ nanosheets showed increased electrochemical activity with a decreased change in potential (ΔE_p). The enhanced electrocatalytic activity of MoS₂ nanosheets was discovered to be due to the anisotropic layered structure of MoS₂ nanosheets, whose electronic structures and electrochemical activities are directly influenced by the layer thicknesses of the nanosheets [122].

Moreover, Sha and co-workers explored the electrocatalytic properties of hydrothermally-grown non-functionalized MoS₂ nanosheets on aluminum foil toward non-enzymatic detection of uric acid in human urine [123]. The group demonstrated a two-step successful growth of a few layered (< 4 layers) MoS₂ nanosheets with a high ratio of 1T phase MoS₂ than 2H phase MoS₂. This was not a typical sensor, in the sense that the aluminum foil was used as a sensor substrate, which contributed to the excellent selectivity and reproducibility, fast response time, and low limit of detection. The impressive sensing ability also resulted from a high proportion of the metallic 1T phase MoS₂, which provided excellent conductivity,

rapid electron transfer kinetics, and more exposed catalytic active sites arising from a significant number of surface defects [123]. The results of these two sensors are based on phenomena that describe the direct structure-dependent properties of MoS₂. Changes in the interlayer coupling, the degree of quantum confinement, and symmetry elements result in major variations in the 2D MoS₂ electronic structure compared to bulk [9][119][124][125]. The reduction in size of MoS₂ offers abundant exposed edges, kinks, and corner atoms that induce additional chemical effects [126][127]. Moreover, the quantum size effects lead to changes in the valence band and the oxidation potential, thereby enabling catalytic activities not possible with the bulk band structure [126] (**Table 2**).

Table 2. Electrochemical biosensors based on 2D-MoS₂/metal-NSs composites.

Sensor	Analyte	Electrochemical Method	Linear Range	LOD	Ref.
Au-MoS ₂ /GCE	ATP	SWV	1 nM–10 mM	0.32 nM	[13]
	Thrombin		0.01 nM–10 μM	0.0014 nM	
GCE/Ni-MoS ₂ /Naf	Glucose	Amperometry	0–4 mM	0.31 M	[35]
MoS ₂ /Au/GOx	Glucose	Amperometry	0.25–13.2 mM	0.042 μM	[65]
CuO/MoS ₂ /GCE	Glucose	Amperometry	35–800 μM	0.017 μM	[78]
MoS ₂ -Au/Pt@GCE	H ₂ O ₂	Amperometry	10 μM–19.07 mM	0.39 μM	[80]
Cu-MoS ₂ /GCE	H ₂ O ₂	Amperometry	0.04–35.6 μM	0.021 μM	[81]
	glucose		1–70 μM	0.32 μM	
ZnO/MoS ₂ /GCE	DNA	DPV	1.0 fM–1.0 μM	0.66 fM	[82]
Au@MoS ₂ /GCE	AA	DPV	20–300 μmol/L	3.0 μmol/L	[83]
	DA		5–200 μmol/L	1.0 μmol/L	
	UA		20–400 μmol/L	5.0 μmol/L	
Au-Pd/MoS ₂ /GCE	H ₂ O ₂	DPV	0.8 μM–10 Mm	0.16 μM	[85]
	Glucose	Amperometry	0.5–20 mM	0.40 mM	
Pt-MoS ₂ /GCE	H ₂ O ₂	Amperometry	0.004–48.5 mM	0.001 mM	[87]

Sensor	Analyte	Electrochemical Method	Linear Range	LOD	Ref.
PtNi@MoS ₂ /GCE	DA	DPV	0.5–250 μ M	0.1 μ M	[88]
	UA		0.5–1800 μ M	0.1 μ M	
Cu ₂ O/MoS ₂ /GCE	Glucose	Amperometry	0.01–4.0 mM	1.0 μ M	[89]
PtW/MoS ₂ /GCE	H ₂ O ₂	Chronoamperometry	1 μ M–0.2 mM	5 nM	[90]
Pd/PDDA–G–MoS ₂ /GCE	TB	DPV	0.0001–40 nM	0.062 pM	[91]
PtNPs@MoS ₂ /GCE	DA	DPV	0.5–150 μ mol/L	0.12 μ mol/L	[93]
	UA		5–1000 μ mol/L	0.8 μ mol/L	
Ag@MoS ₂ /GCE	DA	DPV	1–500 μ M	0.2 μ M	[94]
MoS ₂ -CPTNPs/GCE	DA	DPV	5–200 μ M	0.39 μ M	[95]
	UA		20–500 μ M	1.8 μ M	
Laminin/Au–Pd–Pt/MoS ₂ /SPCE	H ₂ O ₂	Amperometry	1–100 nM	0.3 nM	[96]
NiO/MoS ₂ /GCE	Glucose	Amperometry	0.01–10 mM	1.62 μ M	[99]
GCE/Cu–MoS ₂ /Nafion	Glucose	Amperometry	0–4 mM	-	[104]
NiCo ₂ O ₄ -MoS ₂ /chitosan/GCE	Glucose	Amperometry	0.0007–13.78 mM	0.23 μ M	[105]
MoS ₂ -PPY-AuNPs/GCE	Glucose	DPV	0.1–80 nM	0.08 nM	[128]
AuNPs@MoS ₂ /GCE	miRNA-21	DPV	10 fM–1 nM	0.78 fM	[129]
Chox/MoS ₂ -AuNPs/GCE	Cholesterol	Amperometry	0.5–48 μ M	0.26 $\pm$ 0.015 μ M	[130]
MoS ₂ -Au-PEI-hemin	Clenbuterol (CLB)	DPV	10 ng/mL–2 μ g/mL	1.92 ng/mL	[131]
NF/AuNPs/CuO-MoS ₂	Glucose	Chronoamperometry	0.5 μ M–5.67 mM	0.5 μ M	[132]

Sensor	Analyte	Electrochemical Method	Linear Range	LOD	Ref.
MCH/dsDNA/MoS ₂ -AuNPs/GCE	T4 polynucleotide kinase (PNK)	SWV	0.001–10 U/mL	2.18 × 10 ⁻⁴ U/mL	[133]
miRNA/MCH/SH-RNA/AuNPs-MoS ₂ /FTO	MicroRNA-155	DPV	1 fM–10 nM	0.32 fM	[134]

ATP; triphosphate, **DA**; dopamine, **DNA**; deoxyribonucleic acid, **DPV**; differential pulse voltammetry, **SWV**; square Wave Voltammetry, **PDDA-G**; poly(diallyldimethylammonium chloride)–graphene, **TB**; thrombin, **CPtNPs**; Clover-like platinum nanoparticle, **PPY**; polypyrrole, **miRNA-21**; microribonucleic acid-21, **Chox**; cholesterol oxidase, **NF**; Nafion, **MCH**; 6-mercaptohexanol, **FTO**; fluorine doped tin oxide.

5.2. Electrochemical Immunosensors

Electrochemical immunosensors (EIs) have received considerable attention due to their high sensitivity, low cost, simple instrumentation and operation, and inherent miniaturization [135][136][137]. They show great potential in the next-generation of point-of-care (POC) diagnostics for early detection and monitoring of diseases. An electrochemical immunosensor is a type of biosensor used to detect the specific antigen–antibody recognition; it quantitatively measures the resulting electrochemical signal [66][103]. The basic immunosensor concept is to load the antibody onto the electrode surface. Following the specific antigen–antibody binding, the electron transfer rate between the electrode surface and the solution interface changes, resulting in the production of membrane potential and change of the current response, which directly reflects the concentration of the targeted antigen [103]. This type of immunoassay sandwich is a common format of an immunosensor. Countless efforts have been made into the advancements of EIs to improve performance by achieving high sensitivity. This includes the use of different nanomaterials, such as layered nanomaterials [138], metal and metal oxides NSs [139][140], and carbon-based nanomaterials [141] to amplify the EI signals. Due to excellent catalytic activity and biocompatibility, MoS₂ functionalized with metal or metal oxide NSs has recently been introduced among nanocomposites used in the construction of immunosensors (**Table 3**).

Table 3. Electrochemical immunosensors based on 2D-MoS₂/metal-NSs composites.

Sensor	Analyte	Electrochemical Method	Linear Range	LOD	Ref.
MoS ₂ @Cu ₂ O-Pt/Ab ₂	hepatitis B antigen	Amperometry	0.5 pg/mL–200 ng/mL	0.15 pg/mL	[66]
BSA/anti-HBs/PtPd NCs@MoS ₂ /GCE	Hepatitis B antigen	DPV	32 fg/mL–100 ng/mL	10.2 fg/mL	[92]
MoS ₂ @Cu ₂ O-Au-Ab ₂	Alpha fetoprotein (AFP)	Amperometry	0.1 pg/mL–50 ng/mL	0.037 pg/mL	[98]
Ab ₂ -Ag/MoS ₂ @Fe ₃ O ₄ /MGCE	carcinoembryonic antigen (CEA)	DPV	0.0001–20 ng/mL	0.03 pg/mL	[103]
HRP/HRP-anti-CEA/MoS ₂ -AuNPs	carcinoembryonic antigen (CEA)	DPV	10 fg/mL–1 ng/mL	1.2 fg/mL	[142]

Sensor	Analyte	Electrochemical Method	Linear Range	LOD	Ref.
GCE/MoS ₂ -Au-Ab ₁	CEA	DPV	1 pg/mL–50 ng/mL	0.27 pg/mL	[143]
Pd NPs@MoS ₂ /NiCo	Procalcitonin	Chronoamperometry	0.001–50 ng/mL	0.36 pg/mL	[144]
Au-MoS ₂ /ITO	Triiodothyronine (T ₃)	EIS	0.01–100 ng/mL	2.5 pg/mL	[145]
Cu-MoS ₂ /GCE	3-phenoxybenzoic acid (3-PBA),	EIS	0–6 µg/mL	3.8 µM	[146]
Tac/BSA/Ab/PS-AuNRs@L-Cys-MoS ₂ /GCE	Tacrolimus (Tac)	DPV	1.0–30 ng/mL	0.17 ng/mL	[147]

Ab₁; primary antibody, **Ab₂**; secondary antibody, **HBs Ag**; Hepatitis B surface antigen, **BSA**; bovine serum albumin, **ITO**; indium tin oxide, **L-Cys**; L-cysteine, **PS-AuNRs**; polystyrene-gold nanorods.

5.3. Photoelectrochemical Sensors

PEC sensing has experienced rapid growth as an important branch of electrochemical detection. PEC analysis, due to high sensitivity, fast detection, and low background current, has been widely adopted in bioanalytical chemistry as a newly emerging and continuously developing analytical method [148]. The standard PEC sensor uses light as an excitation source and photocurrent as a signal identifier. Photoactive materials are immobilized on the electrode surface as a photo-to-current converter to generate photocurrent signals under light irradiation. The photo-to-current conversion results from the electron excitation and subsequent charge transfer of a material after absorbing photons [149][150]. The total separation of the source of excitation (light) and detection signal (photocurrent) enables this method to have the advantages of a low background signal and high sensitivity to recognize target analytes in complex samples as opposed to traditional optical methods [151][152]. Photoactive materials play critical roles in PEC systems; The PEC sensor output depends on the properties of these materials since they can influence the sensitivity and selectivity of the PEC sensor. Different photoactive materials, such as metal-based NPs [152][153], quantum dots (QDs) [154], carbon-based nanomaterials [155], layered nanomaterials [148], etc., have been studied in PEC application to fulfil specific demands. Furthermore, biological molecules, such as enzymes, antibodies, nucleic acids, etc., are also important for specific recognition in PEC biosensors and immunosensors. Amongst the photoactive materials, 2D MoS₂ is the latest emerging material for use in PEC biosensors and immunosensors because of its special optical properties. Hun et al. [148] developed a PEC sensor based on a single-layer MoS₂ nanosheet for detection of dopamine (DA). The fabricated sensor showed an incredible photocurrent response, which demonstrated that PEC activity was enhanced by the single-layer MoS₂. That is because single-layer MoS₂ exhibits exceptional semiconducting electronic properties as well as a good photocurrent with a sensitive photoresponse compared to multilayer MoS₂. The photocurrent proportionally increased with the concentration of DA in the range of 0.01 nM to 10 µM with a detection limit of 0.0023 nM. Even though different photoactive materials are available for the fabrication of PEC sensors, due to the limitations of a single material, it is difficult to achieve the ever-increasing demands for detection. However, any drawbacks of the pristine photoactive material, such as MoS₂, can be resolved by flexible nanocomposites with the tailor-made structure and composition [156]. Additionally, certain biological molecules, such as cells and DNA, can produce photocurrents by themselves. Thus, the interactions between these biomolecules and other photoactive materials can be examined through the change of photocurrents [149]. In general, PEC biosensing or immunosensing refers to the effect on the photocurrent signal of the interaction between the biorecognition molecule and the analyte, which involves the charge and energy transfer of the PEC reaction between the electron donor/acceptor and the photoactive material during light irradiation [151] (Table 4).

Table 4. Photoelectrochemical sensors based on 2D-MoS₂/metal-NSs composites.

Sensor	Analyte	Linear Range	LOD	Ref.
TTR/AuCNs/MoS ₂ /GCE	Tetrabromobisphenol A	0.1 nM–1.0 μM.	0.045 nM	[76]
BSA aptamer TiO ₂ -MoS ₂ -AuNP ITO	kanamycin	0.2 nM–450 nM	0.05 nM	[86]
GOx MoS ₂ -TiO ₂ ITO	Glucose	0.1–10.5 mM	0.015 mM	[102]
MoS ₂ -ZnO ITO	Propyl gallate	0.1249–1643 μmol/L	1.2 × 10 ⁻⁸ mol/L	[157]
Au/MoS ₂ /TiO ₂	Glucose	5–1000 μM	1.3 nM	[158]
Pro-GRP-MIP/AuNPs/2D-MoS ₂ /GCE	Pro-gastrin-releasing peptide (Pro-GRP)	0.02–5 ng/mL	0.0032 ng/mL	[159]
Au-MoS ₂ /FTO	anti-human IgG	41.7 nM–4.17 μM	4.17 nM	[160]
ITO/MTiO ₂ -AuNPs-MoS ₂ -GOx	Glucose	0.004–1.75 mM	1.2 μM	[161]
biotin DNA/MoS ₂ -AuNPs/ITO	miRNA	10 fM–1 nM	4.21 fM	[162]

MIP; molecularly imprinted polymer.

5.4. Electrochemiluminescence Sensors

ECL detection is commonly used in the various applications for biosensors. This technique combines the advantages of electrochemistry and chemiluminescence in resolving single sensing limitations, making it more desirable for precise detection and enhancement of a sensor's sensitivity and specificity. ECL refers to the light emission from an excited state produced by the electron transfer reaction between species at electrode surfaces following electrochemical reactions [163]. ECL detection consists of measuring photon output and, thus, the light intensity emitted in the solution during an electrochemical reaction. The light intensity is therefore directly proportional to the concentration of one or more of the reactants involved in the electrochemical reaction [164]. ECL has many advantages over photoluminescence, such as simplicity, high sensitivity, and rapidity response, and does not require the use of an external light source, leading to a high luminescent purity and a low optical background noise [163][165]. Furthermore, the ECL emission light can be initiated and controlled with high reproducibility and accuracy by alternating the applied potential [163][166]. Unfortunately, one of the drawbacks of the ECL method is the possibility of electrode fouling, which can result in poor reproducibility. While this could sometimes be a concern in the presence of complex samples, this effect can be avoided by frequent electrochemical cleaning of the electrodes. Moreover, new electrode materials that are less prone to fouling, such as boron-doped diamond and disposable screen-printed electrodes, have been introduced and have become more popular [167]. The continuous development of nanomaterials offers new opportunities for conventional ECL research, mainly owing to their large surface area, abundant active sites, and distinctive optical properties. Nanomaterials with good electron transfer capabilities, such as 2D nanomaterials [168], quantum dots [169], and metal nanoparticles [170], have also been implemented to improve the efficiency of ECL sensors. Among these nanomaterials, the use of 2D MoS₂ in ECL sensors is not so prominent. This is attributable to the fact that 2D MoS₂ is not capable of generating electrochemiluminescence; however, it serves other functions, such as acting as a robust substrate or amplifying the signal [171]. MoS₂ can also be used as a carrier for other nanomaterials with structural and compositional benefits to improve the ECL performance.

Table 5 summarizes the performances of a few ECL sensors that have been reported based on 2D-MoS₂/metal-NSs composites.

Table 5. Electrochemiluminescence sensors based on 2D-MoS₂/metal-NSs composites.

Sensor	Analyte	Linear Range	LOD	Ref.
luminol-Au@BSA-Ab ₂ /AFP/BSAT/Ab ₁ /Chi/MoS ₂ -PEI-Au/GCE.	Alpha fetal protein (AFP),	0.0001–200.0 ng/mL	1.0 × 10 ⁻⁵ ng/mL	[77]
BSA/Ab ₂ /ABEI-Cys/Au–Pd–Pt/MoS ₂	cystatin C (CYSC)	1.0 fg/mL–5.0 ng/mL	0.35 fg/mL	[172]
QDs–Apt ₂ /PDGF-BB/Apt ₁ /MoS ₂ –AuNPs/GCE	platelet-derived growth factor-BB	0.01–100 pmol/L	1.1 fmol/L	[173]

ABEI; N-(aminobutyl)-N-(ethylisoluminol), **PDGF-BB**; platelet-derived growth factor BB, **QDs**; quantum dots.

Focusing on the application of 2D MoS₂-metal NS composites on various electrochemical sensors, it can be inferred that 2D MoS₂ represents a new class of highly electroactive materials. The large surface areas of 2D MoS₂ nanosheets enable surface functionalization with a variety of nanomaterials, providing new opportunities for 2D material-based functional devices. The effective support structure of MoS₂ nanosheets allows for a good distribution of metal-based NSs, resulting in a synergistic effect that enhances catalytic efficiency and conductivity over a pristine MoS₂. Furthermore, 2D-MoS₂/metal-NS composites provide a convenient platform for the immobilization of biorecognition molecules and enhance electron transfer, resulting in faster reaction times as well as increased sensitivity and selectivity. Therefore, 2D MoS₂-NSs composites are thought to have considerable potential as effective electrocatalysts for the production of highly responsive electrochemical sensors with low limits of detection.

References

- Bhimanapati, G.R.; Lin, Z.; Meunier, V.; Jung, Y.; Cha, J.; Das, S.; Xiao, D.; Son, Y.; Strano, M.S.; Cooper, V.R.; et al. Recent Advances in Two-Dimensional Materials beyond Graphene. *ACS Nano* 2015, 9, 11509–11539.
- Butler, S.Z.; Hollen, S.M.; Cao, L.; Cui, Y.; Gupta, J.A.; Gutiérrez, H.R.; Heinz, T.F.; Hong, S.S.; Huang, J.; Ismach, A.F.; et al. Progress, Challenges, and Opportunities in Two-Dimensional Materials Beyond Graphene. *ACS Nano* 2013, 7, 2898–2926.
- Xu, M.; Liang, T.; Shi, M.; Chen, H. Graphene-Like Two-Dimensional Materials. *Chem. Rev.* 2013, 113, 3766–3798.
- Hu, G.; Kang, J.; Ng, L.W.T.; Zhu, X.; Howe, R.C.T.; Jones, C.G.; Hersam, M.C.; Hasan, T. Functional Inks and Printing of Two-Dimensional Materials. *Chem. Soc. Rev.* 2018, 47, 3265–3300.
- Fiori, G.; Bonaccorso, F.; Iannaccone, G.; Palacios, T.; Neumaier, D.; Seabaugh, A.; Banerjee, S.K.; Colombo, L. Electronics Based on Two-Dimensional Materials. *Nat. Nanotechnol.* 2014, 9, 768–779.
- Wang, Q.H.; Kalantar-Zadeh, K.; Kis, A.; Coleman, J.N.; Strano, M.S. Electronics and Optoelectronics of Two-Dimensional Transition Metal Dichalcogenides. *Nat. Nanotechnol.* 2012, 7, 699–712.
- Mann, J.; Ma, Q.; Odenthal, P.M.; Isarraraz, M.; Le, D.; Preciado, E.; Barroso, D.; Yamaguchi, K.; von Son Palacio, G.; Nguyen, A.; et al. 2-Dimensional Transition Metal Dichalcogenides with Tunable Direct Band Gaps: MoS₂(1–x)Se_{2x} Monolayers. *Adv. Mater.* 2014, 26, 1399–1404.
- Zhang, X.; Lai, Z.; Tan, C.; Zhang, H. Solution-Processed Two-Dimensional MoS₂ Nanosheets: Preparation, Hybridization, and Applications. *Angew. Chem. Int. Ed.* 2016, 55, 8816–8838.
- Das, S.; Kim, M.; Lee, J.; Choi, W. Synthesis, Properties, and Applications of 2-D Materials: A Comprehensive Review. *Crit. Rev. Solid State Mater. Sci.* 2014, 39, 231–252.
- Mutalik, C.; Krisnawati, D.I.; Patil, S.B.; Khafid, M.; Atmojo, D.S.; Santoso, P.; Lu, S.-C.; Wang, D.-Y.; Kuo, T.-R. Phase-Dependent MoS₂ Nanoflowers for Light-Driven Antibacterial Application. *ACS Sustain. Chem. Eng.* 2021, 9, 7904–7912.
- Hossain, R.F.; Deaguero, I.G.; Boland, T.; Kaul, A.B. Solution Dispersed 2D Graphene & MoS₂ for an Inkjet Printed Biocompatible Photodetector. In Proceedings of the 2016 Lester Eastman Conference (LEC), Bethlehem, PI, USA, 2–4 August 2016; pp. 19–22.

12. Radisavljevic, B.; Radenovic, A.; Brivio, J.; Giacometti, V.; Kis, A. Single-Layer MoS₂ Transistors. *Nat. Nanotechnol.* 2011, 6, 147–150.
13. Su, S.; Sun, H.; Cao, W.; Chao, J.; Peng, H.; Zuo, X.; Yuwen, L.; Fan, C.; Wang, L. Dual-Target Electrochemical Biosensing Based on DNA Structural Switching on Gold Nanoparticle-Decorated MoS₂ Nanosheets. *ACS Appl. Mater. Interfaces* 2016, 8, 6826–6833.
14. Kabachii, Y.A.; Golub, A.S.; Kochev, S.Y.; Lenenko, N.D.; Abramchuk, S.S.; Antipin, M.Y.; Valetsky, P.M.; Stein, B.D.; Mahmoud, W.E.; Al-Ghamdi, A.A.; et al. Multifunctional Nanohybrids by Self-Assembly of Monodisperse Iron Oxide Nanoparticles and Nanolamellar MoS₂ Plates. *Chem. Mater.* 2013, 25, 2434–2440.
15. Sreeprasad, T.S.; Nguyen, P.; Kim, N.; Berry, V. Controlled, Defect-Guided, Metal-Nanoparticle Incorporation onto MoS₂ via Chemical and Microwave Routes: Electrical, Thermal, and Structural Properties. *Nano Lett.* 2013, 13, 4434–4441.
16. Yu, S.H.; Lee, Y.; Jang, S.K.; Kang, J.; Jeon, J.; Lee, C.; Lee, J.Y.; Kim, H.; Hwang, E.; Lee, S.; et al. Dye-Sensitized MoS₂ Photodetector with Enhanced Spectral Photoresponse. *ACS Nano* 2014, 8, 8285–8291.
17. Gomathi, P.T.; Sahatiya, P.; Badhulika, S. Large-Area, Flexible Broadband Photodetector Based on ZnS–MoS₂ Hybrid on Paper Substrate. *Adv. Funct. Mater.* 2017, 27, 1701611.
18. Zhang, H.; Tian, Y.; Zhao, J.; Cai, Q.; Chen, Z. Small Dopants Make Big Differences: Enhanced Electrocatalytic Performance of MoS₂ Monolayer for Oxygen Reduction Reaction (ORR) by N- and P-Doping. *Electrochim. Acta* 2017, 225, 543–550.
19. Cui, S.; Wen, Z.; Huang, X.; Chang, J.; Chen, J. Stabilizing MoS₂ Nanosheets through SnO₂ Nanocrystal Decoration for High-Performance Gas Sensing in Air. *Small* 2015, 11, 2305–2313.
20. Zhang, D.; Sun, Y.; Jiang, C.; Yao, Y.; Wang, D.; Zhang, Y. Room-Temperature Highly Sensitive CO Gas Sensor Based on Ag-Loaded Zinc Oxide/Molybdenum Disulfide Ternary Nanocomposite and Its Sensing Properties. *Sens. Actuators B Chem.* 2017, 253, 1120–1128.
21. Fedorov, V.E.; Naumov, N.G.; Lavrov, A.N.; Tarasenko, M.S.; Artemkina, S.B.; Romanenko, A.I.; Medvedev, M.V. Tuning Electronic Properties of Molybdenum Disulfide by a Substitution in Metal Sublattice. In *Proceedings of the 2013 36th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*, Opatija, Croatia, 20–24 May 2013; pp. 11–14.
22. Chen, X.; Berner, N.C.; Backes, C.; Duesberg, G.S.; McDonald, A.R. Functionalization of Two-Dimensional MoS₂: On the Reaction Between MoS₂ and Organic Thiols. *Angew. Chem. Int. Ed.* 2016, 55, 5803–5808.
23. Wu, S.; Zeng, Z.; He, Q.; Wang, Z.; Wang, S.J.; Du, Y.; Yin, Z.; Sun, X.; Chen, W.; Zhang, H. Electrochemically Reduced Single-Layer MoS₂ Nanosheets: Characterization, Properties, and Sensing Applications. *Small* 2012, 8, 2264–2270.
24. Najmaei, S.; Zou, X.; Er, D.; Li, J.; Jin, Z.; Gao, W.; Zhang, Q.; Park, S.; Ge, L.; Lei, S.; et al. Tailoring the Physical Properties of Molybdenum Disulfide Monolayers by Control of Interfacial Chemistry. *Nano Lett.* 2014, 14, 1354–1361.
25. Mouri, S.; Miyauchi, Y.; Matsuda, K. Tunable Photoluminescence of Monolayer MoS₂ via Chemical Doping. *Nano Lett.* 2013, 13, 5944–5948.
26. Kang, Y.; Najmaei, S.; Liu, Z.; Bao, Y.; Wang, Y.; Zhu, X.; Halas, N.J.; Nordlander, P.; Ajayan, P.M.; Lou, J.; et al. Plasmonic Hot Electron Induced Structural Phase Transition in a MoS₂ Monolayer. *Adv. Mater.* 2014, 26, 6467–6471.
27. Lin, Y.-C.; Dumcenco, D.O.; Huang, Y.-S.; Suenaga, K. Atomic Mechanism of the Semiconducting-to-Metallic Phase Transition in Single-Layered MoS₂. *Nat. Nanotechnol.* 2014, 9, 391–396.
28. Sarkar, D.; Xie, X.; Kang, J.; Zhang, H.; Liu, W.; Navarrete, J.; Moskovits, M.; Banerjee, K. Functionalization of Transition Metal Dichalcogenides with Metallic Nanoparticles: Implications for Doping and Gas-Sensing. *Nano Lett.* 2015, 15, 2852–2862.
29. Chen, X.; McDonald, A.R. Functionalization of Two-Dimensional Transition-Metal Dichalcogenides. *Adv. Mater.* 2016, 28, 5738–5746.
30. Wang, Y.; Wang, B.; Huang, R.; Gao, B.; Kong, F.; Zhang, Q. First-Principles Study of Transition-Metal Atoms Adsorption on MoS₂ Monolayer. *Phys. E Low-Dimens. Syst. Nanostruct.* 2014, 63, 276–282.
31. Lu, J.; Lu, J.H.; Liu, H.; Liu, B.; Gong, L.; Tok, E.S.; Loh, K.P.; Sow, C.H. Microlandscaping of Au Nanoparticles on Few-Layer MoS₂ Films for Chemical Sensing. *Small* 2015, 11, 1792–1800.
32. Tan, Y.; Liu, P.; Chen, L.; Cong, W.; Ito, Y.; Han, J.; Guo, X.; Tang, Z.; Fujita, T.; Hirata, A.; et al. Monolayer MoS₂ Films Supported by 3D Nanoporous Metals for High-Efficiency Electrocatalytic Hydrogen Production. *Adv. Mater.* 2014, 26, 8023–8028.

33. Shi, Y.; Wang, J.; Wang, C.; Zhai, T.-T.; Bao, W.-J.; Xu, J.-J.; Xia, X.-H.; Chen, H.-Y. Hot Electron of Au Nanorods Activates the Electrocatalysis of Hydrogen Evolution on MoS₂ Nanosheets. *J. Am. Chem. Soc.* 2015, 137, 7365–7370.
34. Miao, J.; Hu, W.; Jing, Y.; Luo, W.; Liao, L.; Pan, A.; Wu, S.; Cheng, J.; Chen, X.; Lu, W. Au Nanoarrays: Surface Plasmon-Enhanced Photodetection in Few Layer MoS₂ Phototransistors with Au Nanostructure Arrays (Small 20/2015). *Small* 2015, 11, 2346.
35. Huang, J.; He, Y.; Jin, J.; Li, Y.; Dong, Z.; Li, R. A Novel Glucose Sensor Based on MoS₂ Nanosheet Functionalized with Ni Nanoparticles. *Electrochim. Acta* 2014, 136, 41–46.
36. Su, S.; Sun, H.; Xu, F.; Yuwen, L.; Wang, L. Highly Sensitive and Selective Determination of Dopamine in the Presence of Ascorbic Acid Using Gold Nanoparticles-Decorated MoS₂ Nanosheets Modified Electrode. *Electroanalysis* 2013, 25, 2523–2529.
37. Zhang, D.; Jiang, C.; Li, P.; Sun, Y. Layer-by-Layer Self-Assembly of Co₃O₄ Nanorod-Decorated MoS₂ Nanosheet-Based Nanocomposite toward High-Performance Ammonia Detection. *ACS Appl. Mater. Interfaces* 2017, 9, 6462–6471.
38. Li, H.; Wu, J.; Yin, Z.; Zhang, H. Preparation and Applications of Mechanically Exfoliated Single-Layer and Multilayer MoS₂ and WSe₂ Nanosheets. *Acc. Chem. Res.* 2014, 47, 1067–1075.
39. Joensen, P.; Frindt, R.F.; Morrison, S.R. Single-Layer MoS₂. *Mater. Res. Bull.* 1986, 21, 457–461.
40. Ambrosi, A.; Sofer, Z.; Pumera, M. Lithium Intercalation Compound Dramatically Influences the Electrochemical Properties of Exfoliated MoS₂. *Small* 2015, 11, 605–612.
41. Grayfer, E.D.; Kozlova, M.N.; Fedorov, V.E. Colloidal 2D Nanosheets of MoS₂ and Other Transition Metal Dichalcogenides through Liquid-Phase Exfoliation. *Adv. Colloid Interface Sci.* 2017, 245, 40–61.
42. Eda, G.; Yamaguchi, H.; Voiry, D.; Fujita, T.; Chen, M.; Chhowalla, M. Photoluminescence from Chemically Exfoliated MoS₂. *Nano Lett.* 2011, 11, 5111–5116.
43. Coleman, J.N.; Lotya, M.; O'Neill, A.; Bergin, S.D.; King, P.J.; Khan, U.; Young, K.; Gaucher, A.; De, S.; Smith, R.J.; et al. Two-Dimensional Nanosheets Produced by Liquid Exfoliation of Layered Materials. *Science* 2011, 331, 568–571.
44. Bonaccorso, F.; Sun, Z. Solution Processing of Graphene, Topological Insulators and Other 2d Crystals for Ultrafast Photonics. *Opt. Mater. Express* 2014, 4, 63–78.
45. Paton, K.R.; Varrla, E.; Backes, C.; Smith, R.J.; Khan, U.; O'Neill, A.; Boland, C.; Lotya, M.; Istrate, O.M.; King, P.; et al. Scalable Production of Large Quantities of Defect-Free Few-Layer Graphene by Shear Exfoliation in Liquids. *Nat. Mater.* 2014, 13, 624–630.
46. Varrla, E.; Backes, C.; Paton, K.R.; Harvey, A.; Gholamvand, Z.; McCauley, J.; Coleman, J.N. Large-Scale Production of Size-Controlled MoS₂ Nanosheets by Shear Exfoliation. *Chem. Mater.* 2015, 27, 1129–1139.
47. May, P.; Khan, U.; O'Neill, A.; Coleman, J.N. Approaching the Theoretical Limit for Reinforcing Polymers with Graphene. *J. Mater. Chem.* 2012, 22, 1278–1282.
48. Gupta, A.; Arunachalam, V.; Vasudevan, S. Liquid-Phase Exfoliation of MoS₂ Nanosheets: The Critical Role of Trace Water. *J. Phys. Chem. Lett.* 2016, 7, 4884–4890.
49. Li, J.; Wu, Q.; Wu, J. Synthesis of Nanoparticles via Solvothermal and Hydrothermal Methods BT—Handbook of Nanoparticles; Aliofkhaezrai, M., Ed.; Springer International Publishing: Cham, Switzerland, 2015; pp. 1–28.
50. Chaudhary, N.; Khanuja, M.; Islam, S.S. Hydrothermal Synthesis of MoS₂ Nanosheets for Multiple Wavelength Optical Sensing Applications. *Sens. Actuators A Phys.* 2018, 277, 190–198.
51. Rajamathi, M.; Seshadri, R. Oxide and Chalcogenide Nanoparticles from Hydrothermal/Solvothermal Reactions. *Curr. Opin. Solid State Mater. Sci.* 2002, 6, 337–345.
52. Wang, X.; Feng, H.; Wu, Y.; Jiao, L. Controlled Synthesis of Highly Crystalline MoS₂ Flakes by Chemical Vapor Deposition. *J. Am. Chem. Soc.* 2013, 135, 5304–5307.
53. Ago, H.; Ito, Y.; Mizuta, N.; Yoshida, K.; Hu, B.; Orofeo, C.M.; Tsuji, M.; Ikeda, K.; Mizuno, S. Epitaxial Chemical Vapor Deposition Growth of Single-Layer Graphene over Cobalt Film Crystallized on Sapphire. *ACS Nano* 2010, 4, 7407–7414.
54. Nguyen, E.P.; Carey, B.J.; Ou, J.Z.; van Embden, J.; Della Gaspera, E.; Chrimes, A.F.; Spencer, M.J.S.; Zhuiykov, S.; Kalantar-Zadeh, K.; Daeneke, T. Electronic Tuning of 2D MoS₂ through Surface Functionalization. *Adv. Mater.* 2015, 27, 6225–6229.
55. KC, S.; Longo, R.C.; Addou, R.; Wallace, R.M.; Cho, K. Impact of Intrinsic Atomic Defects on the Electronic Structure of MoS₂ monolayers. *Nanotechnology* 2014, 25, 375703.

56. Zhong, X.; Yang, H.; Guo, S.; Li, S.; Gou, G.; Niu, Z.; Dong, Z.; Lei, Y.; Jin, J.; Li, R.; et al. In Situ Growth of Ni–Fe Alloy on Graphene-like MoS₂ for Catalysis of Hydrazine Oxidation. *J. Mater. Chem.* 2012, 22, 13925–13927.
57. Kibsgaard, J.; Chen, Z.; Reinecke, B.N.; Jaramillo, T.F. Engineering the Surface Structure of MoS₂ to Preferentially Expose Active Edge Sites for Electrocatalysis. *Nat. Mater.* 2012, 11, 963–969.
58. Kwon, H.J.; Shin, K.; Soh, M.; Chang, H.; Kim, J.; Lee, J.; Ko, G.; Kim, B.H.; Kim, D.; Hyeon, T. Large-Scale Synthesis and Medical Applications of Uniform-Sized Metal Oxide Nanoparticles. *Adv. Mater.* 2018, 30, 1704290.
59. Huang, A.; He, Y.; Zhou, Y.Y.; Zhou, Y.Y.; Yang, Y.; Zhang, J.; Luo, L.; Mao, Q.; Hou, D.; Yang, J. A Review of Recent Applications of Porous Metals and Metal Oxide in Energy Storage, Sensing and Catalysis. *J. Mater. Sci.* 2019, 54, 949–973.
60. Falcaro, P.; Ricco, R.; Yazdi, A.; Imaz, I.; Furukawa, S.; Maspoch, D.; Ameloot, R.; Evans, J.D.; Doonan, C.J. Application of Metal and Metal Oxide Coord. *Chem. Rev.* 2016, 307, 237–254.
61. Chavali, M.S.; Nikolova, M.P. Metal Oxide Nanoparticles and Their Applications in Nanotechnology. *SN Appl. Sci.* 2019, 1, 607.
62. Huang, Q.; Zhu, Y. Printing Conductive Nanomaterials for Flexible and Stretchable Electronics: A Review of Materials, Processes, and Applications. *Adv. Mater. Technol.* 2019, 4, 1800546.
63. Corr, S.A. Metal Oxide Nanoparticles. *Nanoscience* 2013, 1, 180–207.
64. Guo, S.; Wang, E. Noble Metal Nanomaterials: Controllable Synthesis and Application in Fuel Cells and Analytical Sensors. *Nano Today* 2011, 6, 240–264.
65. Parlak, O.; İncel, A.; Uzun, L.; Turner, A.P.F.; Tiwari, A. Structuring Au Nanoparticles on Two-Dimensional MoS₂ Nanosheets for Electrochemical Glucose Biosensors. *Biosens. Bioelectron.* 2017, 89, 545–550.
66. Li, F.; Li, Y.; Feng, J.; Gao, Z.; Lv, H.; Ren, X.; Wei, Q. Facile Synthesis of MoS₂@Cu₂O–Pt Nanohybrid as Enzyme-Mimetic Label for the Detection of the Hepatitis B Surface Antigen. *Biosens. Bioelectron.* 2018, 100, 512–518.
67. Lassoued, A.; Dkhil, B.; Gadri, A.; Ammar, S. Control of the Shape and Size of Iron Oxide (α -Fe₂O₃) Nanoparticles Synthesized through the Chemical Precipitation Method. *Results Phys.* 2017, 7, 3007–3015.
68. Xiao, T.; Huang, J.; Wang, D.; Meng, T.; Yang, X. Au and Au-Based Nanomaterials: Synthesis and Recent Progress in Electrochemical Sensor Applications. *Talanta* 2020, 206, 120210.
69. Su, S.; Zou, M.; Zhao, H.; Yuan, C.; Xu, Y.; Zhang, C.; Wang, L.; Fan, C.; Wang, L. Shape-Controlled Gold Nanoparticles Supported on MoS₂ Nanosheets: Synergistic Effect of Thionine and MoS₂ and Their Application for Electrochemical Label-Free Immunosensing. *Nanoscale* 2015, 7, 19129–19135.
70. Han, J.; Ma, J.; Ma, Z. One-Step Synthesis of Graphene Oxide–Thionine–Au Nanocomposites and Its Application for Electrochemical Immunosensing. *Biosens. Bioelectron.* 2013, 47, 243–247.
71. Su, S.; Zhang, C.; Yuwen, L.; Chao, J.; Zuo, X.; Liu, X.; Song, C.; Fan, C.; Wang, L. Creating SERS Hot Spots on MoS₂ Nanosheets with in Situ Grown Gold Nanoparticles. *ACS Appl. Mater. Interfaces* 2014, 6, 18735–18741.
72. Shetti, N.P.; Bukkigar, S.D.; Reddy, K.R.; Reddy, C.V.; Aminabhavi, T.M. ZnO-Based Nanostructured Electrodes for Electrochemical Sensors and Biosensors in Biomedical Applications. *Biosens. Bioelectron.* 2019, 141, 111417.
73. Montiel, M.A.; Vidal-Iglesias, F.J.; Montiel, V.; Solla-Gullón, J. Electrocatalysis on Shape-Controlled Metal Nanoparticles: Progress in Surface Cleaning Methodologies. *Curr. Opin. Electrochem.* 2017, 1, 34–39.
74. Kebede, M.A.; Imae, T. Chapter 1.1—Low-Dimensional Nanomaterials. In *Micro and Nano Technologies*; Ariga, K., Aono, M.B.T.-A.S.N., Eds.; William Andrew Publishing: London, UK, 2019; pp. 3–16.
75. Singh, A.K.; Srivastava, O.N.; Singh, K. Shape and Size-Dependent Magnetic Properties of Fe₃O₄ Nanoparticles Synthesized Using Piperidine. *Nanoscale Res. Lett.* 2017, 12, 298.
76. Wang, Y.; Chen, F.; Ye, X.; Wu, T.; Wu, K.; Li, C. Photoelectrochemical Immunosensing of Tetrabromobisphenol A Based on the Enhanced Effect of Dodecahedral Gold Nanocrystals/MoS₂ Nanosheets. *Sens. Actuators B Chem.* 2017, 245, 205–212.
77. Zhang, X.; Guo, W.; Wang, Z.; Ke, H.; Zhao, W.; Zhang, A.; Huang, C.; Jia, N. A Sandwich Electrochemiluminescence Immunosensor for Highly Sensitive Detection of Alpha Fetal Protein Based on MoS₂–PEI–Au Nanocomposites and Core/Shell Nanoparticles. *Sens. Actuators B Chem.* 2017, 253, 470–477.
78. Arunbalaji, S.; Vasudevan, R.; Arivanandhan, M.; Alsalmeh, A.; Alghamdi, A.; Jayavel, R. CuO/MoS₂ Nanocomposites for Rapid and High Sensitive Non-Enzymatic Glucose Sensors. *Ceram. Int.* 2020, 46, 16879–16885.
79. Zhang, Y.; Wen, F.; Tan, J.; Jiang, C.; Zhu, M.; Chen, Y.; Wang, H. Highly Efficient Electrocatalytic Oxidation of Nitrite by Electrodeposition of Au Nanoparticles on Molybdenum Sulfide and Multi-Walled Carbon Nanotubes. *J. Electroanal.*

80. Zhou, J.; Zhao, Y.; Bao, J.; Huo, D.; Fa, H.; Shen, X.; Hou, C. One-Step Electrodeposition of Au-Pt Bimetallic Nanoparticles on MoS₂ Nanoflowers for Hydrogen Peroxide Enzyme-Free Electrochemical Sensor. *Electrochim. Acta* 2017, 250, 152–158.
81. Lin, X.; Ni, Y.; Kokot, S. Electrochemical and Bio-Sensing Platform Based on a Novel 3D Cu Nano-Flowers/Layered MoS₂ Composite. *Biosens. Bioelectron.* 2016, 79, 685–692.
82. Yang, T.; Chen, M.; Kong, Q.; Luo, X.; Jiao, K. Toward DNA Electrochemical Sensing by Free-Standing ZnO Nanosheets Grown on 2D Thin-Layered MoS₂. *Biosens. Bioelectron.* 2017, 89, 538–544.
83. Zou, H.L.; Li, B.L.; Luo, H.Q.; Li, N.B. 0D-2D Heterostructures of Au Nanoparticles and Layered MoS₂ for Simultaneous Detections of Dopamine, Ascorbic Acid, Uric Acid, and Nitrite. *Sens. Actuators B Chem.* 2017, 253, 352–360.
84. Song, D.; Wang, Y.; Lu, X.; Gao, Y.; Li, Y.; Gao, F. Ag Nanoparticles-Decorated Nitrogen-Fluorine Co-Doped Monolayer MoS₂ Nanosheet for Highly Sensitive Electrochemical Sensing of Organophosphorus Pesticides. *Sens. Actuators B Chem.* 2018, 267, 5–13.
85. Li, X.; Du, X. Molybdenum Disulfide Nanosheets Supported Au-Pd Bimetallic Nanoparticles for Non-Enzymatic Electrochemical Sensing of Hydrogen Peroxide and Glucose. *Sens. Actuators B Chem.* 2017, 239, 536–543.
86. Liu, X.; Liu, P.; Tang, Y.; Yang, L.; Li, L.; Qi, Z.; Li, D.; Wong, D.K.Y. A Photoelectrochemical Aptasensor Based on a 3D Flower-like TiO₂-MoS₂-Gold Nanoparticle Heterostructure for Detection of Kanamycin. *Biosens. Bioelectron.* 2018, 112, 193–201.
87. Duan, K.; Du, Y.; Feng, Q.; Ye, X.; Xie, H.; Xue, M.; Wang, C. Synthesis of Platinum Nanoparticles by Using Molybdenum Disulfide as a Template and Its Application to Enzyme-like Catalysis. *ChemCatChem* 2014, 6, 1873–1876.
88. Ma, L.; Zhang, Q.; Wu, C.; Zhang, Y.; Zeng, L. PtNi Bimetallic Nanoparticles Loaded MoS₂ Nanosheets: Preparation and Electrochemical Sensing Application for the Detection of Dopamine and Uric Acid. *Anal. Chim. Acta* 2019, 1055, 17–25.
89. Fang, L.; Wang, F.; Chen, Z.; Qiu, Y.; Zhai, T.; Hu, M.; Zhang, C.; Huang, K. Flower-like MoS₂ Decorated with Cu₂O Nanoparticles for Non-Enzymatic Amperometric Sensing of Glucose. *Talanta* 2017, 167, 593–599.
90. Zhu, L.; Zhang, Y.; Xu, P.; Wen, W.; Li, X.; Xu, J. PtW/MoS₂ Hybrid Nanocomposite for Electrochemical Sensing of H₂O₂ Released from Living Cells. *Biosens. Bioelectron.* 2016, 80, 601–606.
91. Jing, P.; Yi, H.; Xue, S.; Chai, Y.; Yuan, R.; Xu, W. A Sensitive Electrochemical Aptasensor Based on Palladium Nanoparticles Decorated Graphene–Molybdenum Disulfide Flower-like Nanocomposites and Enzymatic Signal Amplification. *Anal. Chim. Acta* 2015, 853, 234–241.
92. Tan, Z.; Dong, H.; Liu, Q.; Liu, H.; Zhao, P.; Wang, P.; Li, Y.; Zhang, D.; Zhao, Z.; Dong, Y. A Label-Free Immunosensor Based on PtPd 2 Nanoenzymes for Hepatitis B Surface Antigen Detection. *Biosens. Bioelectron.* 2019, 142, 111556.
93. Chao, J.; Han, X.; Sun, H.; Su, S.; Weng, L.; Wang, L. Platinum Nanoparticles Supported MoS₂ Nanosheet for Simultaneous Detection of Dopamine and Uric Acid. *Sci. China Chem.* 2016, 59, 332–337.
94. Sookhakian, M.; Basirun, W.J.; Goh, B.T.; Woi, P.M.; Alias, Y. Molybdenum Disulfide Nanosheet Decorated with Silver Nanoparticles for Selective Detection of Dopamine. *Colloids Surf. B Biointerfaces* 2019, 176, 80–86.
95. Zhu, Z.; Jin, C.; Miao, X.; Shen, Y. Simultaneous Determination of Dopamine and Uric Acid on a MoS₂-CPTNPs Nanocomposite-Modified Electrode. *Int. J. Electrochem. Sci.* 2020, 15, 3969–3979.
96. Dou, B.; Yang, J.; Yuan, R.; Xiang, Y. Trimetallic Hybrid Nanoflower-Decorated MoS₂ Nanosheet Sensor for Direct in Situ Monitoring of H₂O₂ Secreted from Live Cancer Cells. *Anal. Chem.* 2018, 90, 5945–5950.
97. Song, D.; Li, Q.; Lu, X.; Li, Y.; Li, Y.; Wang, Y.; Gao, F. Ultra-Thin Bimetallic Alloy Nanowires with Porous Architecture/Monolayer MoS₂ Nanosheet as a Highly Sensitive Platform for the Electrochemical Assay of Hazardous Omethoate Pollutant. *J. Hazard. Mater.* 2018, 357, 466–474.
98. Ma, N.; Zhang, T.; Fan, D.; Kuang, X.; Ali, A.; Wu, D.; Wei, Q. Triple Amplified Ultrasensitive Electrochemical Immunosensor for Alpha Fetoprotein Detection Based on MoS₂@Cu₂O-Au Nanoparticles. *Sens. Actuators B Chem.* 2019, 297, 126821.
99. Jeevanandham, G.; Jerome, R.; Murugan, N.; Preethika, M.; VEDIAPPAN, K.; Sundramoorthy, A.K. Nickel Oxide Decorated MoS₂ Nanosheet-Based Non-Enzymatic Sensor for the Selective Detection of Glucose. *RSC Adv.* 2020, 10, 643–654.
100. Wang, H.; Chen, P.; Wen, F.; Zhu, Y.; Zhang, Y. Flower-like 2 Nanocomposite Decorated Glassy Carbon Electrode for the Determination of Nitrite. *Sens. Actuators B Chem.* 2015, 220, 749–754.

101. Zhang, Y.; Chen, P.; Wen, F.; Yuan, B.; Wang, H. Fe₃O₄ Nanospheres on MoS₂ Nanoflake: Electrocatalysis and Detection of Cr(VI) and Nitrite. *J. Electroanal. Chem.* 2016, 761, 14–20.
102. Liu, X.; Huo, X.; Liu, P.; Tang, Y.; Xu, J.; Liu, X.; Zhou, Y. Assembly of MoS₂ Nanosheet-TiO₂ Nanorod Heterostructure as Sensor Scaffold for Photoelectrochemical Biosensing. *Electrochim. Acta* 2017, 242, 327–336.
103. Wang, Y.; Zhao, G.; Zhang, Y.; Pang, X.; Cao, W.; Du, B.; Wei, Q. Sandwich-Type Electrochemical Immunosensor for CEA Detection Based on Ag/MoS₂@Fe₃O₄ and an Analogous ELISA Method with Total Internal Reflection Microscopy. *Sens. Actuators B Chem.* 2018, 266, 561–569.
104. Huang, J.; Dong, Z.; Li, Y.; Li, J.; Tang, W.; Yang, H.; Wang, J.; Bao, Y.; Jin, J.; Li, R. MoS₂ Nanosheet Functionalized with Cu Nanoparticles and Its Application for Glucose Detection. *Mater. Res. Bull.* 2013, 48, 4544–4547.
105. Zhao, H.; Xu, J.; Sheng, Q.; Zheng, J.; Cao, W.; Yue, T. NiCo₂O₄ Nanorods Decorated MoS₂ Nanosheets Synthesized from Deep Eutectic Solvents and Their Application for Electrochemical Sensing of Glucose in Red Wine and Honey. *J. Electrochem. Soc.* 2019, 166, H404–H411.
106. Govindasamy, M.; Mani, V.; Chen, S.M.; Karthik, R.; Manibalan, K.; Umamaheswari, R. MoS₂ Flowers Grown on Graphene/Carbon Nanotubes: A Versatile Substrate for Electrochemical Determination of Hydrogen Peroxide. *Int. J. Electrochem. Sci.* 2016, 11, 2954–2961.
107. Li, C.; Zhang, D.; Wang, J.; Hu, P.; Jiang, Z. Magnetic MoS₂ on Multiwalled Carbon Nanotubes for Sulfide Sensing. *Anal. Chim. Acta* 2017, 975, 61–69.
108. Yang, T.; Chen, H.; Ge, T.; Wang, J.; Li, W.; Jiao, K. Highly Sensitive Determination of Chloramphenicol Based on Thin-Layered MoS₂/Polyaniline Nanocomposite. *Talanta* 2015, 144, 1324–1328.
109. Sadeghi, M.; Jahanshahi, M.; Javadian, H. Highly Sensitive Biosensor for Detection of DNA Nucleobases: Enhanced Electrochemical Sensing Based on Polyaniline/Single-Layer MoS₂ Nanosheets Nanocomposite Modified Carbon Paste Electrode. *Microchem. J.* 2020, 152, 104315.
110. Li, Y.; Lin, H.; Peng, H.; Qi, R.; Luo, C. A Glassy Carbon Electrode Modified with MoS₂ Nanosheets and Poly(3,4-Ethylenedioxythiophene) for Simultaneous Electrochemical Detection of Ascorbic Acid, Dopamine and Uric Acid. *Microchim. Acta* 2016, 183, 2517–2523.
111. Huang, K.-J.; Wang, L.; Li, J.; Liu, Y.-M. Electrochemical Sensing Based on Layered MoS₂–Graphene Composites. *Sens. Actuators B Chem.* 2013, 178, 671–677.
112. Lee, C.; Rath, S.; Khan, M.A.; Lim, D.; Kim, Y.; Yun, S.J.; Youn, D.-H.; Watanabe, K.; Taniguchi, T.; Kim, G.-H. Comparison of Trapped Charges and Hysteresis Behavior in HBN Encapsulated Single MoS₂ Flake Based Field Effect Transistors on SiO₂ and HBN Substrates. *Nanotechnology* 2018, 29, 335202.
113. Keçili, R.; Büyüktiryaki, S.; Hussain, C.M. Chapter 57—Engineered Nanosensors Based on Molecular Imprinting Technology. In *Micro and Nano Technologies*; Hussain, C.M., Ed.; Elsevier: Amsterdam, The Netherlands, 2018; pp. 1031–1046.
114. Ananda Murthy, H.C.; Wagassa, A.N.; Ravikumar, C.R.; Nagaswarupa, H.P. 17—Functionalized Metal and Metal Oxide Nanomaterial-Based Electrochemical Sensors. In *Woodhead Publishing Series in Electronic and Optical Materials*; Hussain, C.M., Manjunatha, J.G., Eds.; Woodhead Publishing: Cambridge, UK, 2022; pp. 369–392.
115. Yogeswaran, U.; Chen, S.-M. A Review on the Electrochemical Sensors and Biosensors Composed of Nanowires as Sensing Material. *Sensors* 2008, 8, 290–313.
116. Chao, J.; Zou, M.; Zhang, C.; Sun, H.; Pan, D.; Pei, H.; Su, S.; Yuwen, L.; Fan, C.; Wang, L. A MoS₂-Based System for Efficient Immobilization of Hemoglobin and Biosensing Applications. *Nanotechnology* 2015, 26, 274005.
117. Yang, H. Enzyme-Based Ultrasensitive Electrochemical Biosensors. *Curr. Opin. Chem. Biol.* 2012, 16, 422–428.
118. Putzbach, W.; Ronkainen, N.J. Immobilization Techniques in the Fabrication of Nanomaterial-Based Electrochemical Biosensors: A Review. *Sensors* 2013, 13, 4811–4840.
119. Kuc, A.; Zibouche, N.; Heine, T. Influence of Quantum Confinement on the Electronic Structure of the Transition Metal Sulfide T S 2. *Phys. Rev. B* 2011, 83, 245213.
120. Splendiani, A.; Sun, L.; Zhang, Y.; Li, T.; Kim, J.; Chim, C.-Y.; Galli, G.; Wang, F. Emerging Photoluminescence in Monolayer MoS₂. *Nano Lett.* 2010, 10, 1271–1275.
121. Kim, E.; Lee, Y.; Ko, C.; Park, Y.; Yeo, J.; Chen, Y.; Choe, H.S.; Allen, F.I.; Rho, J.; Tongay, S.; et al. Tuning the Optical and Electrical Properties of MoS₂ by Selective Ag Photo-Reduction. *Appl. Phys. Lett.* 2018, 113, 13105.
122. Wang, X.; Nan, F.; Zhao, J.; Yang, T.; Ge, T.; Jiao, K. A Label-Free Ultrasensitive Electrochemical DNA Sensor Based on Thin-Layer MoS₂ Nanosheets with High Electrochemical Activity. *Biosens. Bioelectron.* 2015, 64, 386–391.

123. Sha, R.; Vishnu, N.; Badhulika, S. MoS₂ Based Ultra-Low-Cost, Flexible, Non-Enzymatic and Non-Invasive Electrochemical Sensor for Highly Selective Detection of Uric Acid in Human Urine Samples. *Sens. Actuators B Chem.* 2019, 279, 53–60.
124. Mak, K.F.; Lee, C.; Hone, J.; Shan, J.; Heinz, T.F. Atomically thin MoS₂: A new direct-gap semiconductor. *Phys. Rev. Lett.* 2010, 105, 136805.
125. Kadantsev, E.S.; Hawrylak, P. Electronic Structure of a Single MoS₂ Monolayer. *Solid State Commun.* 2012, 152, 909–913.
126. Chhowalla, M.; Shin, H.S.; Eda, G.; Li, L.-J.; Loh, K.P.; Zhang, H. The Chemistry of Two-Dimensional Layered Transition Metal Dichalcogenide Nanosheets. *Nat. Chem.* 2013, 5, 263–275.
127. Tuxen, A.; Kibsgaard, J.; Gøbel, H.; Lægsgaard, E.; Topsøe, H.; Lauritsen, J.V.; Besenbacher, F. Size Threshold in the Dibenzothiophene Adsorption on MoS₂ Nanoclusters. *ACS Nano* 2010, 4, 4677–4682.
128. Ma, K.; Sinha, A.; Dang, X.; Zhao, H. Electrochemical Preparation of Gold Nanoparticles-Polypyrrole Co-Decorated 2D MoS₂ Nanocomposite Sensor for Sensitive Detection of Glucose. *J. Electrochem. Soc.* 2019, 166, B147–B154.
129. Su, S.; Cao, W.; Liu, W.; Lu, Z.; Zhu, D.; Chao, J.; Weng, L.; Wang, L.; Fan, C.; Wang, L. Dual-Mode Electrochemical Analysis of MicroRNA-21 Using Gold Nanoparticle-Decorated MoS₂ Nanosheet. *Biosens. Bioelectron.* 2017, 94, 552–559.
130. Lin, X.; Ni, Y.; Kokot, S. Electrochemical Cholesterol Sensor Based on Cholesterol Oxidase and MoS₂-AuNPs Modified Glassy Carbon Electrode. *Sens. Actuators B Chem.* 2016, 233, 100–106.
131. Yang, Y.; Zhang, H.; Huang, C.; Yang, D.; Jia, N. Electrochemical Non-Enzyme Sensor for Detecting Clenbuterol (CLB) Based on MoS₂-Au-PEI-Hemin Layered Nanocomposites. *Biosens. Bioelectron.* 2017, 89, 461–467.
132. Bao, J.; Qi, Y.; Huo, D.; Hou, J.; Geng, X.; Samalo, M.; Liu, Z.; Luo, H.; Yang, M.; Hou, C. A Sensitive and Selective Non-Enzymatic Glucose Sensor Based on AuNPs/CuO NWs-MoS₂ Modified Electrode. *J. Electrochem. Soc.* 2019, 166, B1179–B1185.
133. Lin, M.; Wan, H.; Zhang, J.; Wang, Q.; Hu, X.; Xia, F. Electrochemical DNA Sensors Based on MoS₂-AuNPs for Polynucleotide Kinase Activity and Inhibition Assay. *ACS Appl. Mater. Interfaces* 2020, 12, 45814–45821.
134. Liu, L.; Zhu, S.; Wei, Y.; Liu, X.; Jiao, S.; Yang, J. Ultrasensitive Detection of MiRNA-155 Based on Controlled Fabrication of 2 Nanostructures by Atomic Layer Deposition. *Biosens. Bioelectron.* 2019, 144, 111660.
135. Zhang, B.; Zhang, Y.; Liang, W.; Yu, X.; Tan, H.; Wang, G.; Li, A.; Jin, J.; Huang, L. Copper Sulfide-Functionalized Molybdenum Disulfide Nanohybrids as Nanoenzyme Mimics for Electrochemical Immunoassay of Myoglobin in Cardiovascular Disease. *RSC Adv.* 2017, 7, 2486–2493.
136. Wan, Y.; Su, Y.; Zhu, X.; Liu, G.; Fan, C. Development of Electrochemical Immunosensors towards Point of Care Diagnostics. *Biosens. Bioelectron.* 2013, 47, 1–11.
137. Liu, G.; Lin, Y. Nanomaterial Labels in Electrochemical Immunosensors and Immunoassays. *Talanta* 2007, 74, 308–317.
138. Kukkar, M.; Tuteja, S.K.; Kumar, P.; Kim, K.-H.; Bhadwal, A.S.; Deep, A. A Novel Approach for Amine Derivatization of MoS₂ Nanosheets and Their Application toward Label-Free Immunosensor. *Anal. Biochem.* 2018, 555, 1–8.
139. Bohli, N.; Belkilani, M.; Mora, L.; Abdelghani, A. Antibody-Functionalised Gold Nanoparticles-Based Impedimetric Immunosensor: Detection Methods for Better Sensitivity. *Micro Nano Lett.* 2019, 14, 629–633.
140. Li, Q.; Liu, D.; Xu, L.; Xing, R.; Liu, W.; Sheng, K.; Song, H. Wire-in-Tube IrOx Architectures: Alternative Label-Free Immunosensor for Amperometric Immunoassay toward α -Fetoprotein. *ACS Appl. Mater. Interfaces* 2015, 7, 22719–22726.
141. Viet, N.X.; Hoan, N.X.; Takamura, Y. Development of Highly Sensitive Electrochemical Immunosensor Based on Single-Walled Carbon Nanotube Modified Screen-Printed Carbon Electrode. *Mater. Chem. Phys.* 2019, 227, 123–129.
142. Su, S.; Sun, Q.; Wan, L.; Gu, X.; Zhu, D.; Zhou, Y.; Chao, J.; Wang, L. Ultrasensitive Analysis of Carcinoembryonic Antigen Based on MoS₂-Based Electrochemical Immunosensor with Triple Signal Amplification. *Biosens. Bioelectron.* 2019, 140, 111353.
143. Wang, X.; Chu, C.; Shen, L.; Deng, W.; Yan, M.; Ge, S.; Yu, J.; Song, X. An Ultrasensitive Electrochemical Immunosensor Based on the Catalytic Activity of MoS₂-Au Composite Using Ag Nanospheres as Labels. *Sens. Actuators B Chem.* 2015, 206, 30–36.
144. Ding, H.; Yang, L.; Jia, H.; Fan, D.; Zhang, Y.; Sun, X.; Wei, Q.; Ju, H. Label-Free Electrochemical Immunosensor with Palladium Nanoparticles Functionalized MoS₂/NiCo Heterostructures for Sensitive Procalcitonin Detection. *Sens. Actuators B Chem.* 2020, 312, 127980.

145. Yagati, A.K.; Go, A.; Vu, N.H.; Lee, M.-H. A MoS₂–Au Nanoparticle-Modified Immunosensor for T3 Biomarker Detection in Clinical Serum Samples. *Electrochim. Acta* 2020, 342, 136065.
146. Giang, H.; Pali, M.; Fan, L.; Suni, I.I. Impedance Biosensing atop MoS₂ Thin Films with Mo–S Bond Formation to Antibody Fragments Created by Disulphide Bond Reduction. *Electroanalysis* 2019, 31, 957–965.
147. Zhang, Z.; Zhang, Y.; Yu, H.; Rong, S.; Gao, H.; Meng, L.; Dai, J.; Pan, H.; Chang, D. Spherical Carrier Amplification Strategy for Electrochemical Immunosensor Based on Polystyrene-Gold Nanorods @L-Cysteine/MoS₂ for Determination of Tacrolimus. *Talanta* 2020, 220, 121321.
148. Hun, X.; Wang, S.; Wang, S.; Zhao, J.; Luo, X. A Photoelectrochemical Sensor for Ultrasensitive Dopamine Detection Based on Single-Layer NanoMoS₂ Modified Gold Electrode. *Sens. Actuators B Chem.* 2017, 249, 83–89.
149. Wang, G.; Xu, J.; Chen, H. Progress in the Studies of Photoelectrochemical Sensors. *Sci. China Ser. B Chem.* 2009, 52, 1789.
150. Zhou, Q.; Tang, D. Recent Advances in Photoelectrochemical Biosensors for Analysis of Mycotoxins in Food. *TrAC Trends Anal. Chem.* 2020, 124, 115814.
151. Zang, Y.; Lei, J.; Ju, H. Principles and Applications of Photoelectrochemical Sensing Strategies Based on Biofunctionalized Nanostructures. *Biosens. Bioelectron.* 2017, 96, 8–16.
152. Syrek, K.; Skolarczyk, M.; Zych, M.; Sołtys-Mróz, M.; Sulka, G.D. A Photoelectrochemical Sensor Based on Anodic TiO₂ for Glucose Determination. *Sensors* 2019, 19, 4981.
153. Liu, W.; Zhan, W.; Jia, X.; Liu, Q.; Chen, R.; Li, D.; Huang, Y.; Zhang, G.; Ni, H. Rapid Synthesis of Vertically-Aligned Zinc Oxide Nanorods on Stainless Steel for Non-Enzymatic Glucose and H₂O₂ Photoelectrochemical Sensor. *Appl. Surf. Sci.* 2019, 480, 341–348.
154. Zhang, N.; Ruan, Y.-F.; Ma, Z.-Y.; Zhao, W.-W.; Xu, J.-J.; Chen, H.-Y. Simultaneous Photoelectrochemical and Visualized Immunoassay of β -Human Chorionic Gonadotrophin. *Biosens. Bioelectron.* 2016, 85, 294–299.
155. Wang, Y.; Zhou, Y.; Xu, L.; Han, Z.; Yin, H.; Ai, S. Photoelectrochemical Apta-Biosensor for Zeatin Detection Based on Graphene Quantum Dots Improved Photoactivity of Graphite-like Carbon Nitride and Streptavidin Induced Signal Inhibition. *Sens. Actuators B Chem.* 2018, 257, 237–244.
156. Shu, J.; Tang, D. Recent Advances in Photoelectrochemical Sensing: From Engineered Photoactive Materials to Sensing Devices and Detection Modes. *Anal. Chem.* 2020, 92, 363–377.
157. Han, F.; Song, Z.; Nawaz, M.H.; Dai, M.; Han, D.; Han, L.; Fan, Y.; Xu, J.; Han, D.; Niu, L. MoS₂/ZnO-Heterostructures-Based Label-Free, Visible-Light-Excited Photoelectrochemical Sensor for Sensitive and Selective Determination of Synthetic Antioxidant Propyl Gallate. *Anal. Chem.* 2019, 91, 10657–10662.
158. Jalali, M.; Moakhar, R.S.; Abdelfattah, T.; Filine, E.; Mahshid, S.S.; Mahshid, S. Nanopattern-Assisted Direct Growth of Peony-like 3D MoS₂/Au Composite for Nonenzymatic Photoelectrochemical Sensing. *ACS Appl. Mater. Interfaces* 2020, 12, 7411–7422.
159. Wang, X.; Deng, H.; Wang, C.; Wei, Q.; Wang, Y.; Xiong, X.; Li, C.; Li, W. A Pro-Gastrin-Releasing Peptide Imprinted Photoelectrochemical Sensor Based on the in Situ Growth of Gold Nanoparticles on a MoS₂ Nanosheet Surface. *Analyst* 2020, 145, 1302–1309.
160. Shi, Y.; Zhang, Q.; Zhai, T.-T.; Zhou, Y.; Yang, D.-R.; Wang, F.-B.; Xia, X.-H. Localized Surface Plasmon Resonance Enhanced Label-Free Photoelectrochemical Immunoassay by Au-MoS₂ Nanohybrid. *Electrochim. Acta* 2018, 271, 361–369.
161. Çakıroğlu, B.; Özacar, M. A Photoelectrochemical Biosensor Fabricated Using Hierarchically Structured Gold Nanoparticle and MoS₂ on Tannic Acid Templated Mesoporous TiO₂. *Electroanalysis* 2020, 32, 166–177.
162. Fu, N.; Hu, Y.; Shi, S.; Ren, S.; Liu, W.; Su, S.; Zhao, B.; Weng, L.; Wang, L. Au Nanoparticles on Two-Dimensional MoS₂ Nanosheets as a Photoanode for Efficient Photoelectrochemical MiRNA Detection. *Analyst* 2018, 143, 1705–1712.
163. Sun, J.; Sun, H.; Liang, Z. Nanomaterials in Electrochemiluminescence Sensors. *ChemElectroChem* 2017, 4, 1651–1662.
164. Ravalli, A.; Voccia, D.; Palchetti, I.; Marrazza, G. Electrochemical, Electrochemiluminescence, and Photoelectrochemical Aptamer-Based Nanostructured Sensors for Biomarker Analysis. *Biosensors* 2016, 6, 39.
165. Li, J.; Guo, S.; Wang, E. Recent Advances in New Luminescent Nanomaterials for Electrochemiluminescence Sensors. *RSC Adv.* 2012, 2, 3579–3586.
166. Chen, X.; Liu, Y.; Ma, Q. Recent Advances in Quantum Dot-Based Electrochemiluminescence Sensors. *J. Mater. Chem. C* 2018, 6, 942–959.

167. Francis, P.S.; Hogan, C.F. Chapter 13—Luminescence. In *Advances in Flow Injection Analysis and Related Techniques*; Kolev, S.D., Mckelvie, I.D., Eds.; Elsevier: Amsterdam, The Netherlands, 2008; Volume 54, pp. 343–373.
168. Fu, X.-L.; Hou, F.; Liu, F.-R.; Ren, S.-W.; Cao, J.-T.; Liu, Y.-M. Electrochemiluminescence Energy Resonance Transfer in 2D/2D Heterostructured g-C₃N₄/MnO₂ for Glutathione Detection. *Biosens. Bioelectron.* 2019, 129, 72–78.
169. Li, M.; Wang, C.; Chen, L.; Liu, D. A Novel Electrochemiluminescence Sensor Based on Resonance Energy Transfer System between Nitrogen Doped Graphene Quantum Dots and Boron Nitride Quantum Dots for Sensitive Detection of Folic Acid. *Anal. Chim. Acta* 2019, 1090, 57–63.
170. Zhang, W.; Xiong, H.; Chen, M.; Zhang, X.; Wang, S. Surface-Enhanced Molecularly Imprinted Electrochemiluminescence Sensor Based on for Ultrasensitive Detection of Fumonisin B1. *Biosens. Bioelectron.* 2017, 96, 55–61.
171. Gan, X.; Zhao, H.; Quan, X. Two-Dimensional MoS₂: A Promising Building Block for Biosensors. *Biosens. Bioelectron.* 2017, 89, 56–71.
172. Li, Y.; Wang, Y.; Bai, L.; Lv, H.; Huang, W.; Liu, S.; Ding, S.; Zhao, M. Ultrasensitive Electrochemiluminescent Immunosensing Based on Trimetallic Au–Pd–Pt/MoS₂ Nanosheet as Coreaction Accelerator and Self-Enhanced ABEI-Centric Complex. *Anal. Chim. Acta* 2020, 1125, 86–93.
173. Liu, Y.-M.; Zhou, M.; Liu, Y.-Y.; Shi, G.-F.; Zhang, J.-J.; Cao, J.-T.; Huang, K.-J.; Chen, Y.-H. Fabrication of Electrochemiluminescence Aptasensor Based on in Situ Growth of Gold Nanoparticles on Layered Molybdenum Disulfide for Sensitive Detection of Platelet-Derived Growth Factor-BB. *RSC Adv.* 2014, 4, 22888–22893.

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