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Two-dimensional gold-tungsten disulphide bio-interface for high-throughput electrocatalytic nano-bioreactors

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Keywords: Nanobioreactor, electrocatalysis, bioelectronics, self-assembly, WS₂ nanosheet.

Nanobioreactors are emerging as advanced bio-devices, which fuse the advantages of nanomaterials with those of nanobiotechnology.^[1] Due to their ultimately small size, high surface area and simulation capacity, they are set to become a versatile tool to fabricate ultra-sensitive and selective novel nanobio-devices, which offer us new platforms to tackle key energy, medical and environmental issues.^[2] Current nanobioreactor researches are focused on the designing of simple-to-use, inexpensive bio-devices, which could be highly selective, sensitive and stable.^[3] However, current designs mostly suffer from a lack of efficiency and sensitivity.^[4] Here, we report for the first time the fabrication of novel two-dimensional (2D) bioreactor consisting of gold nanoparticle-structured (Au NPs) tungsten disulphide (WS₂) nanosheets, which offer a simple and effective way to overcome many limitations that have been faced by previous designs. Using electrochemical techniques, we demonstrate that 2D electrocatalytic bio-interfaces can be implemented to produce and regulate biological reactions for novel bioreactors, biofuel cells and biosensors applications.

Tungsten disulphide, a prototype semiconducting transition metal dichalcogenide, which possesses a nanoscale dimension in one-axis and infinite length in the plane, is a fundamentally and technologically promising material.^[5] It has shown various physical and chemical properties which are present in bulk, layered counterparts, including high charge density, large surface area, remarkable electron mobility, high electron transport having a sizeable band gap, and high density of electronic state.^[6] WS₂ can be seen as an inorganic graphene analogue, similar to graphene and *h*-BN. The structure of WS₂ is based on a hexagonal crystal, where W atom is six-fold coordinated and hexagonally packed between two trigonally coordinated sulphur atoms. One S-W-S layer is weakly bonded to another S-W-S layer through weak Van der Waals interactions. The crystalline form of layered structures of WS₂ usually leads to strong anisotropy in their electrical, chemical mechanical and thermal properties which make WS₂ an ideal candidate for many applications ranging from electronics to catalysis.^[7] However, the electrochemical and especially bio-electrochemical applications of WS₂ nanosheets have not been yet widely explored. Herein, we report Au nanoparticle structured WS₂ nanosheets as a bioreactor platform for efficient and highly sensitive enzymatic H₂O₂ electrocatalysis.

We have demonstrated a fundamentally new bioreactor design to overcome restrictions by applying 2D nanostructured catalytic surfaces. In the place of lithography, chemical etching or multi-steps electrodeposition techniques for particle structuring, we have developed a facile approach using direct self-assembling of Au nanoparticles on to WS₂ nanosheets. Herein, the WS₂ acts as a semiconductor, which is a good candidate to form homogenous passivation layer for the assembling of nanoparticles, which is mainly responsible for biocatalysis and effective electron transfer, since it can be easily deposited as single-layer films on Au electrode surface. As a common model, positively charged horseradish peroxidase (HRP) is chosen and assembled on negatively charged WS₂/Au NPs 2D hybrid nanostructure by electrostatic attractions under the physiological conditions. It is

demonstrated that the components of the WS₂/Au NP/HRP self-assembled nanobioreactor are well dispersed in aqueous solution, and that they spontaneously assemble into ordered structures. The novel nanostructured design is confirmed by transmission electron microscopy (TEM), zeta potential and contact angle (CA) measurements. This approach delivered high sensitivity and recovery limits along with wide linear evolution range of H₂O₂, which are greatly improved in comparison with previous reports.

Scheme 1 illustrates the overall process for the structuring of the Au NP arrays on WS₂ nanosheets and enzyme based hybrid structure for high order enzymatic evolution of H₂O₂. The synthesis strategy is to initially obtain self-assembled WS₂/Au NP hybrid nanosheets on a gold electrode surface. This is the crucial step to achieve free-standing and stable dispersion for further enzyme assembly. The second step involves the conjugation of the enzyme with WS₂/Au NP nanosheets to acquire an orderly self-assembled bio-interface.

Figure 1 shows the TEM images of WS₂ nanosheets before (a-b) and after (c-d) assembling of colloidal Au NPs. The panel a-b in Figure 1 illustrates wrinkled and folded sheet structure, which might be resulting from reaction sites involved in oxidation and reduction process. Although the WS₂ nanosheets are very thin, a stack of a few layers is visible (Figure 1a). WS₂ nanosheets with a thickness of 5-6 nm would contain approximately 10 monolayers, considering an interlayer spacing of 0.62 nm.^[8] Figure 1c-d indicates a homogenous assembling of WS₂ with surface coverage of approximately 50%. In addition, the inset of Figure 1c reveals that assembling yield of Au NPs on the surface of WS₂ is about 92%. The results show that Au NPs selectively prefer WS₂ surface due to the affinity between sulphur atoms in WS₂ coordinated structure with Au NPs similar to the affinity between any gold surface and sulphur atom in thiol compounds.

We prepared ordered WS₂/Au NPs/enzyme hybrid structures through electrostatic self-assembly. The horseradish peroxidase was chosen as a representative enzyme that is positively charged (IEP = 8.8) in physiological media.^[9] The surface charge of neat WS₂

nanosheets was measured in different pH values. The results show that the nanosheet was highly negatively charged over a wide pH range. This varied between -65 mV and -32 mV over a range of pH 2 to 10, respectively (Figure S1a). **Figure 2a** illustrates that the WS₂ nanosheet carries highly negative charge on the surface (-50.0 ± 3.0 mV) when the zeta potential measurements are performed at physiological conditions (pH 7.4). The surface charge of the Au NP colloid was also measured at different pH's ranging from 2.0 to 12.0. (Figure S1b). The results reveal that Au NPs are highly negatively charged at acidic pH, 2.0 – 6.0, however surface charge starts to turn positive in the basic pH range, i.e., above pH 7.4. It reached +7.0 mV at pH 8.0 and finally +18 mV at pH 12. The presence of positive charge provides an ionic interaction to support Au NP loading in the bio-reactor assembly. Stronger charge interaction between WS₂ and HRP results in better self-assembly. However, a decrease in surface zeta potential was observed while Au NPs were assembled on the WS₂ surface and the particles were randomly distributed; the negative value of surface zeta potential slightly shifted to -40.0 ± 2.5 mV due to association of the AuNP. After enzyme immobilisation on WS₂/Au NP assembled nanosheets, the value further decreased to -32.0 ± 4.0 mV. The wettability of the surface also decreased. The water contact angle decreased from 58° to 47° and 38° after assembling of Au NP and enzyme immobilisation, respectively (Figure 2a). The enzyme immobilisation efficiency on the WS₂/Au NPs structure with respect to the different pH was studied (Figure 2b). The enzyme assay has been prepared according to previously reported literature.^[10] An efficiency test was conducted using 1.0 mg/mL of WS₂/Au NPs and 1.0 mg of HRP at pH 7.4. The results show that immobilisation was pH dependent and could be controlled by varying the pH of the reaction medium. For instance, at pH 4, the surface of WS₂/Au NPs nanosheets was negatively charged (-30.0 mV) and the immobilisation efficiency was found to be 30 wt%. The maximum efficiency was achieved at pH 8.0, and was about 65 wt%. Then, a sharp decrease to about 5 wt% was observed at pH 12 because the surface charge reduced to the lowest level (-10 mV). The results demonstrate that electrostatic

attraction is the driving force for the immobilisation and can be controlled by changing the pH of the reaction medium.

The electrochemical properties of all modified electrodes were characterised by cyclic voltammetry (CV), electrochemical impedance (EIS) and differential pulse voltammetry (DPV) in 0.1 M phosphate buffer saline (PBS) solutions containing 5 mM $\text{Fe}(\text{CN})_6^{3-/4-}$ and 0.1 M KCl (**Figure 3a-b** and Figure S2-5). The CV responses of all WS_2 nanosheets based structure displayed a classical sigmoidal shape with narrow peak-to-peak potential separations, indicating fast electron transfer kinetics. When the electrode surface was modified by the WS_2 -Au NPs assembly on nanosheets, the peak current of $\text{Fe}(\text{CN})_6^{3-/4-}$ increased relative to the WS_2 modified nanosheets alone, which indicates that structuring of the nanoparticle creates a higher electroactive surface area and provided a conductive interlayer for the electron transfer. The electroactive surface area (A) for the modified electrodes was calculated based on Randles–Sevcik equation, which assumes mass transport occurred only by diffusion:^[11]

$$I_p = 2.69 \times 10^5 AD^{1/2} n^{3/2} \gamma^{1/2} C \quad (1)$$

where n is the number of electron involving in the redox process, D is the diffusion coefficient of the molecule ($6.70 \times 10^{-6} \text{ cm}^2/\text{s}$), C is the concentration of the probe molecule in the solution (mol/cm^3) and γ is the scan rate ($\text{V} \cdot \text{s}^{-1}$). The surface area for WS_2 and WS_2/Au NPs nanosheets are found to be 0.32 cm^2 and 0.45 cm^2 , respectively. Thus, the structuring of particles increased the effective surface area of the nanosheets by about 40%.

The charge transfer properties of electrodes modified by different WS_2 based self-assembled nanostructures were further characterised by electrochemical impedance spectroscopy (Figure 3b). The Randles circuit was chosen to fit the impedance outputs.^[12] The

Nyquist plots of spectra, which contain semi-circular and linear portions, indicate both electron transfer limited (semi-circular portion) and diffusion process (linear portion) occurred at the same time. The charge transfer resistance (R_{CT}) at the electrode surface can be quantified based on the diameter of the semi-circular part of the plot.^[13] According to calculation, the R_{CT} of WS_2 and WS_2/Au NPs nanosheet-modified electrode were 0.40 k Ω and 0.42 k Ω , respectively, which was higher than bare gold electrode (0.06 k Ω). Thus, after immobilisation of enzyme on the surface of WS_2/Au NPs nanosheets, a slight inhibition of electron transfer of the redox couple was observed (0.9 k Ω) due to the insulating property of enzymes.

Moreover, we investigated the electrocatalytic oxidation of H_2O_2 at the WS_2 , WS_2/HRP and WS_2/Au NPs/ HRP nanosheet-electrodes by amperometric measurement (**Figure 4a**) for the successive additions of H_2O_2 at an applied voltage of + 500 mV (vs. SCE) in 0.1 M PBS (pH 7.4). WS_2 -modified nanosheet electrodes showed only a rapid electrocatalytic response to the first couple of additions of H_2O_2 , but further additions of H_2O_2 , even at higher concentrations, did not yield any significant current increase. In contrast, the WS_2/Au NPs/ HRP and WS_2/HRP nanosheet-electrodes displayed a rapid and sensitive response to the addition of H_2O_2 , and a steady-state current was obtained within 3 and 5 s, respectively. The fast response may be attributed to the fast diffusion in the open three-dimensional structure of the assembly and the synergistic catalytic effect of the immobilised systems toward H_2O_2 . Furthermore, well-defined current responses proportional to H_2O_2 concentrations were observed with both electrode surfaces.

The calibration curve of the electrocatalytic currents of the bioreactor to the concentrations of H_2O_2 is shown in Figure 4b. The catalytic current displays a linear relationship to H_2O_2 concentration in the range from 0.1 to 8.2 mM for WS_2/HRP nanosheets. However, the dynamic range is greatly improved for WS_2/Au NPs/ HRP assembled nanosheets. The sensitivity and detection limit of WS_2/Au NPs/ HRP electrode were 11.64 $\mu A/\mu M/cm^2$ and

0.085 μM (S/N=3), respectively (**Table 1**). Based on the Lineweaver-Burk equation,^[14] the apparent Michaelis-Menten constant (K_m^{app}) was calculated to be 1.55 mM for WS₂/Au NPs/HRP, which is smaller than for WS₂/HRP (2.0 mM). Such a low K_M value indicates that the enzyme intercalated in WS₂/Au NPs nanosheets possesses high catalytic efficiency for the oxidation of H₂O₂, with a concomitant low diffusion barrier. Accordingly, the WS₂/Au NPs/HRP nanosheet-electrode provided excellent catalytic performance for the detection of H₂O₂ over a wide linear range, high sensitivity, and a low detection limit. Such high catalytic properties of the enzyme electrode is ascribed to the open structures of the WS₂/Au NPs/HRP assembly, the large surface area of WS₂ nanosheets for enzyme immobilisation, fast mass transport due to the large interlayer distance of ordered structure, biocompatibility of WS₂ and the synergistic catalytic effect of WS₂/Au NPs. In conclusion, we have demonstrated for the first time fabrication of a bioreactor on WS₂ nanosheets based on a simple-to-use, inexpensive and high order two-dimensional biosystem, which has high electrocatalytic activity. (**Table S2**). The results have shown that bioelectrocatalytic reactions can be controlled and regulated by modifying the nanointerface. The material we have designed could potentially provide significant improvements in biocatalysis and nanotechnology by exploiting this novel biocatalytic interface.

Experimental Section

Materials: WS₂ nanosheets ($\geq 99.0\%$ purity, 50-150 nm lateral size, 1-4 monolayers) were obtained from graphene-supermarket (www.graphene-supermarket.com, USA). Gold nanoparticles (Au NPs) (5 nm diameter, 5.5×10^{13} particles/mL, stabilized suspension in 0.1 M PBS, reactant free), peroxidase from horseradish (HRP, 300 units/mg), 4-aminoantipyrine (4-AAP, $\geq 99.0\%$), hydrogen peroxide (H₂O₂, ACS reagent, 30 wt.% in H₂O), phenol ($\geq 99.5\%$), potassium dihydrogen phosphate (KH₂PO₄, $\geq 99.0\%$), dipotassium hydrogen phosphate (K₂HPO₄, $\geq 99.0\%$), potassium chloride (KCl, $\geq 99.0\%$), potassium ferrocyanide

($\text{K}_3[\text{Fe}(\text{CN})_6]$, $\geq 98.5\%$) and potassium ferricyanide ($\text{K}_4[\text{Fe}(\text{CN})_6]$, $\geq 99.0\%$) were purchased from Sigma-Aldrich (St. Louis, MO, USA) and were used without further purification. Phosphate buffer saline (PBS, 0.1 M, pH 7.4) and ferri/ferro cyanide solutions were used as supporting electrolyte for all amperometric measurements. Aqueous solutions were prepared with Milli-Q water ($18.2\text{-}\Omega\cdot\text{cm}$) obtained by Millipore system (Billerica, MA, USA).

Preparation of nanobioreactor: WS_2 nanosheets (2.6 mg) were dispersed in 0.1 M PBS solution (1 mL) by ultrasonic treatment 30 min and greenish solution was obtained. The WS_2 solution was mixed with gold nanoparticle suspension (100 μL) and the mixture was incubated at 4 °C for 3 hours to achieve high amount of assembled gold nanoparticles onto the WS_2 surface. The resulting suspension was isolated by centrifugation at 5000 rpm for 10 min and rewashed several times with deionized water to remove unassembled particles. Then, WS_2/Au NPs self-assembled nanosheets was re-dispersed in PBS solution (1 mL) by ultrasonication around 5 min and mixed with HRP solution in 0.1 M PBS (1.0 mg/mL). The mixture was sonicated for 1 min and then kept at 4 °C for 12 hours. Subsequently, the mixture was centrifuged at 5000 rpm for 5 min and supernatant solution was collected for the determination of enzyme loading efficiency. The precipitate was washed with PBS and centrifuged successively three times to remove loosely attached enzymes. Same procedure was performed for different enzyme loading conditions with fixed amount of WS_2/Au NPs solution. The immobilisation efficiency of HRP was determined indirectly by collecting the amount of free enzyme in supernatant solution.

Fabrication of bio-electrode: Prior to coating, gold electrodes were polished using 1.0, 0.3, and 0.05 micron Buehler alumina slurry on Buehler polishing microcloth (Buehler, Ltd. USA) respectively. The electrodes were then cleaned in the mixture of aqueous ammonia, hydrogen peroxide and water solution (1:1:5 v/v) at 80 °C for 10 min and rinsed with excess deionized water. The electrodes were electrochemically cleaned in 0.05 M H_2SO_4 solution by cycling

between 0.0 V to 1.5 V and allowed to dry at room temperature. Then the dispersions containing WS₂ based hybrid structures (10 μ L) were dropped onto the gold electrode surface and then dried at 4 °C for overnight. The other modified electrodes were similarly prepared using WS₂ and WS₂/HRP nanosheets dispersions.

Characterisation: Transmission electron microscopy (TEM) was performed by a G² Sprit/Biotwin (FEI-Technai, Hillsboro, OR, USA) with working voltage of 120 kV. The TEM specimens were prepared by dropping 2 μ L of each sample on polymer-coated copper grid (Agar Scientific, Essex, UK). The zeta potential of dispersions was determined using a Nano ZS dynamic light-scattering (DLS) instrument (Malvern Instruments, Worcestershire, UK). Absorptions of all self-assembled structure in PBS solutions were measured with a Cary 50 UV-vis Spectrometer (Varian, St. Clara, USA). Water contact angle measurement was performed using a CAM 200 optical contact angle meter (KSV Instrument, Helsinki, Finland). All voltammetric and amperometric measurements were carried out with an Ivium Stat.XR electrochemical analyser (Ivium Tech., Eindhoven, Netherlands). Impedance measurements were carried out with Autolab potentiostat-galvanostat (Metrohm Autolab B. V., Utrecht, Netherlands). A three-electrode cell with gold working electrode, having 0.07 cm² surface area, and platinum wire auxiliary and Ag/AgCl (3 M KCl) reference electrodes were used in the voltammetric and amperometric measurements.

Supporting information available: Zeta potential of WS₂ nanosheets at various pH, UV-vis spectra of all WS₂-based assemblies and additional electrochemical characterisation (CV and DPV) of fabricated biosensor have been demonstrated. This material is available free of charge via the internet.

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References

- [1] D. M. Vriezema, M. C. Aragonés, J. Elemans, J. Cornelissen, A. E. Rowan, R. J. M. Nolte, *Chem. Rev.* **2005**, 105, 1445; D. G. Shchukin, G. B. Sukhorukov, *Adv. Mater.* **2004**, 16, 671; Y. Lu, Y. Mei, M. Drechsler, M. Ballauff, *Angew. Chem. Int. Edit.* **2006**, 45, 813; S. J. Li, Y. Ge, A. Tiwari, S. S. Cao, *Small* **2010**, 6, 2453; M. P. Pileni, *Nat. Mater.* **2003**, 2, 145; J. H. Fendler, *Chem. Mater.* **1996**, 8, 1616.
- [2] A. P. F. Turner, *Chem. Soc. Rev.* **2013**, 42, 3184.
- [3] O. Parlak, A. P. F. Turner, A. Tiwari, *Adv. Mater.* **2014**, 26, 482.
- [4] W. A. Solomonsz, G. A. Rance, B. J. Harris, A. N. Khlobystov, *Nanoscale* **2013**, 5, 12200; I. Louzao, J. C. M. van Hest, *Biomacromolecules* **2013**, 14, 2364.
- [5] Z. Zeng, Z. Yin, X. Huang, H. Li, Q. He, G. Lu, F. Boey, H. Zhang, *Angewandte Chemie-International Edition* **2011**, 50, 11093.
- [6] A. Yella, E. Mugnaioli, M. Panthoef, U. Kolb, W. Tremel, *Angew. Chem. Int. Edit.* **2010**, 49, 3301.
- [7] Y. Zhang, Y. Zhang, Q. Ji, J. Ju, H. Yuan, J. Shi, T. Gao, D. Ma, M. Liu, Y. Chen, X. Song, H. Y. Hwang, Y. Cui, Z. Liu, *ACS Nano* **2013**, 7, 8963.
- [8] J. N. Coleman, M. Lotya, A. O'Neill, S. D. Bergin, P. J. King, U. Khan, K. Young, A. Gaucher, S. De, R. J. Smith, I. V. Shvets, S. K. Arora, G. Stanton, H.-Y. Kim, K. Lee, G. T. Kim, G. S. Duesberg, T. Hallam, J. J. Boland, J. J. Wang, J. F. Donegan, J. C. Grunlan, G. Moriarty, A. Shmeliov, R. J. Nicholls, J. M. Perkins, E. M. Grieveson, K. Theuwissen, D. W. McComb, P. D. Nellist, V. Nicolosi, *Science* **2011**, 331, 568.
- [9] Q. O. Zeng, J. S. Cheng, L. H. Tang, X. F. Liu, Y. Z. Liu, J. H. Li, J. H. Jiang, *Adv. Funct. Mater.* **2010**, 20, 3366.
- [10] C. X. Lei, S. Q. Hu, G. L. Shen, R. Q. Yu, *Talanta* **2003**, 59, 981.
- [11] J. Lu, I. Do, L. T. Drzal, R. M. Worden, I. Lee, *ACS Nano* **2008**, 2, 1825.
- [12] B. Y. Chang, S. M. Park, *Anal. Chem.* **2006**, 78, 1052.
- [13] O. Parlak, A. Tiwari, A. P. F. Turner, A. Tiwari, *Biosens. Bioelectron.* **2013**, 49, 53.
- [14] R. A. Kamin, G. S. Wilson, *Anal. Chem.* **1980**, 52, 1198.

Scheme 1. Schematic representation of Au nanoparticle-structuring on a WS₂ interface and electron transfer process in the WS₂/Au NPs/HRP hybrid structure on the gold electrode. Note that Scheme 1 is obviously not to scale.

Base Material	Detection Limit ^a	Dynamic Range ^b	Sensitivity ^c	Response Time ^d
	[μM]	[mM]	[$\mu\text{A}/\mu\text{M}/\text{cm}^2$]	[s]
WS ₂ /AuNPs/ HRP	0.085	0.05-12.0	11.64	3
WS ₂ /HRP	0.150	0.1-8.2	9.43	5

Table 1. Detection limit, sensing range, sensitivity and response time of WS₂/Au NPs/HRP WS₂/HRP and electrodes.

^aDetection limits are calculated from the characteristic signal-to-noise ratio ($S/N=3$).

^bDynamic range is determined the linear portion of calibration curve.

^cSensitivity is obtained from the slopes of each calibration plots (concentration of H₂O₂ vs. current signal).

^dResponse time is determined when the currents reach to steady-state at each addition of H₂O₂.

Figure 1. TEM images of WS₂ nanosheets at (a) low, and (b) high magnification, and Au NPs structured WS₂ nanosheets at (c) low and (d) high magnification.

Figure 2. The zeta potential (*x-axis*) and water contact angle (*y-axis*) of WS₂, WS₂/Au NPs and WS₂/Au NPs/HRP assemblies (a) and the variation of enzyme immobilisation efficiency in pH 2-12 (b).

Figure 3. Cyclic voltammetry (a) and impedance (b) response of bare and modified electrodes in 5 mM $\text{Fe}(\text{CN})_6^{3-/4-}$ and 0.1 M PBS at 50 mV/s vs. Ag/AgCl reference electrode. The inset in (b) is the equivalent of Randles circuit which is used to fit the data.

Figure 4. Amperometric responses (a) and the calibration curves (b) for the sensing of H_2O_2 with WS_2/HRP and $\text{WS}_2/\text{Au NPs}/\text{HRP}$ electrodes in 0.1 M PBS at 0.5 V applied potential vs. Ag/AgCl.

The Table of Content

High-throughput electrocatalytic nanobioreactor on tungsten disulphide nanosheets is demonstrated for the first time. The fundamental goal of this research is to develop a higher surface area, resulting in a greater enzyme loading and thereby increasing bio-catalytic activity within nano-confined volume. As a result, nanobio-system is capable of highly specific recognition of target bioanalytes, therefore, showing significant potentials in a range of bioreactor applications.

Keyword: Nanobioreactor, electrocatalysis, bioelectronics, self-assembly, WS₂ nanosheet

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