

Competitive Electrochemical Detection of SARS-CoV-2 Antigen on a 2D MoWSe₂-Based Biosensor

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Summary:

The ongoing spread of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has posed significant global public health challenges, highlighting the need for rapid and reliable surveillance strategies. A competitive electrochemical biosensor based on two-dimensional molybdenum tungsten diselenide was developed for SARS-CoV-2 antigen detection in wastewater. Using antibody-conjugated polyethyleneimine-coated gold nanoparticles as nanotags and thionine as a signal amplifier, the sensor achieves sensitive detection with a low limit of detection, a wide detection range, stability, and selectivity.

Keywords: electrochemical immunosensor, competitive detection, SARS-CoV-2, 2D MoWSe₂, PEI-AuNPs

Background, Motivation, and Objective

On March 11, 2020, the World Health Organization officially declared the COVID-19 outbreak a global pandemic. Since then, a diverse array of biosensing technologies has been developed to enable efficient and accurate detection of the virus [1]. Biosensors targeting the spike (S) protein have attracted significant attention due to their critical role in viral entry via ACE2 receptor binding. The urgent need for reliable virus monitoring, especially in complex matrices such as wastewater, has driven rapid advancements in biosensor development [2,3]. Here, we present a competitive electrochemical immunosensor for rapid SARS-CoV-2 detection utilizing a novel single-component 2D MoWSe₂ material integrated onto a screen-printed carbon electrode (SPCE), adapted from previous research [4], offering a more time-efficient and accessible alternative to conventional diagnostic methods.

Description of the New Method or System

A competitive immunosensor was developed using RBD antibody (Ab)/PEI-AuNPs nanotags for the detection of SARS-CoV-2 protein via differential pulse voltammetry (DPV). The detection mechanism relies on competitive binding between the target antigen and nanotags. Only unbound RBD Ab/PEI-AuNPs nanotags attach to the electrode surface, while antibody-antigen immune complexes are subsequently washed away. Consequently, the electrochemical signal is directly proportional to unbound nanotags and inversely related to antigen concentration. The sensing platform was fabricated by modifying SPCE with 2D MoWSe₂, followed by thionine

adsorption, SARS-CoV-2 protein immobilization, and BSA blocking, yielding BSA/SARS-CoV-2 protein/TH/2D MoWSe₂-SPCE. Unlike conventional competitive assays, where signals decrease with antigen, reduced surface-bound nanotags in our design lower steric hindrance, enhancing electron transfer through the TH redox mediator and producing an increasing electrochemical signal, as illustrated in Fig. 1.

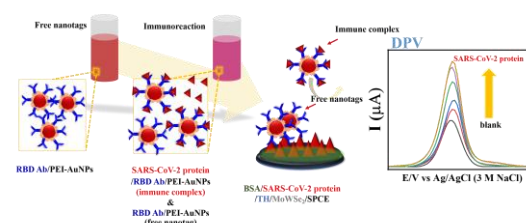


Fig. 1. Fabrication of a competitive immunosensor for the detection of SARS-CoV-2 proteins.

Results

SEM images confirmed successful modification of SPCE with uniform rectangular MoWSe₂ nanosheets (Fig. 2). Electrochemical characterization in PBS (pH 7.4) with 5.0 mM [Fe(CN)₆]^{4-/3-} showed enhanced peak currents (i_{pa} : 93.15 μ A, i_{pc} : -82.28 μ A) and reduced peak separation (0.249 V) for 2D MoWSe₂-SPCE compared to bare SPCE (Fig. 3a). EIS confirmed improved conductivity, with charge transfer resistance (R_{ct}) decreasing from 1383 to 829.4 Ω (Fig. 3b). Thionine (5.0 mM) was adsorbed as a signal amplifier, followed by SARS-CoV-2 protein immobilization and BSA blocking, yielding the final platform: BSA/SARS-CoV-2 protein/TH/2D MoWSe₂-SPCE (Fig. 1). For competitive

detection, a mixture of RBD Ab/PEI-AuNPs nanotags and SARS-CoV-2 protein was incubated and applied to the modified electrode, followed by DPV measurement. The current response increased with antigen concentration due to the competitive binding mechanism (Fig. 4a). A linear relationship was observed between the peak current and the logarithm of antigen concentration: $I (\mu A) = 4.44 \log [\text{SARS-CoV-2 proteins (pg/mL)}] - 1.97$ ($R^2 = 0.991$), over a range of 0–50,000 pg/mL (Fig. 4b). The LOD was 0.496 ng/mL. The sensor demonstrated strong potential for sensitive SARS-CoV-2 detection in environmental and clinical samples.

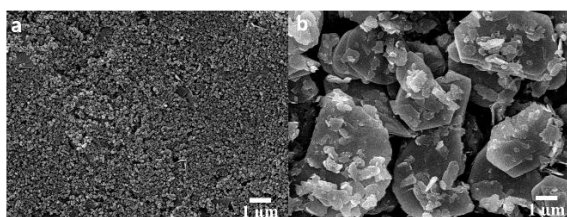


Fig.2. SEM images of (a) bare and (b) 2D MoWSe₂-modified SPCEs.

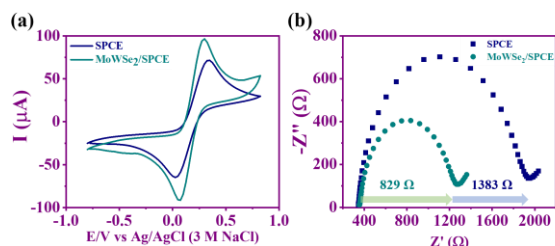


Fig. 3. (a) CVs and (b) Nyquist plots of bare and 2D MoWSe₂-modified SPCE in contact with 0.010 M PBS (pH 7.4) containing 5.0 mM $[\text{Fe}(\text{CN})_6]^{3-/4-}$.

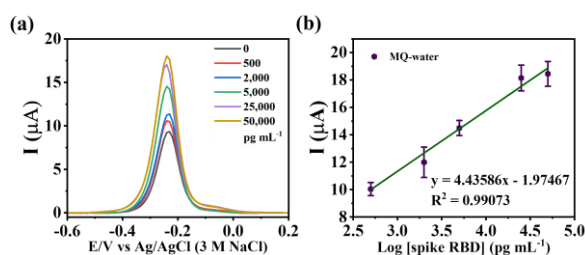


Fig. 4. (a) DPV responses and (b) corresponding calibration curve obtained from the detection of SARS-CoV-2 protein at various concentrations.

References

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