Highly sensitive electrochemical detection of folic acid by using hollow carbon nanospheres@molybdenum disulfide modified electrode

Huiming Ye *,a, Liang Song b,c, Fuhui Zhang a, Juan Li a, Zhiying Su d,*, Yun Zhang b,c,e,*

a Department of Clinical Laboratory, Women and Children's Hospital, School of Medicine, Xiamen University

b CAS Key Laboratory of Design and Assembly of Functional Nanostructures, and Fujian Provincial Key Laboratory of Nanomaterials, Fujian Institute of Research on the Structure of Matter, Chinese Academy of Sciences, Fuzhou, China.

c Department of Translational Medicine, Xiamen Institute of Rare-earth Materials, Haixi Institutes, Chinese Academy of Sciences, Xiamen, China.

d Department of Obstetrics and gynecology, Women and Children's Hospital, School of Medicine, Xiamen University

e University of Chinese Academy of Sciences, Beijing, China.

† These authors contributed equally to this work.

Corresponding author: dyyyszy@126.com (ZY. Su), Tel.(fax): +(86)592-2662001
zhangy@fjirsm.ac.cn (Y.Zhang), yehuiming@xmu.edu.cn(HM.Ye)
Abstract

As a nutrient in body functions, folic acid (FA) plays a very important role for human health, thus developing highly sensitive method for its determination is of great significance. In the present work, hollow carbon nanospheres decorated with molybdenum disulfide nanosheets (CHN@MoS$_2$) nanomaterials were produced through a simple method and adopted to modify glassy carbon electrode for assembling a highly sensitive electrochemical sensor of FA. After characterizing the prepared nanomaterials using scanning-/transmission-electron microscopy and Raman spectra as well as optimizing various testing conditions including pH value of buffer solution, accumulation time and amount of nanomaterials on electrode surface, the electrochemical determination of FA was carried out using CHN@MoS$_2$ electrode. Owing to the coordinative advantages from CHN and MoS$_2$, the results show that CHN@MoS$_2$ exhibits excellent sensing responses for FA, and it has wide linear range from 0.08 to 11.0 μM coupled with a low detection limit of 0.02 μM. Finally, the proposed method for FA detection was applied successfully in human serum analysis and the obtained results are satisfactory, revealing the developed method based on CHN@MoS$_2$ nanomaterials has important applications for FA determination.

Keywords: folic acid; hollow carbon nanospheres; electrochemical determination; molybdenum disulfide; nanomaterials; sensors.

Introduction

As an indispensable nutrient for the body functions, folic acid (FA), called also vitamin B$_9$, is very vital in the periods of rapid cell growth and division,$^{1,2}$ and it is also crucial to produce red blood cell, improve brain health and hearing loss, synthesize and repair DNA/RNA. The lack of FA can arouse various numerous diseases such as megaloblastic anemia, cancer, metabolic syndromes,
disorders hypertension and diabetes. For pregnant women, FA is a necessary nutrient to avoid the fetus to cause malformations of skull, spine and brain.\textsuperscript{3-5} Consequently, developing simple and reliable method for detecting FA is very important.

Presently, several kinds of methods including fluorescence, ultra-performance liquid chromatography, spectrophotometry, HPLC and electrochemical techniques have been proposed to detect FA.\textsuperscript{6-8} Among these methods, the electrochemical techniques have attracted a lot of attentions resulted from their distinctive advantages such as simple operation, low-cost, high reproducibility and rapid response.\textsuperscript{9-11} For instance, Wang and his colleagues\textsuperscript{10} prepared ZrO\textsubscript{2}/ZnO nanocomposites for sensing FA electrochemically, the related results revealed that ZrO\textsubscript{2}/ZnO modified electrode has a linear range from 2.0 to 400.0 \textmu{}M and detection limit (LOD) of 0.037 \textmu{}M. In another work, Jost et.\textsuperscript{11} prepared carbon nanotubes/nickel hydroxide nanocomposite and used it to construct an electrochemical sensor of FA, a linear range from 0.5 to 26.0 \textmu{}M and LOD of 0.095 \textmu{}M were obtained. Although these methods for detecting FA are very important, achieving highly sensitive and reliable detection of FA is still a great challenge.

For achieving efficient and sensitive determination, the employ of materials for modifying electrode is a key factor in electrochemical sensing.\textsuperscript{12-15} Molybdenum disulfide (MoS\textsubscript{2}) nanosheet, a 2D transition metal dichalcogenide, exhibits graphene-like layered nanostructure and constituted of a Mo layer which is sandwiched between 2 sulfur layers,\textsuperscript{16-19} and it possesses many interesting characteristic properties (e.g., excellent catalytic ability, low cost, design flexibility, abundant marginal active sites), presently MoS\textsubscript{2} nanosheets have received extensive attentions in many fields.\textsuperscript{20-22} Meanwhile, some reports indicated the advantages of MoS\textsubscript{2} nanosheet enables it to be one of the promising nanomaterials for developing next-generation electrochemical sensors,\textsuperscript{23} this makes us believe that MoS\textsubscript{2} can be selected to construct highly sensitive electrochemical sensor for
FA. However, pure MoS$_2$ nanosheet is easy to stack with each other and its conductivity is not desirable.$^{24-29}$

For overcoming the MoS$_2$ defects and improving its practical performance, integrating MoS$_2$ nanosheets with carbon materials is considered as an ideal project, because the formed nanostructures can exhibit specific coordinative properties of each component to avoid MoS$_2$ stack and enhance the electrochemical properties.$^{30-34}$ Hollow carbon nanospheres (CHN) are a desirable candidate to integrate MoS$_2$ nanosheets due to the high surface area, conductivity and stability. In this work, for achieving highly sensitive determination of FA, CHN decorated with MoS$_2$ nanosheets (CHN@MoS$_2$) nanomaterials were synthesized firstly via a simple and green method, and CHN@MoS$_2$ was then applied to modify GCE to assemble electrochemical sensor (CHN@MoS$_2$/GCE) of FA. The experimental results show that CHN@MoS$_2$/GCE exhibits much higher sensing performances than pure CHN or MoS$_2$ modified GCE resulted from the synergetic effects from MoS$_2$ and CHN. Importantly, after optimizing various conditions, a wide linearity range and low LOD were achieved by CHN@MoS$_2$/GCE for FA. It’s expected the developed electrochemical method for detecting FA has important applications in the analysis of real samples.

**Experimental section**

*Synthesizing CHN@MoS$_2$*

CHN was prepared firstly according to the previous work.$^{35}$ Then, CHN was added in to ultrapure water and ultrasonicated for some minutes, and L-cysteine/Na$_2$MoO$_4$ were added to CHN dispersion via stirring. Next, the formed mixture was moved in Teflon-autoclave to be heated for 12 h at 200 °C, and the autoclave was left further to cool down. The produced CHN@MoS$_2$ nanohybdrd was collected via centrifugation and cleaned with water/ethanol, and then it was dried overnight.
Finally, the prepared CHN@MoS$_2$ were annealed in N$_2$ atmosphere at high temperature. For comparison, the pure MoS$_2$ nanosheets were prepared with the similar processes.

**Preparing CHN@MoS$_2$/GCE and electrochemical texts**

The GCE surface was polished carefully with 0.5 and 0.05 μm alumina respectively, and then cleaned with ultrapure water, followed by cleaned ultrasonically in acetone and ultra-pure water, respectively. 2.0 mg CHN@MoS$_2$ was added into 4.0 mL ultrapure water and sonicated for 20 min to form homogeneous suspension. CHN@MoS$_2$/GCE was prepared through dropping different amount of CHN@MoS$_2$ suspension on GCE surface. For comparison, MoS$_2$/GCE and CHN/GCE was prepared through the similar steps. The electrochemical sensing of CHN@MoS$_2$/GCE towards FA was carried out following 2 consecutive processes: (i) pre-concentration of FA to the electrode surface with certain of accumulation time; and (ii) measuring with electrochemical technologies.

**Results and discussion**

**Characterization of the CHN@MoS$_2$**

Scanning- and transmission- electron microscopy (SEM, TEM) were used to investigate the structures and morphologies of CHN@MoS$_2$ and related nanomaterials. As depicted in Figure 1A, the pure MoS$_2$ nanosheets tend to agglomerate with each other. Figure 1B exhibits the SEM image of pure CHN, it's noted that CHN is distributed uniformly with hollow structure and smooth surface. As for CHN@MoS$_2$ (Figure 1C), it can be found that the MoS$_2$ nanosheets loosely wrap with the CHN surface, showing flower-like nanostructures. Figure 1D to 1F show the TEM images of MoS$_2$ (Figure 1D), CHN (Figure 1E) and CHN@MoS$_2$ (Figure 1F). As shown in Figure 1D, the pure MoS$_2$ tends to stack tightly together with interlaced nanostructure. For CHN, the hollow structures are observed visibly with the thickness of ~10 nm carbon layer, which could offer a large surface...
area for loading MoS$_2$ nanosheets. As for the CHN@MoS$_2$ hybrids (Figure 1F), CHN as substratum affords more attachment sites for supporting the formation and impeding the agglomeration of MoS$_2$ nanosheets, hence it can be noted MoS$_2$ sheets are uniformly dispersed on CHN surface, these result is inconsistent with the former SEM characterization.

Raman spectra were further used to study the prepared CHN@MoS$_2$ and related nanohybrids (Figure 2). For the pure MoS$_2$ and prepared CHN@MoS$_2$, there are 2 distinct peaks at ~405.0 and 377.0 cm$^{-1}$ ascribed to the out-of-plane $A_{1g}$ phonon modes and in-plane $E_{2g}^1$ from MoS$_2$ respectively. For CHN and CHN@MoS$_2$ materials, the 2 characteristic peaks presented at ~1590 and 1340 cm$^{-1}$ correspond to G and D band respectively owing to the presence of carbon. The intensity proportion of D and G band (denoted as $I_D/I_G$) is used frequently to assess graphitization degree in carbon nanomaterials. The figure shows the relative intensity from G band is stronger compared to D band, suggesting CHN is graphitized well via the calcining step. Meanwhile, the $I_D/I_G$ value from CHN@MoS$_2$ is even smaller than that from CHN attributed to two-time annealing. These indicate CHN@MoS$_2$ nanomaterials were produced successfully.

Next, the electrochemical impedance technique was adopted to study electron transfer behaviors in various electrodes. Figure 3 shows the corresponding impedance spectroscopy (EIS) of MoS$_2$/GCE (a), CHN/GCE (b) and CHN@MoS$_2$/GCE (c) recorded in 5.0 mM [Fe(CN)$_6$]$^{3-}/4^-$ solution. Through simulating the EIS data using Randles equivalent circuit, it can be known the charge-transfer resistance ($R_{CT}$) of MoS$_2$/GCE (~350.0 Ω) is larger than those from the other electrodes since the conductivity of pure MoS$_2$ nanosheet is not desirable, while the $R_{CT}$ value of CHN is considerable small and even it can be neglected, suggesting that the electron transfer rate in CHN is very high. It’s worth noting that the CHN@MoS$_2$/GCE has a much lower $R_{CT}$ value (~130.0 Ω) compared to MoS$_2$/GCE, indicating the introduction of CHN could improve obviously the
conductivity of MoS$_2$-based nanomaterials.

**Electrochemical behaviors of FA**

The electrochemical behaviors of FA at CHN@MoS$_2$/GCE and the related modified electrodes were studied by cyclic voltammetry (CV) technology in 0.1 M phosphate buffer solution (PBS, pH 7.0). As depicted in Figure 4, the CV response of FA at GCE shows a weak and broad oxidation peak located at 0.85 V, while MoS$_2$/GCE shows an apparently increased oxidation peak current and it’s much stronger than that at GCE resulted from the high catalytic ability and abundant marginal active sites of MoS$_2$. Owing to the high surface area and prominent electrochemical activity of CHN, CHN/GCE also shows much larger oxidation current than the bare GCE. Interesting, it’s noted the peak current value of FA at CHN@MoS$_2$/GCE displays a significant increase comparing to all the other modified electrodes and the oxidation potential was shifted to 0.73 V negatively, specifically the current value at CHN@MoS$_2$/GCE is ~16.1, ~3.3 and ~2.6 times higher than those at GCE, MoS$_2$/GCE and CHN/GCE, respectively, implying that CHN@MoS$_2$/GCE can exhibit the coordinative advantages from MoS$_2$ (high catalytic ability and abundant marginal active sites) and CHN (large surface area and prominent electrochemical activity) for electrochemically detecting FA, which is expected to possess promising applications for constructing highly sensitive electrochemical sensor of FA.

**Optimization of the conditions**

As a powerful electrochemical technology, differential pulse voltammetry (DPV), has higher sensitivity and resolution comparing to the CV technology. For achieving highly sensitive determination of FA based on CHN@MoS$_2$/GCE, various experimental text conditions were optimized in 0.1 M PBS by DPV and the related results were exhibited in Figure 5.

Firstly, the influence from the pH value of PBS was studied over the pH value from 4.0 to 9.0
(Figure 5A, accumulation time 50 s; amount of CHN@MoS\textsubscript{2} 10.0 μL). It’s noted from the figure the oxidation current of FA keeps increasing along with the increase of pH value from 4.0 to 7.0, while it begins to reduce when pH value increases further to 9.0 since protons are involved in the FA oxidation. For achieving high sensitivity, pH of 7.0 was selected in the following experiments. Next, the influence from the amount of CHN@MoS\textsubscript{2} nanomaterials on electrode surface was also studied (Figure 5B), it can be found the oxidation current from FA obviously increases along with the increase of CHN@MoS\textsubscript{2} suspension amount (0.5 mg·mL\textsuperscript{-1}) from 2.0 to 10.0 μL. As for the amount from 10.0 to 14.0 μL, the peak current show only weak increases. Hence, 10.0 μL as the optimum amount was applied throughout the work. It’s no doubt that the sensing sensitivity is affected by the accumulation time, thus the influence from accumulation time was investigated also. As shown in Figure 5C, the oxidation current of FA increases with the increase of the accumulation time, obtaining a maximum at 50 s, hence this time was used as the optimal value time in the study.

Analytical performance of CHN@MoS\textsubscript{2}/GCE

Under the above optimal conditions, the analytical performance of CHN@MoS\textsubscript{2}/GCE toward FA was evaluated through plotting the related calibration curve containing the changes from DPV peak currents upon the increase from FA concentration, it’s found the peak current of FA linearly increases with FA concentration ranging from 0.08 to 11.0 μM (Figure 6). The corresponding linear regression equation is defined as \( I_p (\mu A) = 1.0844+0.7847C (\mu M) \) coupled with the correlation coefficient of \( R^2=0.9945 \), and the LOD is calculated to be 0.02 μM (S/N=3). In addition, the proposed detection method for FA in the work is compared with the previous studies (Table 1). The comparative results indicate that CHN@MoS\textsubscript{2}/GCE has a lower LOD than most of the previous researches, and meanwhile it possesses wide linear range resulted from the abundant marginal active sites and large surface of CHN@MoS\textsubscript{2}, suggesting that it can be used in the highly sensitive
determination for FA. And it should be pointed out that the preparation method for CHN@MoS₂ is simple, low cost and green.

Reproducibility, stability and selectivity

For evaluating the CHN@MoS₂/GCE reproducibility, which is expressed via relative standard deviation (RSD), six parallel-made CHN@MoS₂/GCE were used to measure 5.0 μM FA by DPV. The RSD value of the peak current response was found to be 4.36%. On other hand, the long-term stability of CHN@MoS₂/GCE was evaluated via testing the peak current response of FA for thirty days with the interval of six days, the results show that CHN@MoS₂/GCE maintains 95.6 % of the initial current response. These results demonstrated that CHN@MoS₂/GCE has acceptable reproducibility and store stability.

The selectivity of CHN@MoS₂/GCE for FA was evaluated through comparing current responses in the presence of potential interfering organic molecules. The results reveal that no evident interference was presented for the following molecules including methotrexate, ascorbic acid, folinic acid, tetrahydofolic acid, uric acid, 5-methyltetrahydrofolate, dopamine and pyridoxine (10 times of FA concentration), suggesting that the CHN@MoS₂/GCE has a satisfactory selectivity for FA analysis.

real samples analysis

For evaluating the feasibility of CHN@MoS₂/GCE in practical application, FA in human urine was determined by the developed method. First, the urine samples were centrifuged, extracted and diluted with PBS, and sequentially the original content of FA in the urine sample was measured by the proposed method, the results show that there is no FA detected. Next, the samples were spiked with various concentrations of FA and the peak current of FA was recorded by CHN@MoS₂/GCE, the recoveries were applied to evaluate the feasibility in real samples (Table 2). As depicted in Table
2, the obtained recoveries are found in the range from 96.0% to 106.0% and the RSD values are below 6.0%, indicating that proposed CHN@MoS$_2$/GCE sensor can detect FA successfully in real samples.

**Conclusion**

In summary, a novel electrochemical sensor for the highly sensitive detection of FA was successfully developed by preparing CHN@MoS$_2$ as electrode nanomaterials. The final results demonstrated that CHN@MoS$_2$ could exhibit the coordinative advantages from MoS$_2$ and CHN for FA analysis, and the prepared CHN@MoS$_2$/GCE shows excellent sensing performances with wide linear range and low LOD. Meanwhile, the developed CHN@MoS$_2$/GCE exhibits high reproducibility and stability, excellent selectivity and practicability. Furthermore, the proposed method for FA analysis is simple, low cost and green. It’s confirmed that the developed method for FA detection based on CHN@MoS$_2$ will have important potentials in real sample analysis.

**Acknowledgment**

This study was financed by the National Natural Science Foundation of China.

**References**

1. S. Akbar, A. Anwar, and Q. Kanwal, *Analytical Biochemistry*, 2016, 510, 98-105.
2. M. Venu, *International Journal of Electrochemical Science*, 2018, 11702-11719.
3. H. Rajabi, and M. Noroozifar, *Materials Science and Engineering: C*, 2017, 75, 791-797.
4. S. Güney, *Journal of Electroanalytical Chemistry*, 2019, 854, 113518.
5. F. Chekin, F. Teodorescu, Y. Coffinier, G.-H. Pan, A. Barras, R. Boukherroub, and S. Szunerits, *Biosensors and Bioelectronics*, 2016, 85, 807-813.
6. W. Ren, Y. Fang, and E. Wang, *ACS Nano*, 2011, 5, 6425-6433.

7. S. Ulusoy, H. Acıdereli, S. Erdoğan, and H. İbrahim Ulusoy, *RSC Advances*, 2016, 6, 40115-40122.

8. X. Li, and L. Chen, *ACS applied materials & interfaces*, 2016, 8, 31832-31840.

9. A. A. Abdelwahab, and Y. Shim, *Sensors and Actuators B-chemical*, 2015, 221, 659-665.

10. Q. Wang, H. Si, L. Zhang, L. Li, X. Wang, and S. Wang, *Analytica Chimica Acta*, 2020, 1104, 69-77.

11. J. P. Winiarski, R. Rampanelli, J. C. Bassani, D. Z. Mezalira, and C. L. Jost, *Journal of Food Composition and Analysis*, 2020, 92, 103511.

12. Y. Yi, D. Zhang, Y. Ma, X. Wu, and G. Zhu, *Analytical Chemistry*, 2019, 91, 2908-2915.

13. J. Hu, K. T. Ho, X. U. Zou, W. H. Smyrl, A. Stein, and P. Buhlmann, *Analytical chemistry*, 2015, 87, 2981-2987.

14. K. Hsieh, B. S. Ferguson, M. Eisenstein, K. W. Plaxco, and H. T. Soh, *Accounts of chemical research*, 2015, 48, 911-920.

15. A. Kotani, M. Kaneko, K. Machida, K. Yamamoto, and H. Hakamata, *Analytical Sciences*, 2020, 10.2116/analsci.20P297.

16. O. Parlak, A. Incel, L. Uzun, A. P. F. Turner, and A. Tiwari, *Biosensors & bioelectronics*, 2017, 89, 545-550.

17. A. Sinha, Dhanjai, B. Tan, Y. Huang, H. Zhao, X. Dang, J. Chen, and R. Jain, *TrAC Trends Analytical Chemistry*, 2018, 102, 75-90.

18. M. Sharifuzzaman, S. C. Barman, M. A. Zahed, N. J. San, and J. Y. Park, *Journal of The Electrochemical Society*, 2019, 166, B249-B257.

19. D. Zhang, Y. Ma, O. J. Kingsford, J. Qian, and Y. Yi, *Journal of The Electrochemical Society*, 11/21
2019, 166, B1392-B1399.

20. B. Mao, B. Wang, F. Yu, K. Zhang, Z. Zhang, J. Hao, J. Zhong, Y. Liu, and W. Shi, *International Journal of Hydrogen Energy*, 2018, 43, 11038-11046.

21. L. Xing, and Z. Ma, *Microchim Acta*, 2015, 183, 257-263.

22. Y. Wang, G. Ning, H. Bi, Y. Wu, G. Liu, and Y. Zhao, *Electrochimica Acta*, 2018, 285, 120-127.

23. S. K. Tuteja, T. Duffield, and S. Neethirajan, *Nanoscale*, 2017, 9, 10886-10896.

24. S. Wang, B. Y. Guan, L. Yu, and X. W. D. Lou, *Advanced materials*, 2017, 29.

25. L. Song, X. Wang, F. Wen, L. Niu, X. Shi, and J. Yan, *Int. J. Hydrogen Energy*, 2016, 41, 18942-18952.

26. P. Jing, H. Yi, S. Xue, Y. Chai, R. Yuan, and W. Xu, *Analytica Chimica Acta*, 2015, 853, 234-241.

27. A. Ambrosi, Z. Sofer, and M. Pumera, *Small*, 2014, 11, 605-612.

28. A. S. Subramanian, J. N. Tey, L. Zhang, B. H. Ng, S. Roy, J. Wei, and X. M. Hu, *Polymer*, 2016, 82, 285-294.

29. D. Geng, X. Bo, and L. Guo, *Sensors and Actuators B-chemical*, 2017, 244, 131-141.

30. S. Y. Park, Y. H. Kim, S. Y. Lee, W. Sohn, J. E. Lee, D. H. Kim, Y.-S. Shim, K. C. Kwon, K. S. Choi, H. J. Yoo, J. M. Suh, M. Ko, J.-H. Lee, M. J. Lee, S. Y. Kim, M. H. Lee, and H. W. Jang, *Journal of Materials Chemistry A*, 2018, 6, 5016-5024.

31. Y. Li, H. Wang, L. Xie, Y. Liang, G. Hong, and H. Dai, *Journal of the American Chemical Society*, 2011, 133, 7296-7299.

32. H. Song, Y. Ni, and S. Kokot, *Biosensors & bioelectronics*, 2014, 56, 137-143.

33. E. B. Bahadır, and M. K. Sezgintürk, *TrAC Trends in Analytical Chemistry*, 2016, 76, 1-14.
34. R. He, J. Hua, A. Zhang, C. Wang, J. Peng, W. Chen, and J. Zeng, *Nano letters*, 2017, 17, 4311-4316.

35. L. Li, W. Zhang, X. Wang, S. Zhang, Y. Liu, M. Li, G. Zhu, Y. Zheng, Q. Zhang, T. Zhou, W. K. Pang, W. Luo, Z. Guo, and J. Yang, *ACS Nano*, 2019, 13, 7939-7948.

36. Y. Chen, W. C. Peng, and X. Y. Li, *Nanotechnology*, 2017, 28, 205-217.
Figure 1. SEM images of MoS$_2$ (A), CHN (B), and CHN@MoS$_2$ (C); TEM images of MoS$_2$ (D), CHN (E), and CHN@MoS$_2$ (F).
Figure 2. The Raman spectra of MoS$_2$ (a), CHN (b) and CHN@MoS$_2$ (c).
Figure 3. EIS plots of the MoS$_2$/GCE (a), CHN/GCE (b), and CHN@MoS$_2$/GCE (c) recorded in Fe(CN)$_6^{3-/4-}$ solution.
Figure 4. CV responses of 25.0 μM FA at (a) GCE, (b) MoS$_2$/GCE, (c) CHN/GCE, and (d) CHN@MoS$_2$/GCE in 0.1 M PBS.
Figure 5. The influence of the pH value (A), amount of CHN@MoS$_2$ (B) and accumulation time (C) on the DPV peak current of 5.0 μM FA at CHN@MoS$_2$/GCE.
Figure 6. (A) DPV responses of CHN@MoS$_2$/GCE in 0.1 M PBS containing various concentrations of FA from 0.08 μM to 11.0 μM. (B) The corresponding standard curve of FA.
Table 1. Comparison of the proposed CHN@MoS₂/GCE with the reported electrochemical sensors in previous literature for detecting FA.

| Materials used                                | Linear range [μM] | LOD [μM] | Refs. |
|------------------------------------------------|-------------------|----------|-------|
| Co₃O₄/rGO/CTAB                                | 500.0-3200.0      | 95.0     | 2     |
| Polyortho-methoxyaniline/carbon nanodots      | 0.5-68.0          | 0.113    | 3     |
| Molecularly imprinted poly(p-aminobenzenesulphonic acid)/carbon nanodots | 0.0049-0.0698 | 0.0045   | 4     |
| Au nanoclusters/graphene/ carbon nanodots     | 10.0-170.0        | 0.1      | 9     |
| ZrO₂/ZnO                                      | 2.0-400.0         | 0.037    | 10    |
| Carbon nanotubes/nickel hydroxide             | 0.5-26.0          | 0.095    | 11    |
| CHN@MoS₂                                      | 0.08-11.0         | 0.02     | This work |
Table 2. The detection of FA in real urine samples.

| Samples | Added [μM] | Found [μM] | RSD [%] | Recovery [%] |
|---------|------------|------------|---------|--------------|
| 1       | 0.5        | 0.53       | 3.55    | 106.0        |
| 2       | 2.0        | 1.92       | 4.36    | 96.0         |
| 3       | 5.0        | 5.25       | 5.72    | 105.0        |
| 4       | 8.0        | 7.88       | 3.83    | 98.5         |