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Molybdenum Disulfide/Graphene Oxide Nanohybrid as an Electrocatalyst for Sensitive Detection of Carbamazepine in Human Body Fluid Samples

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Abstract
Molybdenum disulfide as a transition metal dichalcogenide was prepared by a hydrothermal method and hybridized with graphene oxide (MoS_2/GO). The as-prepared materials were investigated by Fourier transform infra-red spectroscopy (FT-IR), X-ray diffraction (XRD), energy dispersive X-ray elemental analysis (EDX) techniques as well transmission electron microscopy (TEM) image. The nanomaterial with its electrocatalytic properties was applied as an electro-nanocatalyst for loading on a glassy carbon electrode (MoS_2/GO-GCE) for detection of carbamazepine as an anti-epileptic in real body samples. The simple and low-cost developed electrochemical sensor detected carbamazepine with a vast linear concentration range(30-350nM), very low detection limit about 6.0nM and significant sensitivity equal to 0.134µA/nM.

Keywords
Carbamazepine; Transition Metal Dichalcogenides; Electrocatalyst; Sensor.

1. INTRODUCTION

5H-dibenzo[b,f]azepine-5-carboxamide,carbamazepine, is an anti-tension medicine [1].Firstly, It was prescribed for bipolar problems. As well, it applied to stand against illnesses such as restless leg syndrome and resistant schizophrenia [2]. Few chromatography techniques(HPLC and LC-MS) [3-6], fluorimetry [7,8] and spectrophotometry [9,10] have been used for carbamazepine determination in physiological fluids and other samples. Though the high-performance liquid chromatographymethod has some benefits such as high separation and excellent validity, but costly equipments, complicated sample preparation, and multiple steps restricts its usage in practice. On the other hand, electroanalytical methods seem to be low precise[11–14]. Hence, suggesting a reliable electrochemical sensor would be important.

Molybdenum disulfide, MoS_2, is a widely used material in industries as an excellent lubricant [15]. MoS_2, is belonged to two-dimensional transition metal dichalcogenides (TMDCs).2D nanomaterials have been lately used in sensors and biosensors. This class of materials possesses semiconductor aspects, huge surface area and significant stability. TMDCs include materials such as MoS_2, WS_2, $MoSe_2$ which chalcogen-transient metal-chalcogen layers (chalcogen = S, Te or Se) placed over each other to organize a two-dimensional structure [16]. Also, hybridizing of these materials with carbonaceous materials like carbon nanotubes or graphene causes to enhancement of electrocatalytic properties and promotion the stability of the electrocatalyst [17].

In the current work, the syntheticMoS_2 mixed with graphene oxide (GO) was used for detection of ultra-trace levels of carbamazepine in real body fluid samples. The synthetic materials was identified with FT-IR, XRD, EDX and TEM image. The glassy carbon electrode modified by the synthetic nanohybrid (MoS_2/GO-GCE) was developed as an effective sensor for detection the carbamazepine in real human body samples.

2. EXPERIMENTAL

2.1. Materials and instrumentals

Ultra-pure carbamazepine was purchased from Sigma-Aldrich. $Na_2MoO_4{\cdot}2H_2O$and L-cysteine were prepared from the Merck. Other chemicals were from their pure grade.

Graphene oxide was synthesized based on modified Hummers´ method [18].

Buffer solutions as phosphate-buffered saline solutions (PBS) was made by adjusting the pHs by adding appropriate amounts of 0.1M of NaOH solution to 0.1M of phosphoric acid.

An OGF500potentiostat/galvanostat (Origalys, France), a 2mm diameter standard glassy carbon electrode (GCE, Azar electrode, Iran), a platinum electrode and a saturated calomel electrode (SCE) were used as the working, auxiliary and reference electrodes, respectively.

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2.2. Synthesis of MoS_2/Go nanohybrid

MoS_2 was synthesized through a hydrothermal procedure. Briefly, synthesized GO (0.05 g) was mixed with 20 ml of deionized water. Then, 0.4 g of $Na_2MoO_4.2H_2O$ was added to the mixture. After sonicating for 20 minutes, the pH reached to neutral with the 0.01M of NaOH solution .0.5 g of L-cysteine dissolved in 70 ml deionized water was added to the mixture and the suspensionconducted into a stainless-steel reactor for heating at 190°C for 48h. The resultant black solution was centrifuged and washed with ethanol and double distilled water for few times. Then, the product was dried in an oven at70°C for 24h. XRD spectrum, EDX elemental analysis and TEM image confirmed the characteristics of the electrocatalyst.

2.3. Electrode modification with MoS_2/GO nanohybrid (MoS_2/GO-GCE)

At first, 0.05 g of MoS_2/GOwas dispersedin 1 ml of tetrahydrofuran solvent (THF) and ultra-sonicated for 20 min to gain a uniform suspension of the MoS_2/GO. For modification the GCE for any future test,10.0 µl of the as-prepared nanohybrid suspension in THF was drop casted on the clean bare surface of the working electrode and kept in the room temperature to dry.

3. RESULT AND DISCUSSION

3.1. Identification of the synthetic materials

The FT-IR spectrum of the prepared GO (Fig.1A) representsthe peaks at1629 and 3429cm^{-1} which are corresponded to C=C in-plane vibration and hydroxyl groups, respectively.

The XRD pattern of the synthetic MoS_2/GO nanohybrid is showed in Fig.1B.The index peaks appeared at 2Θs of 33,39,44.5,50 and 58.5 are agree with MoS_2 pattern through JCPDS card No. 37-1492[19].Also, EDX elemental analysis of MoS_2confirmed the presence of Mo and S atoms in the structure of the as-prepared MoS_2(Fig.1C).

TEM image of MoS_2/GO nanohybrid (Fig.1D) shows apparently the MoS_2 layers being on the graphene nanosheets.

3.2. Electrochemical characterization

Firstly, in order to study the behavior of the bare glassy carbon electrode for red/ox process of carbamazepine, various buffer solutions(pH=2-9) of 1mM of carbamazepine were prepared and the behavior of the unmodified glassy carbon electrode was investigated at the potential scan rate equal to 40mV/s.As can be seen in Fig.2A, there was not any clear red/ox peaks at the selected potential range except for greater capacitive currents in the higher pHs.

In the next step, the MoS_2/GO modified glassy carbon electrode was inserted in various pHs in presence of 1mM of carbamazepine.As it was found in Fig2.B, the oxidation peak related to carbamazepine was observed in alkaline pHs which pH=8 was selected as the optimum pH in future tests due to the peak height and shape.

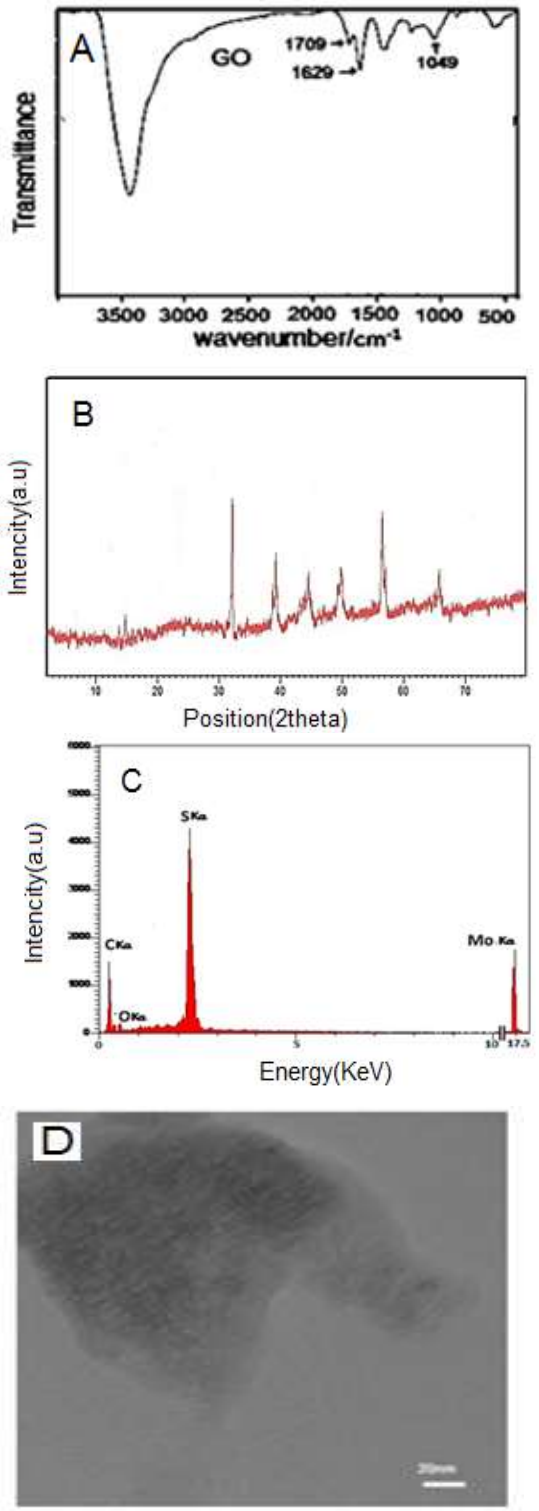


Fig. 1. FT-IR spectrum of synthetic graphene oxide(A),XRD pattern of the as-prepared MoS_2(B),EDX elemental analysis of the as-prepared MoS_2(C) and TEM image of MoS_2/GO(D).

Based on literature [20], the suggested mechanism for electrooxidation of carbamazepine, electrocatalized by MoS_2/GO, is presented in scheme 1.

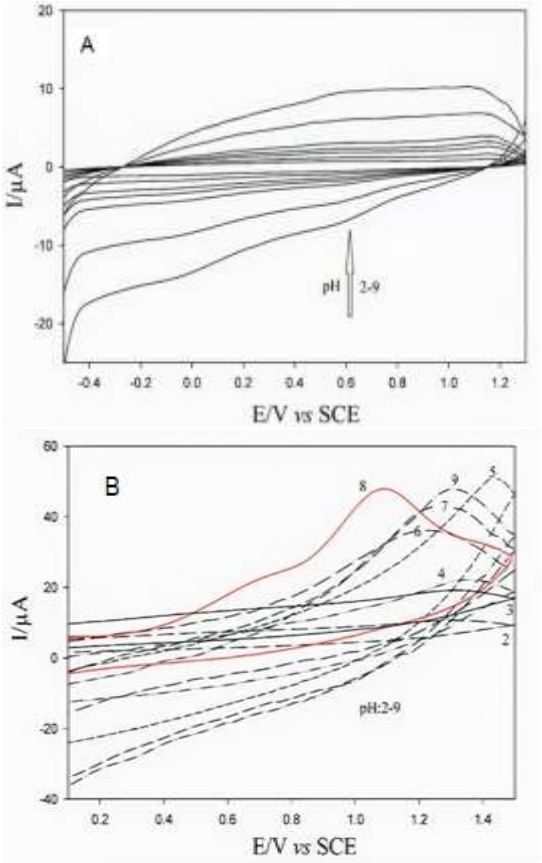
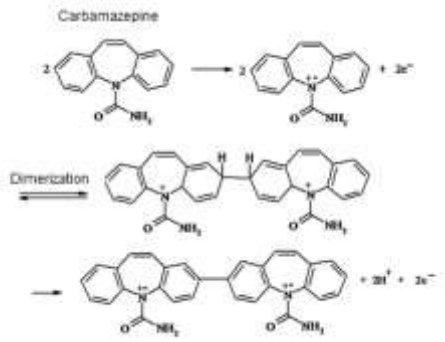


Fig. 2. Cyclicvoltammograms of the bare GCE (A) and MoS_2/GO-GCE inserted in various buffer solutions (PH=2-9) in presence of 1mM of carbamazepine and 0.1 M of KCl as the supporting electrolyte with 40 mV/s potential scan rate.



Schem.1. mechanism of carbamazepine electrooxidation in alkaline media

To anticipate the effect of potential scan rates , the peak currents extracted from cyclic voltammograms of MoS_2/GO-GCE inserted in 1mM of carbamazepine (pH=8)(Fig.3A),were plotted against the root of potential scan rates (Fig.3B).The linearity of the plot confirmed the predominant of diffusion manner for electrooxidation of carbamazepine by MoS_2/GO-GCE.

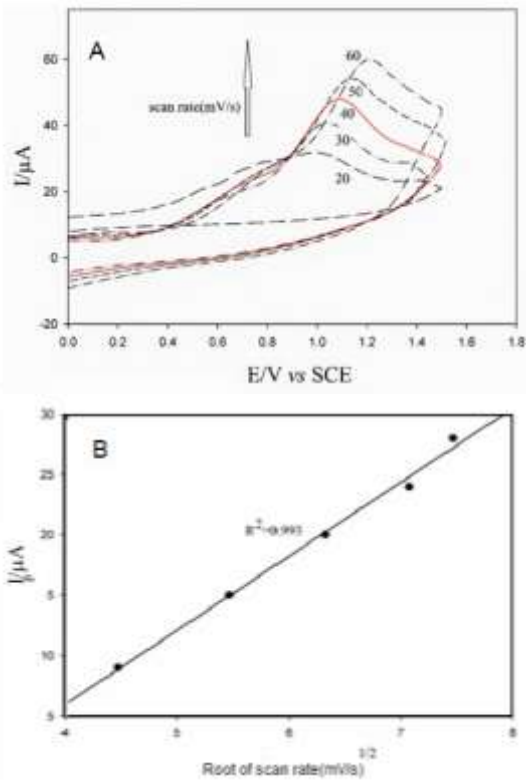


Fig. 3. Cyclic voltammograms of MoS_2/GO-GCE inserted in 1mM of carbamazepine (pH=8) in presence of 0.1M of KCl with different potential scan rates(A), the plot of corresponded peak currents versus root of the scan rates(B).

3.3. Analysis aspects of carbamazepine by fabricated MoS_2/GO-GCE

Without a doubt, differential pulse voltammetry (DPV) is a strong and reliable technique for quantitative electrochemical analysis because of its low capacitive current. Thus, based on the results and Fig.4A, various concentrations of carbamazepine added to PBS (pH=8) solutions were tested by MoS_2/GO-GCE through DPV fortracing the calibration plot (peak potential (Ip)against the concentrations). Fig.4B describes an extensive linear dynamic range of ultra-trace levels of carbamazepine(30-350nM) with the slope (sensitivity) equal to 0.134μA/nM.

As it is clear, the limit of detection, L.O.D, is specified as $3S_b/b$ which S_b and b stand for standard deviation of at least seven repeated analysis of the blank solution and the sensitivity extracted from the calibration plot, respectively. According to the obtained results,the L.O.D was calculated about 6nM for carbamazepine by the MoS_2 /GO-GCE.

Table 1. The results of real sample analysis by MoS_2 /GO-GCE for carbamazepine.

Analyte	Sample	Added (nM)	Detected in blood serum(nM)	Detected in Urine(nM)	Recovery (%) in blood serum	Recovery (%) in Urine
Carbamazepine	1	0.0	no detection	no detection	---	---
	2	40	41.20	42.10	103.0	105.0
	3	150	152.60	148.50	101.7	99.0
	4	320	317.40	324.10	99.2	101.3

The stability of theMoS_2 /GO-GCEelectrochemical sensor was anticipated by applying 40 repetitive scans for a specific concentration of carbamazepine and it was seen that lower than 3% decrease in the peak current was found for drug analysis. Also, for evaluating the within results repeatability, nine frequent detection of carbamazepineweredone by a typical fabricated sensor. From the output results, the relative standard deviation wascalculated1.98%. Overall, the good durability and repeatability were observed for the developed MoS_2/GO-GCE electrochemical sensor for detection of carbamazepine.

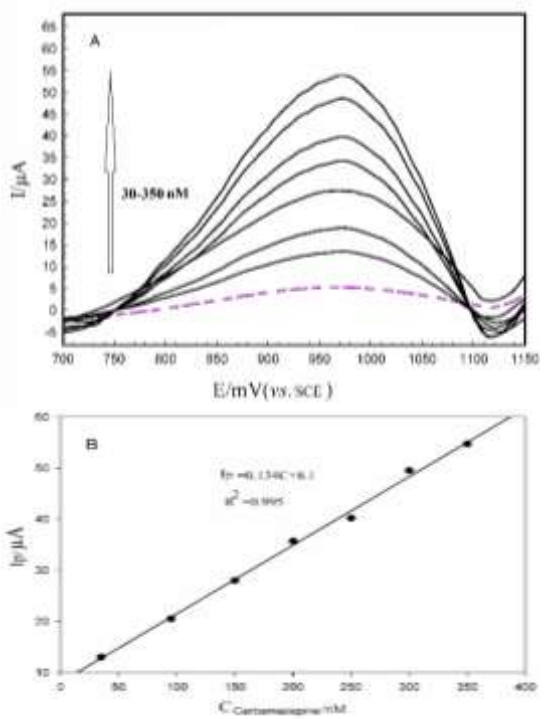


Fig. 4. DPV analysis of various concentrations of carbamazepine by MoS_2/GO-GCE in presence of 0.1M of KCl as the supporting electrolyte (PBS, pH=8) (A) and the corresponded calibration plot(B).

To evaluating of the prepared MoS_2/GO-GCE sensor application in real samples, the given concentrations of thecarbamazepine were added to 4 samples of blood serum and urine belonged to healthful persons after diluting for few times with buffer solution (PBS, pH=8). The calculated recovery percentages are reported in table 1. As it was seen, the notable detections were calculated for carbamazepine in real human body samples.

4. CONCLUSION

A modified glassy carbon electrode as an electrochemical sensor was developed by a hybrid of a TMDC material with graphene oxide (MoS_2/GO). The fabricated inexpensive sensor was used promisingly for determination of ultra-trace concentrations of carbamazepine by DPV in physiological samples. The limit of detections for carbamazepine by the fabricated sensor wasestimated about 6nM which was a very brilliant in its type. The stability and repeatability of the fabricated electrochemical sensor was satisfying regard to its simplicity.

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نانوهیبرید مولیبدن دی سولفید/گرافن اکسید، به عنوان یک الکتروکاتالیست موثر در تعیین حساس کاربامازپین در نمونه های سیالات بدن انسان

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چکیده
مولیبدن دی سولفید به عنوان یک دی کلکوژنید فلز واسطه (TMDC) با یک روش هیدروترمال ساده سنتز و با اکسید گرافن به صورت (MoS2/GO) هیبریدشد. مواد نانوهیبرید سنتزشده توسط طیف سنجی مادون قرمز تبدیل فوریه (FT-IR) ، پراش اشعه ایکس (XRD) ، آنالیز عنصری پراکندگی انرژی اشعه ایکس (EDX) و همچنین تصویر میکروسکوپ الکترونی عبوری (TEM) مشخصه یابی شد. موادسنتزی به عنوان یک الکتروکاتالیست موثر و پایدار برای اصلاح الکترود کربن شیشه ای (MoS2 / GO-GCE) در جهت تعیین کاربامازپین به عنوان داروی ضد صرع در نمونه های سیالات بدن انسان استفاده گردید. حسگر الکتروشیمیایی ساخته شده، کاربامازپین را با دامنه غلظتی وسیع ۳۰ تا ۳۵۰ نانومولار، حد تشخیص بسیار کم در حدود ۶,۰ نانومولار و حساسیت قابل توجه برابر با ۰,۱۳۴ µA / nM تعیین نمود.

واژه‌های کلیدی
کاربامازپین؛ دی کلگوژنیدهای فلزات واسط؛ الکتروکاتالیست؛ حسگر.