Anal. Bioanal. Electrochem., Vol. 12, No. 4, 2020, 458-467

Analytical & Bioanalytical Electrochemistry

Full Paper

A New Electrochemical Sensor for Determination of Zolpidem by Carbon Paste Electrode Modified with SnS@SnO_2NP

Ebrahim Naghian,[1] and Esmail Sohouli[2,*]

[1]*Department of Chemistry, South Tehran Branch Islamic Azad University, Tehran, 1777613651, Iran*

[2]*Young Researchers and Elites Club, Science and Research Branch, Islamic Azad University, Tehran, Iran*

*Corresponding Author, Tel.: +989106710637

E-Mail: esmailshimi@yahoo.com

Received: 16 March 2020 / Received in revised form: 7 April 2020 / Accepted: 7 April 2020 / Published online: 30 April 2020

Abstract- Zolpidem is a drug that is easily attached to the GABA receptors in the brain. This property makes it very effective for tranquilizing as well as hypnagogia. According to the advantages of electrochemical analysis like high selectivity, high sensitivity, low concentration of analyte, cost-effective, portable and easy-to-use setup, they gained high amount of attention among scientists for determination of different compounds. So in the work, an electrochemical sensor was prepared by the modification of a carbon paste with sulfur-tin@tin oxide nanocomposite (SnS@SnO_2NP/CPE) and was investigated for the determination of zolpidem in an aqueous solution. For this reason the electrochemical characteristic of SnS@SnO_2NP /CPE including cyclic voltammetry and electrochemical impedance techniques were used. Cyclic voltammetry studies indicated that the process was irreversible. Determination of zolpidem was performed using differential pulse differential technique at the modified electrode surface and linear relationship of oxidation peak current with concentration of this drug show a LOD of 0.66 µM was in the range of 2-80 µM.

Keywords- Zolpidem; Electrochemical sensor; Carbon paste electrode; Sulfur-tin @tin oxide nanocomposite

1. INTRODUCTION

The unique physical and chemical features of nanosized structures has been attracting considerable attention and this attention has led to the development nanostructures [1-10]. Furthermore, among all types of such specific materials, nanocomposites have received much consideration, because their behaviors are strongly dependent on their dimension and shape [11-18]. A non-benzodiazepine hypnagogic used to treat insomnia is zolpidem was approved by the US Food and Drug Administration in 1990 to treat neurological disorders [19]. Seven years later, it was able to improve Parkinson's disease, however, 9 years later the US Food and Drug Administration announced that overdosage of zolpidem was dangerous for women [20]. Zolpidem has low affinity for α-1 receptor at low concentrations [19, 20]. This drug with a shelf-life of less than three hours is used by criminals to commit certain crimes such as sexual assault and theft. It is also reported that zolpidem increases the risk of cancer in sleep-deprived patients [21, 22]. Based on these serious side effects of zolpidem, its sensitive and selective analysis in pharmaceutical and biological samples is important. The electrochemical method is the best choice for analysis of zolpidem compared to the other approaches (such as chromatograph, spectroscopy and radioimmunoassay) [23-26] due to low cost, high and selectivity sensitivity, rapid response and also electroactive nature of zolpidem compound.

A number of articles in the field of electrochemistry referred to the measurement of zolpidem are limited. In two first published works glassy carbon electrode [27] and pencil electrode [28] have been applied for the determination of zolpidem. In 2019, Najafi et al. reported an interesting sensor based on graphene quantum dot modifier for developed detection of zolpidem [29]. Based on our latest studies, carbon paste electrode (CPE) has not been used for zolpidem oxidation. So, CPEs are widely used for electrochemical measurement of a variety of compound species with low detection limit. Metal and metal oxide nanoparticles especially SnO_2 nanoparticles (Sn and SnO_2NPs) have been considered for applications in some areas such as drug delivery, photovoltaics, electrode materials, catalysis etc. due to its high electrical conductivity [30-33]. This nanoparticle has been applied in some fields including gas sensor and transparent electrode. On the other hand, sulfur (S)-doped SnNP showed enhanced sensitivity, increased surface area, more active surface sites [34-36]. Accordingly, utilizing the sulfur-tin @tin oxide nanocomposite (SnS@SnO_2NP) may be a good choice for fabrication of the sensitive sensor. Our motivation in this study is to prepare a paste of the SnS@SnO_2NP for modification of CPE and use it to construct a novel electrochemical sensor for detection of zolpidem.

2. EXPERIMENTAL

2.1. Reagents and materials

Zolpidem, dopamine and acetaminophen was taken from Tofigh Daru Company (Tehran,

Iran). Graphite powder was obtained from Nanolab Inc. Distilled water was used to prepare all aqueous solutions. All chemicals used including NH_4CH_3COO, NaOH, HCl, CH_3CSNH_2, H_2SO_4, $SnCl_4$, H_3PO_4, H_2O_2, $K_3[Fe(CN)_6]$, $SnCl_2$, $FeSO_4$, KCl as well as the solvents were purchased from Merck (Germany) and Aldrich. Phosphate buffer solution (0.1 M) was used as an electrolyte. The human blood serum sample were obtained from the Clinic of Taleghani Hospital (Tehran, Iran).

2.2. Apparatus

Voltammetry experiments were performed with a Palmsencs with PSTrace software. A three-electrode system including CPE and modified CPE electrodes as working electrodes (separately), Pt wire as a counter electrode and Ag/AgCl/3M KCl as a reference electrode was used to measure the electrochemical properties. The SEM (scanning electron microscopy) image were recorded by a MIRA3 TESCAN to characterize the morphology of the prepared electrode.

2.3. Preparation of SnS@SnO_2NP

The SnS@SnO_2NP were synthesized based on the literature [37]. Briefly, 8.0 mL of 1.0 M $NH_4CH_3CO_2$ and 8.0 mL of 0.5 M $SnCl_2.2H_2O$ were mixed. Then, 10.0 mL of 8% (V/V) $SnCl_4$ and 10.0 mL of 0.4 M C_2H_5NS were added to the mixture and diluted to 50 mL by de-ionized (DI) water. Next, the solution was transferred into an autoclave and heated at 80 °C for 24 h. Finally, by centrifuging the obtained homogenous solution at 8000 rpm, washing several times by the DI water and drying, the SnS@SnO_2NP was synthesized.

2.4. Fabrication of the SnS@SnO_2NP/CPE

0.14 g of graphite and 0.01 g of the synthesized SnS@SnO_2NP were ground in a mortar. Then, 0.1 mL of oil was added mixed to achieve an appropriate paste. The paste was completely packed into a Teflon tube with an inner diameter of 2 mm and copper wire was put in the tube to establish an electrical connection. The wide head of the obtained electrode was smoothened on one piece of small aluminum foil. For comparison, a CPE were also prepared in the same way by replacing the graphite powder instead of the SnS@SnO_2NP in the fabrication protocol.

3. RESULTS AND DISCUSSION

3.1. FE-SEM

SEM technique was used to investigate the surface morphology of the SnS@SnO_2NP. Figure. 1A shows the SEM image of the SnS@SnO_2NP which supports the homogenous distribution of the spherical shape nanoparticles with an approximate diameter of 10-20 nm.

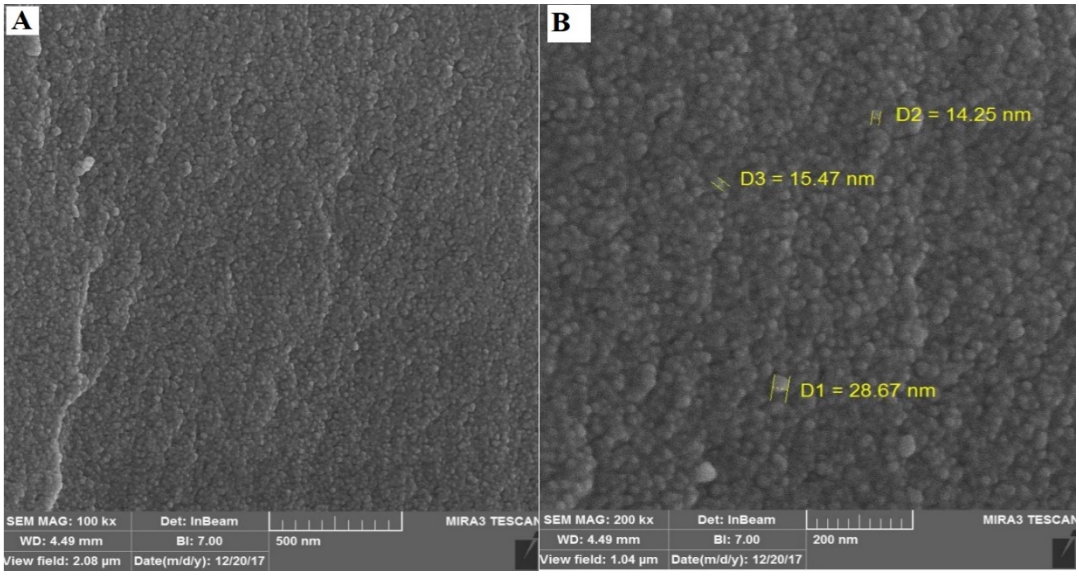

Fig. 1. The SEM image of SnS@SnO_2NP (A) 100 Kx and (B) 200 Kx

3.2. Study of the electrochemical behavior of prepared electrodes

A cyclic voltammetry technique was developed to measure the performance of the CPE and SnS@SnO_2NP/CPE. For this purpose, electrochemical measurements were used in 5 mM probe redox ($Fe(CN)_6^{3-/4-}$) over the potential range -0.3 to 0.7 V. At the bare CPE surface, the redox peaks of $Fe(CN)_6^{3-/4-}$ are very weak. However, when the CPE modified with SnS@SnO_2NP was applied, the peak differences between oxidation and reduction peaks for $Fe(CN)_6^{3-/4-}$ solution was 0.18 V which is higher than that for CPE indicating that the modified CPE has better rate of electron rather than the CPE. The results obtained from the electrochemical impedance in $Fe(CN)_6^{3-/4-}$ solution confirmed the same results such a way that the transfer resistance for CPE (0.65 kΩ) is higher than the transfer resistance of SnS@SnO_2NP/CPE (0.25kΩ) indicating the better kinetics of charge transfer for SnS@SnO_2NP/CPE is better which facilitates electron transfer [37-45]. Figure 2A shows the voltammograms obtained from different electrodes in $Fe(CN)_6^{3-/4-}$solution. The results of the electrochemical impedance is shown in Figure 2B**.** Figure. 2C shows cyclic voltammograms of zolpidem on bare CPE and SnS@SnO_2NP/CPE in 0.1 M PB solution with pH = 7.4, accumulation time 90 s with scan rate of 50 mV/s scan rate of 50 mVs^{-1}. In this figure, the scans (a) and (b) show the cyclic voltammograms of zolpidem (1×10^{-4} M) on the bare electrode and scan (b) show the cyclic voltammograms SnS@SnO_2NP/CPE in the same solution. It can be seen that over the potential window (0.5 to 1.3 V), cyclic voltammograms of the both electrodes show a single irreversible oxidation peak. The SnS@SnO_2NP/CPE modified electrode shows significant oxidation current starting at 0.65 V *vs.* Ag/AgCl. This result shows low redox activity at the bare CPE over the same potential range and the zolpidem oxidation current was started at *ca.* 0.9 V. A considerable negative shift of the onset potential for electrooxidation of zolpidem and a large enhancement of zolpidem peak current indicate the

significant catalytic ability of SnS@SnO_2NP toward the zolpidem oxidation.

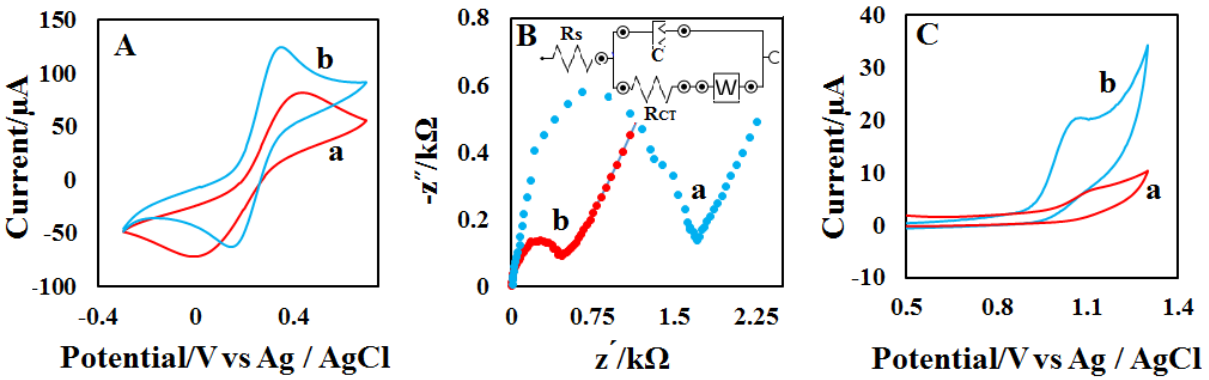

Fig. 2. (E) Cyclic voltammetry of the surface of the CPE (a) and SnS@SnO_2NP/CPE (b) in the prob redox and scan rate of 50 mV/s. (B) recorded Nyquist plots the CPE (a) and SnS@SnO_2NP/CPE in the probe redox. (C) Cyclic voltammograms of CPE (a) and SnS@SnO_2NP/CPE in the PB solution with pH = 7.4, accumulation time 90 s and scan rate = 50 mV/s the presence of 1×10^{-4} M zolpidem

The effective of scan rate in the range of 10-500 mVs^{-1} on the cyclic voltammograms of the SnS@SnO_2NP, in 0.1 M PB solution containing 1×10^{-4} M zolpidem was investigated and presented in Fig. 3A. Also Fig. 3B shows the plots of logarithm peak currents for electro-oxidation of zolpidem versus the logarithm of υ. The linear correlations between the logarithm of the anodic currents and logarithm of the scan rate are observed. This indicates that the kinetic of the overall process is controlled by a mixed adsorption-diffusion on the SnS@SnO_2NP/CPE.

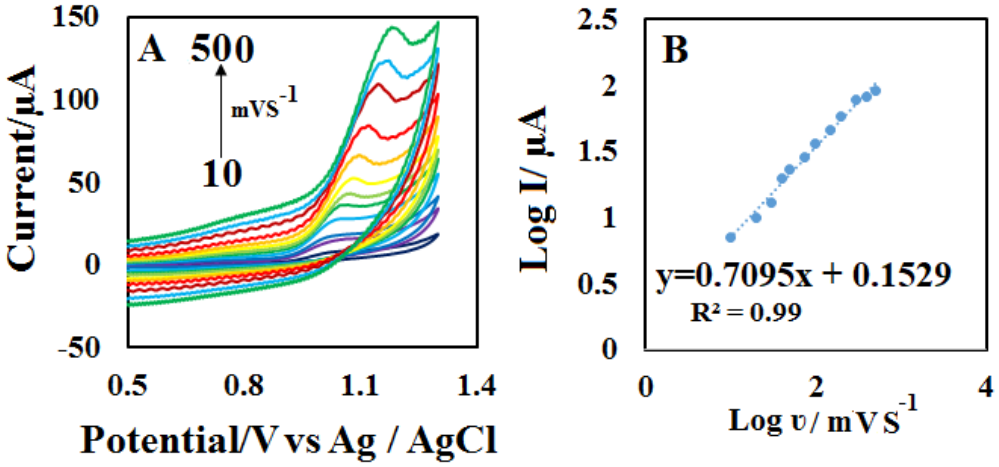

Fig. 3. (A) Effect of the scan rate on cyclic voltammograms response of 1×10^{-4} M zolpidem (pH=7.4) and accumulation time 90 s, at SnS@SnO_2NP electrode with different scan rates (10-500 mVs^{-1}) and (B) Dependency of the logarithm peak currents to logarithm scan rate

3.3. Differential pulse voltammetry measurement

Fig. 4A shows the differential pulse voltammograms of the zolpidem at the SnS@SnO_2NP surface towards the different concentration in PB (pH =7.4). In Fig. 4A, it is obvious that the peak current versus the zolpidem concentration has a linear relationship with a slope of 0.4476 μA μM^{-1} in the concentration range of the zolpidem from 2 to 80 μM (equation regression y = 0. 4476 x – 1.3339 with R^2=0.9973). The calculated LOD was 660 nM. As listed in Table 1 [32-35], it can be stated that the sensor exhibits a comparable or even higher sensitivity (observed through the slope of the calibration curve), wide linear dynamic range and lower LOD compared to the other reported zolpidem sensors in the previous studies. These fantastic results from the sensor can be related to the increased effective surface area of SnS@SnO_2NP.

Table 1. Analytical characteristics for determination of zolpidem at several reported methods. In this work, determination was performed after 90 s accumulation time under open circuit potential

Electrode	Method	pH	LOD (μM)	Linear range (μM)	Ref.
Glassy carbon	Differential pulse voltammetry	8	0.2	0.5-10	[27]
Pencil graphite	cyclic voltammetry	8	1	10-30	[28]
carbon ceramic modified graphene quantum dots	Differential pulse voltammetry	7.4	0.06	0.1-10	[29]
SnS@SnO_2NP/CPE	Differential pulse voltammetry	7.4	0.66	2-80	This work

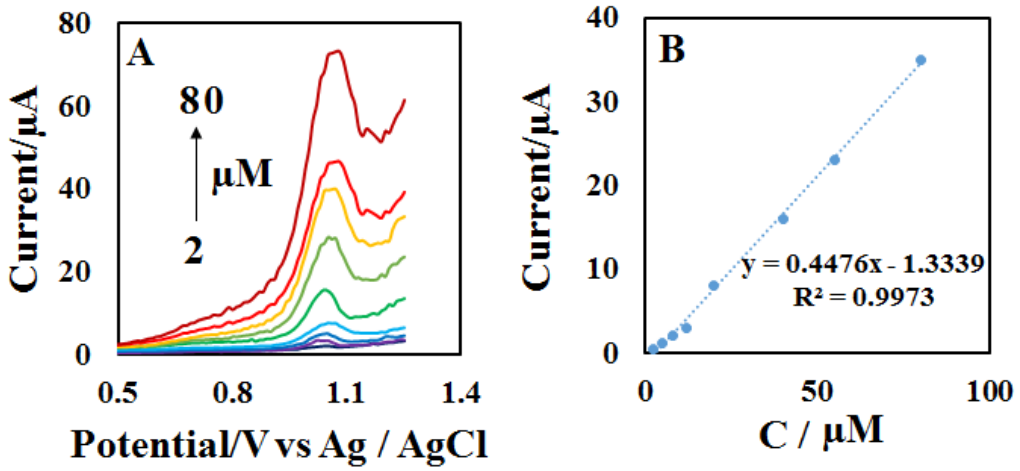

Fig. 4. The recorded differential pulse voltammograms for v concentrations of zolpidem from 2-80 μM on the SnS@SnO_2NP/CPE in PB with pH= 7.4 and (B) relative calibration curve and accumulation time 90 s

3.4. Effect of interfering species

The interference effect of 1mM NH_4^+, NO_3^-, H_2O_2, K^+, SO_4^{2-}, Fe^{3+}, Cl^-, dopamine (DA) acetaminophen (AC), D-glucose, L-cysteine and citric acid on the voltammetry response of zolpidem (25 µM) were examined under the optimal conditions. The results showed no significant changes in the current responses of SnS@SnO_2NP/CPE for zolpidem determination in the presence of these species. Therefore, this electrode can be used for the zolpidem determination in the presence of several other species that may be present in real samples.

3.5. Analytical application

To perform the possible application of the proposed method, differential pulse voltammetric response was employed to measure zolpidem in protein-free spiked human serum sample at the surface of SnS@SnO_2NP/CPE electrode. The standard addition method was used to prepare the samples (Table 2). In these tests, no amount of zolpidem was detected in healthy serum samples. The accuracy of the analysis was calculated by achieving the recovery of known amounts of zolpidem spiked in the serum solutions at 3 different concentrations. The results show an average recovery of 97% and 103% for zolpidem added to the serum samples which indicates the reliable accuracy of the method.

Table 2. Analysis of human serum sample by differential pulse voltammetry on the SnS@SnO_2NP/CPE

Sample	Added (µM)	Found (µM)	Recovery (%)	RSD (%) (n = 5)
Serum	0	-	-	-
	5.00	5.08	101.60	3.67
	10.00	9.75	97.50	3.10
	15.00	15.53	103.53	2.82

4. CONCLUSION

The SnS@SnO_2NP/CPE provides electroactive sites for accumulation of zolpidem at open circuit potential. This electrode was used for the determination of zolpidem with a low detection limit applying differential pulse voltammetry method. This electrode is simple to prepare and provides a good selectivity for determination of zolpidem. The overpotential for oxidation of fentanyl is decreased at the surface of this modified electrode compared to an unmodified electrode. Furthermore, electro-oxidation peak current of zolpidem was increased applying the modified electrode indicates in comparison with the bare CPE. The modified electrode was also successfully utilized the measurement of zolpidem in serum sample.

Acknowledgments

The authors would like to thank Islamic Azad University, Science and Research Branch for financial supports.

REFERENCES

[1] F. Gandomi, S. M. Peymani-Motlagh, M. Rostami, A. Sobhani-Nasab, M. Fasihi-Ramandi, M. Eghbali-Arani, R. Ahmadian, N. Gholipour, and M. Fasihi-Ramandi, J. Mater. Sci. Mater. Electron. 30 (2019) 19691.

[2] A. Sobhani-Nasab, M. Behpour, M. Rahimi-Nasrababdi, F. Ahmadi, S. Pourmasoud, and F. Sedighi, Ultrason. Sonochem. 50 (2019) 46.

[3] S. M. Peymani-Motlagh, N. Moeinian, M. Rostami, M. Fasihi-Ramandi, A. Sobhani-Nasab, M. Rahimi-Nasrababdi, M. Eghbali-Arani, M. R. Ganjali, T. Jesionowski, H. Ehrlich, M. A. Karimi, and N. Ajami, J. Rare Earths. 37 (2019) 1288.

[4] M. Rostami, M. Rahimi-Nasrabadi, M. R. Ganjali, F. Ahmadi, A. Fallah Shojaei, and M. Delavar Rafiee, J. Mater. Sci. 52 (2017) 7008.

[5] S. M. Asgarian, S. Pourmasoud, Z. Kargar, and A. Sobhani-Nasab, Mater. Res. Express. 6 (2018) 15023.

[6]S. M. Peymani-Motlagh, A. Sobhani-Nasab, M. Rostami, H. Sobati, M. Eghbali-Arani. Fasihi-Ramand, M. R. Ganjali and M. Rahimi-Nasrabadi, J. Mater. Sci. Mater. Electron. 30 (2019) 6902.

[7] H. Kooshki, A. Sobhani-Nasab, M. Eghbali-Arani, F. Ahamadi, V. Ameri and M. Rahimi-Nasrabadi, Sep. Purif. Technology 211 (2019) 873.

[8] F. Sedighi, and A. Sobhani-Nasab, J. Mater. Sci. Mater. Electron. 16 (2018) 13737.

[9] M. Rahimi-Nasrabadi, F. Ahmadi, and M. Eghbali-Arani, J. Mater. Sci.: Mater. Electron. 27 (2016) 13294.

[10] S. S. Hosseinpour-Mashkani, and A. Sobhani-Nasab, J. Mater. Sci. Mater. Electron. 28 (2017) 16459.

[11] M. A. Marsooli, M. Eghbali-Arani, K. Adib, E. Sohouli, Rahimi-Nasrabadi and F. Ahmadi, Front. Pharmacol. 11 (2020) 192.

[12] S. Behvandi, A. Sobhani-Nasab, M. A. Karimi, E. Sohouli, M. Sadeghpour Karimi, M. R. Ganjali, F. Ahmadi and M. Rahimi-Nasrabadi, Polyhedron. 180 (2020) 114424.

[13] M. Rahimi-Nasrabadi, A. Ghaderi, H. R. Banafshe, M. Eghbali-Arani, M. Akbari, S. Pourmasoud, and A. Sobhani-Nasab, J. Mater. Sci. Mater. Electron. 30 (2019) 15854.

[14] A. Sobhani-Nasab, Sh. Behvandi, M. A. Karimi, E. Sohouli, M. Sadeghpour Karimi, N. Gholipour, F. Ahmadi, and M. Rahimi-Nasrabadi, Ceram. Int. 45 (2019) 17847.

[15] M. A. Marsooli, M. Fasihi-Ramandi, K. Adib, S. Pourmasoud, F. Ahmadi, M. R. Ganjali, A. Sobhani-Nasab, M. Rahimi-Nasrabadi, and M. E. Plonska-Brezinska, Materials. 12 (2019) 3274.

[16] A. Sobhani-Nasab, M. Behpour, M. Rahimi-Nasrabadi, F. Ahmadi, and S. Pourmasoud, J. Mater. Sci. Mater. Electron. 30 (2019) 5854.

[17] A. Sobhani-Nasab, A. Pourmasuod, F. Ahmadi, M. Wysokowski, T. Jesionowski, H. Ehrlich, and M. Rahimi-Nasrabdi, Mater. Lett. 238 (2019) 159.

[18] A. Khoobi, F. Shahdostfard, M. Akbari, H. Mirzaei and H. R. Banafshe,. Polyhedron. 177 (2020) 114302.

[19] M. N. Bomalaski, E. S. Claflin, W. Townsend and M. Peterson. JAMA Neurol. 74 (2017) 1130.

[20] E. Neumann and U. Knustan, Front. Pharmacol. 9 (2019) 1523.

[21] S. C. Lin, Y. S. Huang and C. C. Lee, Res. J. Med. Sci. 36 (2016) 68.

[22] D. J. Greenblatt, J. S. Harmatz, and T. Roth, Clin. Psychopharmacol. 39 (2019) 189.

[23] Y.Shin, T. Y. Kong and J. K. Kim, Biomed Chromatogr. 33 (2019) 4600.

[24] G. D. Mendes and T. S. Pereira, Biomed Chromatogr. 34 (2020) 4731.

[25] K. Patil, Y. Pore and S. Bhise, Int. J Pharm Sci Rev Res. 2 (2010) 1.

[26] I. Clerck, Analyst. 122 (1997) 1119

[27] A. E. Radi, G. Bekhiet, and T. Wahdan, Chem. Pharm. Bulletin. 52 (2004) 1063.

[28] A. Naeemy, E. Sedighi, and A. Mohammadi, J. Electrochem. Sci. Technol. 7 (2016) 68.

[29] S. Dehgan-Reyhan, and M. Najafi, J. Electroanal. Chem. 832 (2019) 241.

[30] N. Cao, M. Li. Y. Zhao, L. Qiu, X. Zou, X., Zhang, and L. Sun, L, Mater. Sci. Eng. C. 59 (2016) 319.

[31] Y. Liu, J. Yang, W. Yang, T. Xie, Y. Bai, and T. Li, J. Nanopart Res. 2 (2000) 309.

[32] C. He, Y. Xiao, H. Dong,Y. Liu, and B. Lei, Electrochim. Acta. 142 (2014) 157

[33] M. Dehbashi, M. Aliahmad, M. Shafiee, and M. Ghashang, Synth. React. Inorg. Met.-Org. Nano-Metal. 43 (2013) 1301.

[34] H. J. Ahn, Russ. J. Phys. Chem. B. 108 (28) 9815.

[35] M. Muti, Talanta. 82 (2010) 1680.

[36] X. Cui, Colloids Surf. A Physicochem. Eng. Asp. 546 (2018) 153

[37] E. Naghian, and M. Najafi, Microchim Acta. 185 (2018) 406.

[38] M. H. Ghanbari, F. Shahdost-Fard, M. Rostami, A. Khoshroo, A. Sobhani-Nasab, N. Gholipour, H. Salehzadeh, M.R. Ganjali, M. Rahimi-Nasrabadi, and F. Ahmadi, Microchim. Acta 186 (2019) 698.

[39] M. H. Ghanbari, A. Khoshroo, H. Sobati, M.R. Ganjali, M. Rahimi-Nasrabadi, and Ahmadi, Microchem. J. 147 (2019) 198.

[40] A. Khoshroo, L. Hosseinzadeh, A. Sobhani-Nasab, M. Rahimi-Nasrabadi, and F. Ahmadi, Microchem. J. 145 (2019) 1185.

[41] M. Rahimi-Nasrabadi, H.R. Naderi, M. Sadeghpour Karimi, F. Ahmadi, and S.M. Pourmortazavi, J. Mater. Sci. Mater. Electron. 28 (2017) 1877.

[42] M. Rahimi-Nasrabadi, V. Pourmohamadian, M. Sadeghpour Karimi, H.R. Naderi, M.A.

Karimi, K. Didehban, and M.R. Ganjali, J. Mater. Sci. Mater. Electron. 28 (2017) 12391.
[43] A. Sobhani-Nasab, H.R. Naderi, M. Rahimi-Nasrabadi, and M.R. Ganjali, J. Mater. Sci.: Mater. Electron. 28 (2017) 8588.
[44] J. Amani, M. Maleki, A. Khoshroo, A. Sobhani-Nasab, and M. Rahimi-Nasrabadi, Anal. Biochem. 548 (2018) 53.
[45] E. Sohouli, A. H. Keihan, F. Shahdost-fard, E. Naghian, M. E. Plonska-Brzezinska, M. Rahimi-Nasrabadi, and F. Ahmadi, Mater. Sci. Eng. C. 110 (2020) 110684.