

## **VOLTAMMETRIC SENSORS BASED ON GOLD ELECTRODES MODIFIED BY “SMART POLYMERS” FOR IDENTIFICATION AND RECOGNITION OF CYSTEINE**

Voltammetric sensors and sensor systems based on modified conductive polymer electrodes are widely used for analytical tasks such as detection of counterfeit medicines, beverages, automotive fluids, etc.<sup>1-2</sup> In addition to the determination of active components is currently an urgent task is to reliably establish the authenticity of the recognized substances, especially drugs and dietary supplements.

L-cysteine ( $\alpha$ -amino- $\beta$ -thiopropionic acid) (Cys) plays an important role in metabolism and cellular homeostasis. Cys is not synthesized in the human body, so it is necessary to use products or drugs, therefore, it is often used in dietary supplements and pharmaceuticals.<sup>3</sup>

In the present work investigated the electrochemical behavior of Cys on gold electrodes modified with "smart polymers"<sup>4</sup>. To modify the electrodes used chlorinated (in position 4) poly (phthalidylidene-fluorene) (PPF-Cl) and poly (phthalidylidene diphenyl) (PPD-Cl), brominated poly (phthalidylidene diphenyl) (PPD-Br), which is a mixture of brominated products. These films contain various functional groups and substituents in the phenylene rings of the main chain and phthalide rings. Using the complex of voltammetric and impedancemetric methods, the electrochemical properties of the sensors modified by these polymers were studied. The analytical characteristics of the proposed sensors were evaluated, the optimal parameters for the registration of the analytical signal, the nature of electrode processes were established. The results of recognition of manufacturers of drugs containing cysteine using the proposed sensors and sensory system are given.

Voltammograms were recorded on the potentiostat / galvanostat AUTOLAB PGSTAT 204 (Metrohm AUTOLAB, Netherlands). Measurements were carried out in a standard three – electrode electrochemical cell thermostated at 25 ° C with a modified by PPF and PPD gold electrode with a diameter of 1 mm, the reference electrode was a silver chloride electrode; the auxiliary electrode was a platinum electrode.

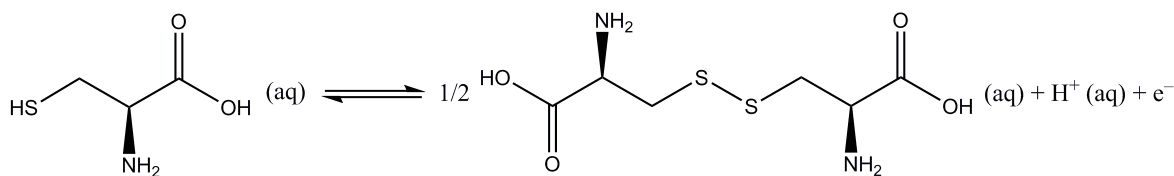
To modify the gold electrode, a solution of 20 mg polymer in 2 ml DMF was used. The resulting solution with a volume of 3  $\mu$ l was applied to

the thoroughly cleaned surface of the gold electrode and dried at 80 C° in the rays of the IR lamp. For polishing the surface of the glass-carbon electrode, GOI paste based on 0.1-0.3 μm Cr<sub>2</sub>O<sub>3</sub> was used.

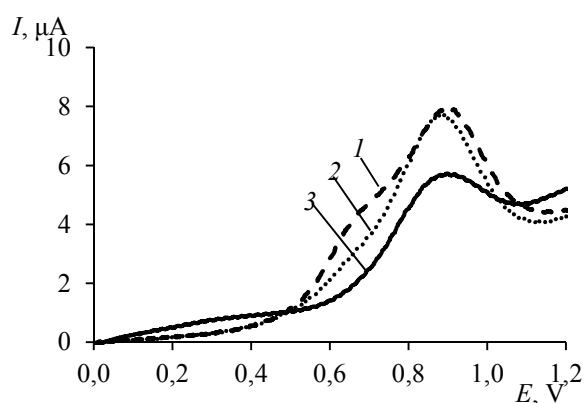
Solutions of Cys and real samples containing Cys were prepared by dissolving the exact attachments of the corresponding samples in the volumetric flasks of 50 ml against phosphate buffer solution (Na<sub>2</sub>HPO<sub>4</sub>+KH<sub>2</sub>PO<sub>4</sub>) with pH 6.86. Solutions with lower concentrations were obtained by successive dilution of the initial solutions with phosphate buffer solution just before measurements.

An array of data for each sample was formed from 5 parallel measurements with registration of 10 voltammograms, including 140 values of instantaneous currents (with a step of 5 mV) at different potentials.

It is known that cysteine is oxidized on the gold electrode with the formation of one peak on the voltammogram in the range from 0.7 to 1.0 V with the formation of cystine (scheme 1) and a weakly expressed second peak in the range from 1.4 to 1.6 with the formation of cysteic acid. The first peak is more pronounced, so voltammograms were recorded in the range from 0 to 1.2 V.

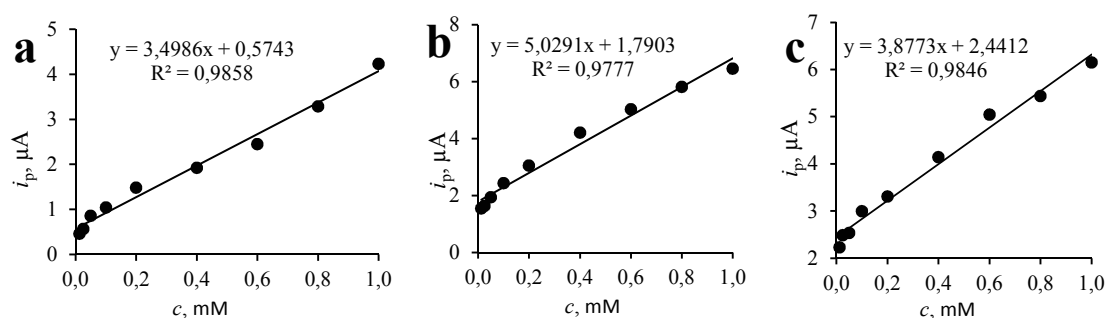


**Scheme. 1.** Oxidation of cysteine to cystine



**Fig. 1.** . Linear voltammograms of gold electrode modified by PFD-Cl(1), PFD-Br(2), PFD-Cl(3), in 0.6 m CYS solution (Na<sub>2</sub>HPO<sub>4</sub>+KH<sub>2</sub>PO<sub>4</sub>, pH 6.86, 100 mV/s).

Figure 2 shows linear voltammograms of oxidation of successively diluted Cys solutions and the corresponding calibration graphs on a gold electrode modified with PPD-Cl, PPD-Br, PPP-Cl. The linear nature of the dependence of the peak of the oxidation current of Cys on its content in the solution is maintained in the concentration range from  $0.125 \times 10^{-6}$  to  $1 \times 10^{-3}$  M. Characteristics of the peaks of the current of oxidation are given in Table 1.



**Fig. 2.** Dependence of the oxidation peak current of CYS on the concentration on the gold electrode modified by PFD-Cl (a), PFD-Br (b), PFF-Cl (c); 1 → 9: 0.0125, 0.025, 0.05, 0.1, 0.2, 0.4, 0.6, 0.8, 1.0 mM ( $\text{Na}_2\text{HPO}_4 + \text{KH}_2\text{PO}_4$ , pH 6.86, 100 mV/s).

**Table 1.** Characteristics of CYS oxidation current peaks on linear voltammograms ( $c = 0.6$  mM,  $\text{Na}_2\text{HPO}_4 + \text{KH}_2\text{PO}_4$ , pH 6.86, 100 mV/s).

Sensor	$E_p$ , V	$I_p$ , $\mu\text{A}$	$\Delta i_p / \Delta c$ , $\mu\text{A} / \mu\text{m}$	Detection limit, $\mu\text{M}$
Au/PFD-Cl	0.897	7.962	5.03	3.69
Au/PFD-Br	0.891	7.712	3.88	4.68
Au/PFF-Cl	0.900	5.725	3.50	5.38

The results of the voltammetric determination of Cys on the proposed sensors are presented in Table 3. It can be seen from it that in all cases, Cys is determined with high accuracy, the relative standard deviation does not exceed 9.3% in all cases.

The possibilities of recognizing dietary supplements containing Cys from different manufacturers (Table 3) using the proposed sensors were considered. To assess the possibility of recognizing dietary supplements containing Cys from various manufacturers, chemometric data processing was carried out using the proposed sensors. Voltammograms were converted by the principal component analysis (PCA). PCA allows to divide the data into a meaningful component and noise, compress and transfer them to a new coordinate system, which is called the principal component system (PC), where each voltammogram will be represented by one point. These points (voltammograms), depending on their similarities

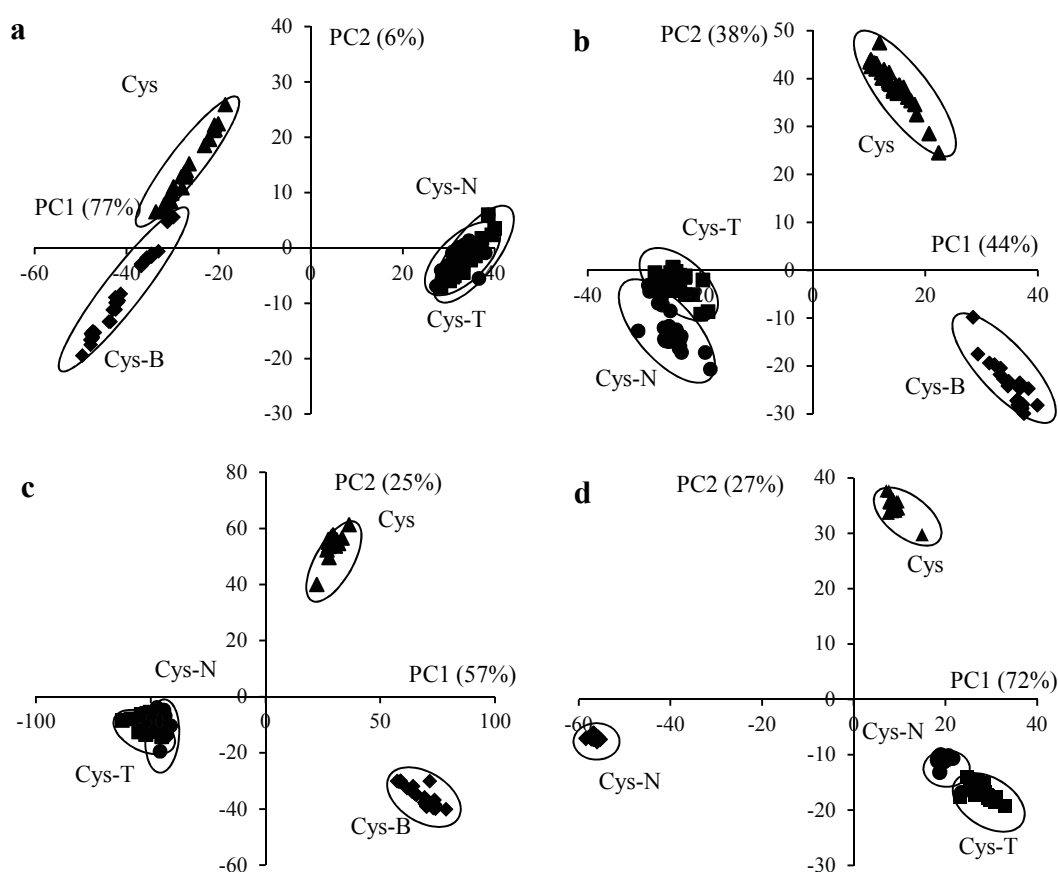
and differences, can be grouped into spheres or ellipsoids. (Fig. 3). Fig. 3 shows that voltammograms of real samples belong to different clusters on the score plots of the PCA-models, while the clusters of samples Cys-N and Cys-T intersect with each other, which indicates their similarity. The proportion of explained dispersion for individual sensors in the first two GCs is 81-82%. When using a sensor system based on the proposed electrodes, clusters of real samples do not intersect with each other, and the proportion of explained dispersion in the first two PCs reaches 99%. Thus, using the sensor system based on Au electrodes modified by proposed polymers, it is possible to recognize unambiguously manufacturers of preparations containing Cys.

**Table 2.** Results of voltammetric determination of Cys on gold electrode modified by PPD-Cl, PPD-Br, PPF-Cl ( $\text{Na}_2\text{HPO}_4 + \text{KH}_2\text{PO}_4$ , pH 6.86, 100 mV/s,  $n = 5$ ,  $P = 0.95$ ).

	Introduced, c, $\mu\text{M}$	Found, ( $x \pm \Delta x$ ), $\mu\text{M}$	$S_r$
Au/PPD-Cl	0.15	$0.14 \pm 0.01$	0.080
	0.30	$0.30 \pm 0.03$	0.072
	0.50	$0.49 \pm 0.02$	0.036
	0.040	$0.039 \pm 0.005$	0.098
Au/PPD-Br	0.15	$0.14 \pm 0.01$	0.064
	0.30	$0.31 \pm 0.02$	0.055
	0.50	$0.48 \pm 0.02$	0.032
	0.040	$0.040 \pm 0.004$	0.081
Au/PPF-Cl	0.15	$0.14 \pm 0.02$	0.093
	0.30	$0.28 \pm 0.02$	0.052
	0.50	$0.48 \pm 0.02$	0.038
	0.040	$0.040 \pm 0.004$	0.075

**Table 3.** The composition of the studied real samples of cysteine

No	Sample name, designation	Manufacturer	The composition of the drug (mg/caps.)
1	L-Cysteine CYS-N	Now (USA)	l-cysteine hydrochloride, ascorbic acid, pyridoxine hydrochloride, cellulose, silica, magnesium stearate, citric acid
2	L-Cysteine CYS-T	Twinlab (USA)	l-cysteine hydrochloride, cellulose, magnesium stearate, medium chain triglycerides, silica
3	L-Cysteine CYS-B	Bluebonnet (USA)	l-cysteine hydrochloride, cellulose, magnesium stearate, silica



**Fig. 3.** Score plots of PCA modelling of voltammograms for 0.6 mM solutions of Cys using Au/PPD-Cl (a), Au/PPD-Br (b), Au / PPD-Cl (c), and the sensory system (d)

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