Electronic Supplementary Material (ESI) for RSC Advances.

An amplified electrochemical sensor employing one-step synthesised nickel-copper-zinc ferrite/carboxymethyl cellulose/graphene oxide nanosheets composite for sensitive analysis of omeprazole

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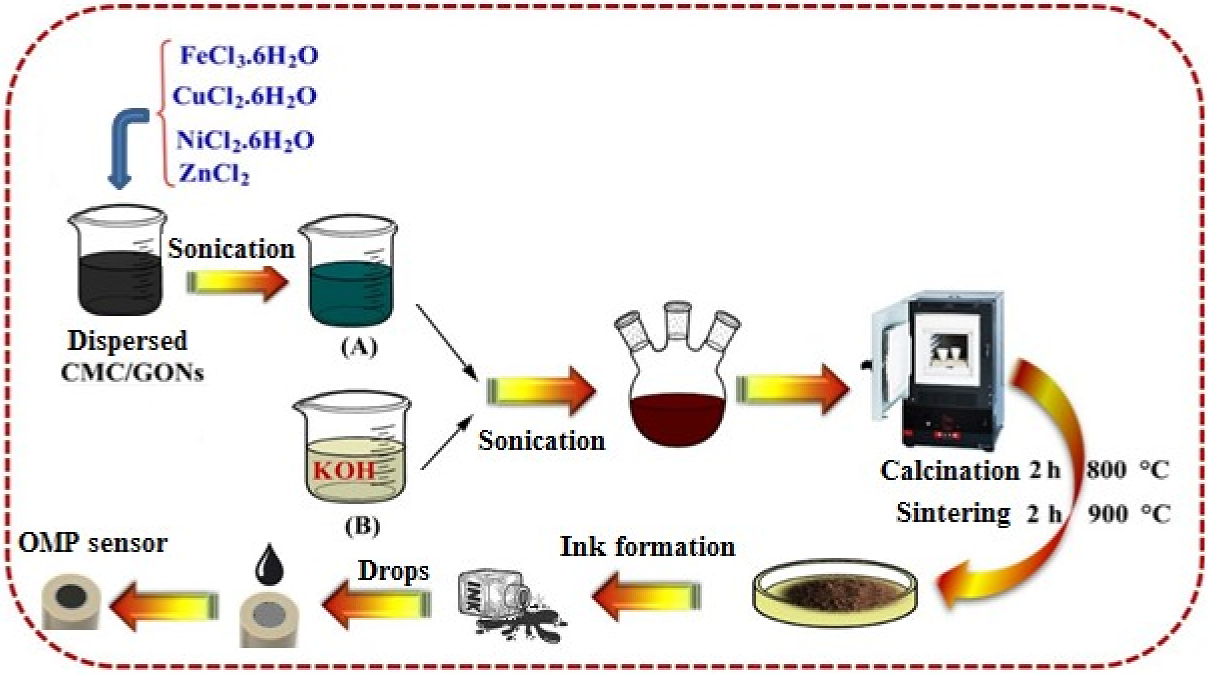
Chemicals and reagents

The chemicals in the present report were the following: Omeprazole ($C_{17}H_{19}N_3O_3S$), nickel chloride hexahydrate ($NiCl_2{\cdot}6H_2O$), copper chloride hexahydrate ($CuCl_2{\cdot}6H_2O$), zinc chloride ($ZnCl_2$), sodium dihydrogen phosphate monohydrate ($H_2NaPO_4.H_2O$), sodium phosphate dibasic heptahydrate ($Na_2HPO_4.7H_2O$), potassium hydroxide (KOH), graphite, sulfuric acid(H_2SO_4), ferric chloride hexahydrate ($FeCl_3{\cdot}6H_2O$), Potassium permanganate (KMnO4), glutaraldehyde ($C_5H_8O_2$), polyethylene glycol ($C_{2n}H_{4n+2}O_{n+1}$), hydrogen peroxide (H_2O_2), sodium nitrate ($NaNO_3$), ethanol (C_2H_5OH), sodium hydroxide (NaOH), potassium chloride (KCl), potassium ferricyanide ($K_3C_6FeN_6$), potassium ferrocyanide ($K_4C_6FeN_6$) and all chemicals were pure analytical grade form Merck or Sigma-Aldrich Companies (Germany) and used without further processing. In all experiments, 0.1 M phosphate buffer solution (PBS, pH 6.0) was utilized as a supporting electrolyte. Standard stoke solution of omeprazole was freshly prepared daily before experiments by dissolving appropriate amounts of analyte in ethanol (1.0×10^{-3} mol L^{-1}) and then diluting by the supporting electrolyte [phosphate buffer solution (0.1 M PBS, pH 6.0)]. All experimental assays are performed at room temperature (RT; ~20-25°C). In all electrochemical measurements double-distilled water was utilized.

Preparation of graphene oxide nanosheets

Pure graphite powder is oxidized to graphene oxide using a modified Hummers' method. Briefly, in a typical preparation 1.0 g of graphite powder is added to 23 mL of concentrated sulfuric acid in an ice bath. The mixture is stirred for 30 minutes and then 3.0 g of potassium permanganate and 0.5 g of sodium nitrate are added to the solution. The rate of addition of materials should be carefully controlled and the temperature should be kept between 10-15 °C. The mixture was then heated and stirred at 35 °C for 30 min. The temperature was raised to 90 °C. After that 250 mL of doubly distilled water was slowly added and stirred for 30 min. Then, to stop the oxidation reaction, 50 mL of distilled water and 5 mL of 30% hydrogen peroxide solution were added to reduce the excess potassium permanganate, respectively (change its color to a light brown, indicating complete oxidation of graphite). In the next step, the solution was filtered and the obtained graphene oxide was washed with 100 mL of distilled water. Deionized water was added to the obtained product and the filtrate was resuspended in deionized water again, followed by ultrasonic treatment for 15 min to produce laminated graphene oxide nanosheets. The resulting product was centrifuged and dried in a vacuum oven at 60 °C for 24 hours.



Scheme S1. Schematic representation of the $Ni_{0.4}Cu_{0.2}Zn_{0.4}Fe_2O_4$/CMC/GONs/GCE preparation.

Synthesis of CMC/GONs

The graphene oxide nanosheets were prepared by using a modified Hummers' method and the preparation procedure is given in detail in the Supporting Information.

In order to prepare the CMC/GONs, a suitable amount of CMC (2 g) was first dispersed in 50 mL of deionized water and sonicated in an ultrasonic bath for 20 minutes. Then 0.2 g of GONs were added to the prepared CMC suspension. In the next step, glutaraldehyde and polyethylene glycol (0.2 g from each) were added to the obtained suspension (at 40 °C) and stirred at a suitable speed for 2 hours on a magnetic stirrer to homogenize the solution. In the last step, the product was separated by centrifuging and washed using ethanol and distilled water. Finally, the precipitate was dried in a vacuum oven for 2 hours at 60 °C.

Synthesis of the $Ni_{0.4}Cu_{0.2}Zn_{0.4}Fe_2O_4$ (alone)

The $Ni_{0.4}Cu_{0.2}Zn_{0.4}Fe_2O_4$ nanoparticle was synthesized through the following steps: firstly, the appropriate amounts of $NiCl_2\cdot 6H_2O$, $CuCl_2\cdot 6H_2O$, $ZnCl_2$, and $FeCl_3\cdot 6H_2O$ are weighed according to the desired stoichiometry and dissolved in distilled water (solution A, at a concentration of 0.25 mol L^{-1} for each) and solution B, which contains 1 mol L^{-1} of potassium hydroxide is prepared. Then, the solution (B) was transferred drop by drop to a three-necked flask containing solution A (in an ultrasonic bath at a rate of 1 mL/min at room temperature) and the pH of the solution was adjusted to 10.5 with ammonia solution. After the completing of the co-precipitation reaction, the sample was kept in a fixed place for 48 hours. The upper clear liquid was poured out and the lower suspension was transferred to a centrifuge tube. The contents of the tube were then centrifuged at 3900 r/ min for 5 minutes and repeated three times. The resulting product was then washed three times with distilled water and dried at 70 °C in an oven for 16 hours. The product was then calcined for two hours at 800 °C and then sintered for another two hours at 900 °C.

Preparation of the modified electrode

To prepare the GCE modified with $Ni_{0.4}Cu_{0.2}Zn_{0.4}Fe_2O_4$/CMC/GONs nanocomposite, at first, the unmodified GCE was polished with alumina slurry using a special polishing pad followed by ultrasonication in ethanol and then distilled water for 10 minutes. To the electroactivation of GCE, the electrode was placed in a 0.1 M H_2SO_4 solution and its potential scanned in range of -

600 to 2000 mV for 20 cycles at a scan rate of 100 mV s^{-1}. In the next step, 10 µL of the nanocomposite suspension ($Ni_{0.4}Cu_{0.2}Zn_{0.4}Fe_2O_4$/CMC/GONs) (1 mg/mL in 1:1 ethanol:distilled water solution) is drip at the surface of the electroactivated GCE and dried in air to obtain the modified electrode ($Ni_{0.4}Cu_{0.2}Zn_{0.4}Fe_2O_4$/CMC/GONs/GCE). A schematic representation of the modified electrode preparation is shown in Scheme S1 (Supporting Information).

Preparation of real samples

Human blood serum: serum samples were prepared according to the following procedure. Briefly, different amounts of OMP were added to 1.0 ml of blood serum sample obtained from the blood diagnostic laboratory (West Azerbaijan Province, Khoy). Then 0.8 ml of acetonitrile was added to the obtained sample to remove serum protein. The mixture was then centrifuged at 3600 rpm for 20 minutes. In the next step, the supernatant plasma solution was carefully separated and transferred to a 25 ml volumetric flask and diluted to the desired volume using 0.1 mol L^{-1} PBS (pH 6.0) phosphate buffer solution. Finally, the signal of the samples was measured by the DPV technique and their recovery percentage was calculated.

Tablet sample: Ten OMP capsules (20 mg) were uniformly powdered in a mortar. A certain amount of the obtained powder was transferred to a 100 ml volumetric flask and dissolved with PBS phosphate buffer solution at pH 6.0. The contents of the flask were subjected to ultrasound for 5 minutes to dissolve completely. The resulting solution was then filtered using What man filter paper, and an appropriate amount of the clear solution was stored in the refrigerator for later use.

Reproducibility and stability of the $Ni_{0.4}Cu_{0.2}Zn_{0.4}Fe_2O_4$/CMC/GONs/GCE

The reproducibility of the modified electrode responses was examined. Therefore, for the reproducibility study, seven modified electrodes were prepared separately in the same manner and their responses were evaluated to determine the 4 µM OMP through DPV technique and measured currents were shown in Fig. S7A. The relative standard deviation (RSD) for the response between the seven modified electrodes was calculated as 2.54%, which is an applicable reproducibility for the sensor fabrication process in OMP determination. In addition, the storage life or stability of the proposed sensor was evaluated. Analysis of 4 µM OMP by the present sensor through DPV technique (measured currents were shown in Fig. S7B) over 30 days shows a stable current response (maintaining 97.6% of the initial signal), and indicates that the proposed sensor has good stability. According to the obtained results, it can be said that the prepared sensor has acceptable and appropriate reproducibility and stability for the analysis of OMP.

Also, the response of sensor before and after long cycling sensing studies was examined by DPV method and results shown in Fig. 8S. As depicted, the DPV response and anodic peak current of the sensor have not changed significantly after long cycling sensing and long storing time (30 days).

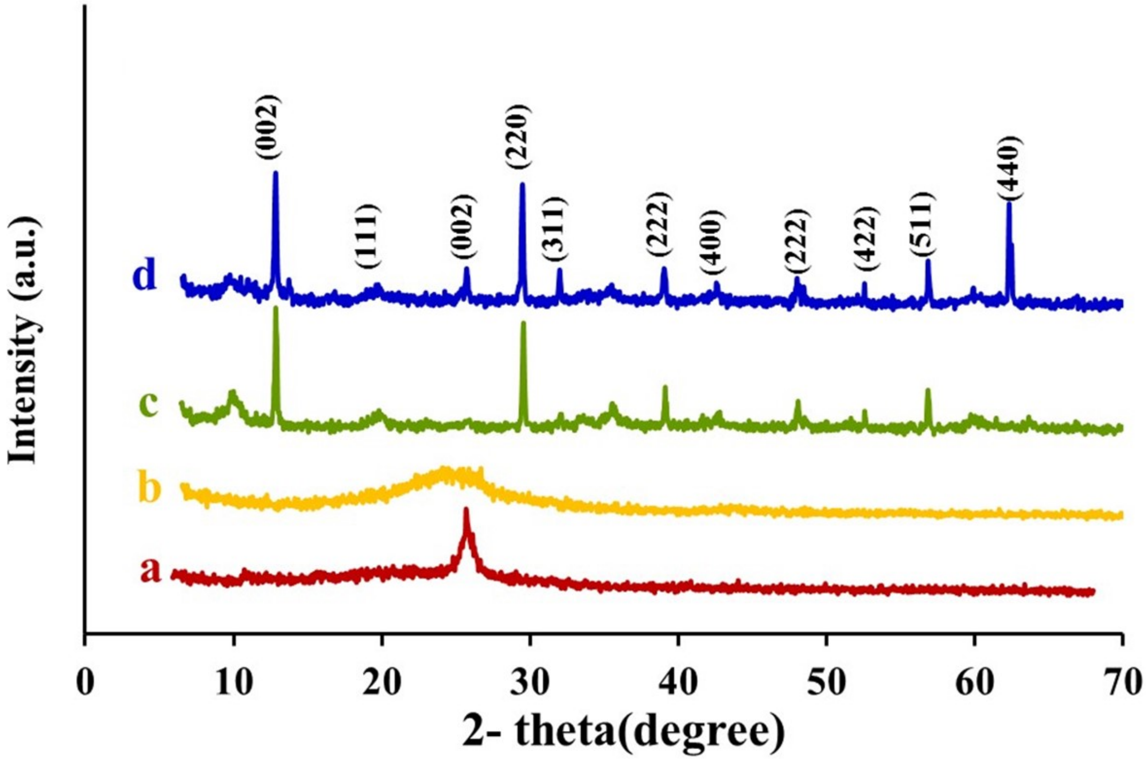


Fig. S1. XRD patterns of (a) GONs, (b) CMC/GONs, (c) $Ni_{0.4}Cu_{0.2}Zn_{0.4}Fe_2O_4$ and (d) $Ni_{0.4}Cu_{0.2}Zn_{0.4}Fe_2O_4$/CMC/GONs.

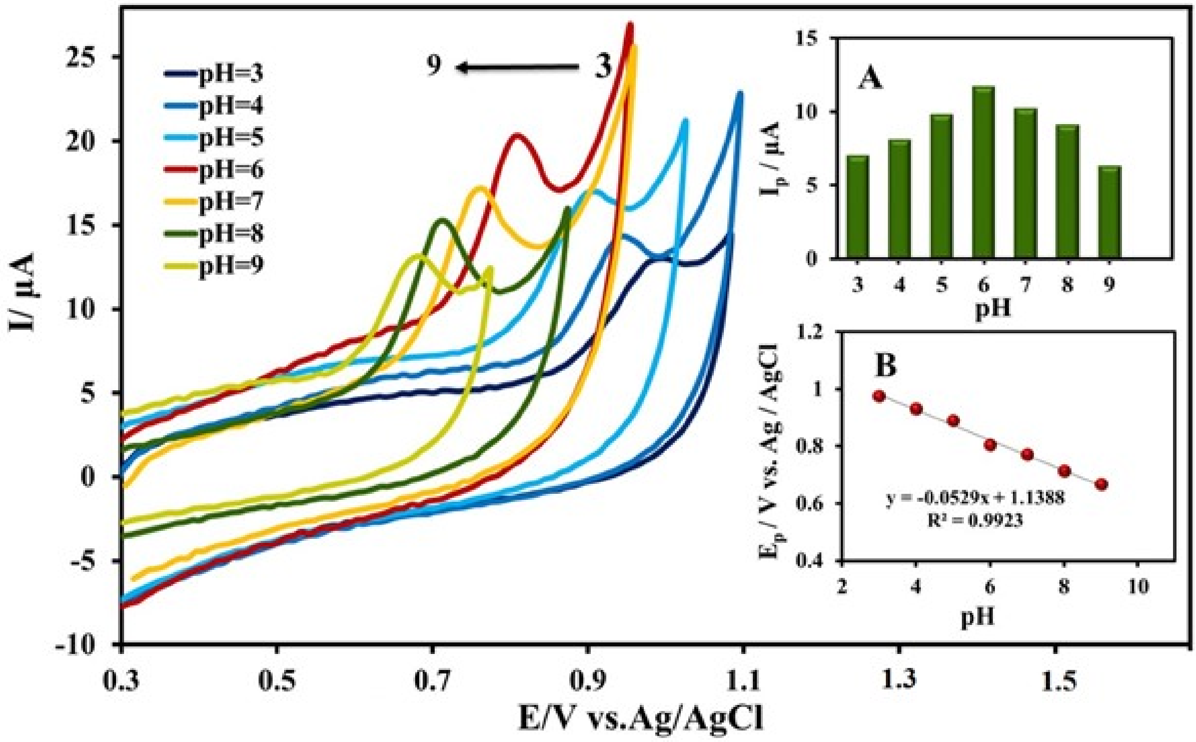
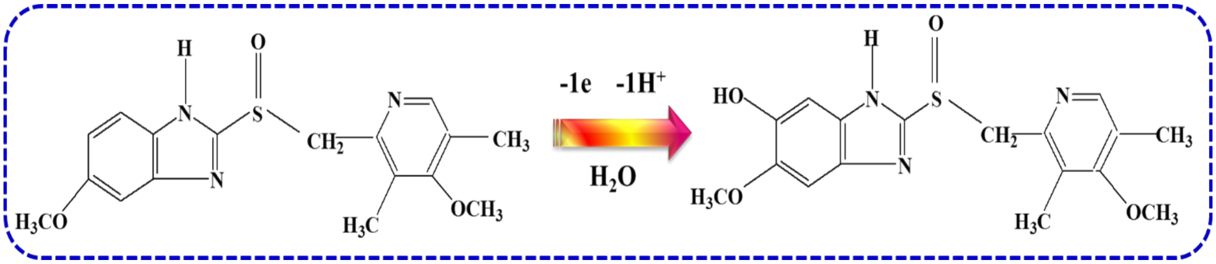


Fig. S2. CVs on the $Ni_{0.4}Cu_{0.2}Zn_{0.4}Fe_2O_4$/CMC/GONs/GCE at a scan rate of 100 mVs^{-1} in 0.1 M PBS in different pH values from 3 to 9 and in the presence of 25 µM OMP. Inset (A): The effect of pH on the I_p and inset (B): The effect of pH on the E_p.



Scheme S2. A possible mechanism of the electrooxidation reaction of OMP.

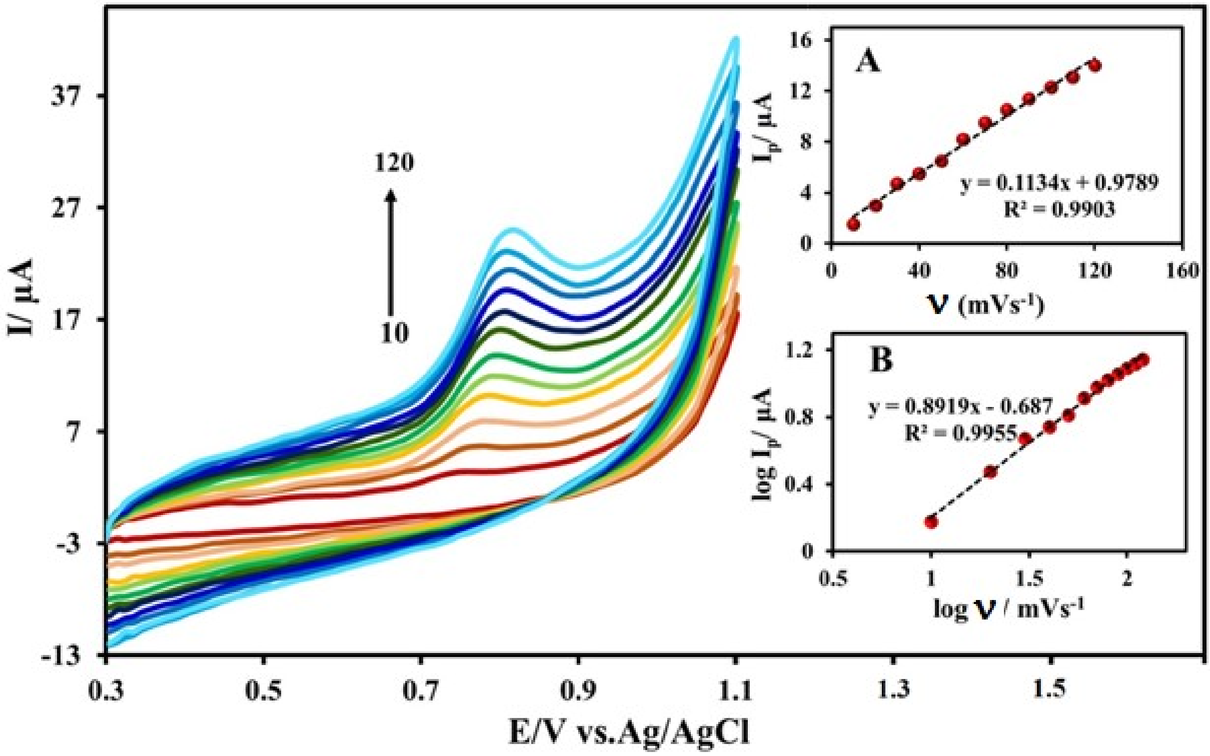


Fig. S3. CVs obtained at the $Ni_{0.4}Cu_{0.2}Zn_{0.4}Fe_2O_4$/CMC/GONs/GCE in 0.1 M PBS (pH=6.0) containing 25 μM OMP solution at different scan rates (10-120 mVs^{-1}). Insets: (A) The plot of I_p vs. ν and (B) Log I_p vs. log ν.

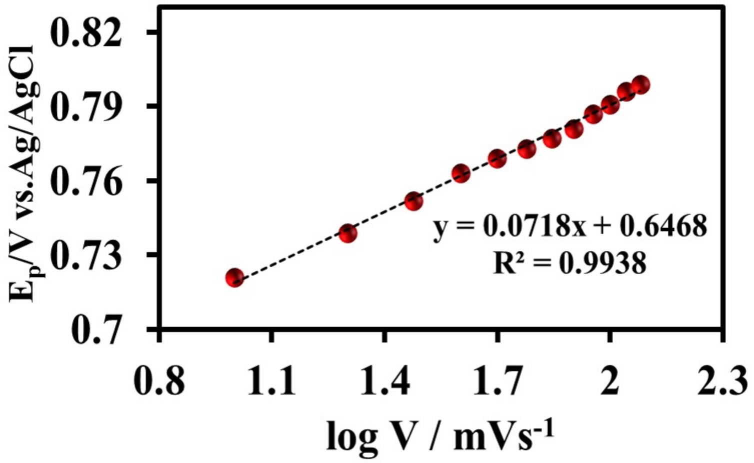


Fig. S4. Plot of E_p vs. log ν from the CVs obtained at the $Ni_{0.4}Cu_{0.2}Zn_{0.4}Fe_2O_4$/CMC/GONs/GCE in 0.1 M PBS (pH=6.0) containing 25 μM OMP solution at different scan rates (10-120 mVs^{-1}).

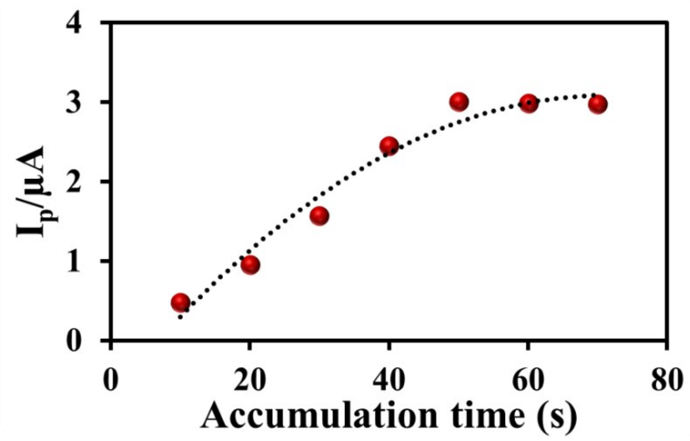


Fig. S5. Influence of the accumulation time on the peak current of OMP oxidation (4 μM) in PBS solution (0.1 M, pH= 6.0) at the $Ni_{0.4}Cu_{0.2}Zn_{0.4}Fe_2O_4$/CMC/GONs/GCE.

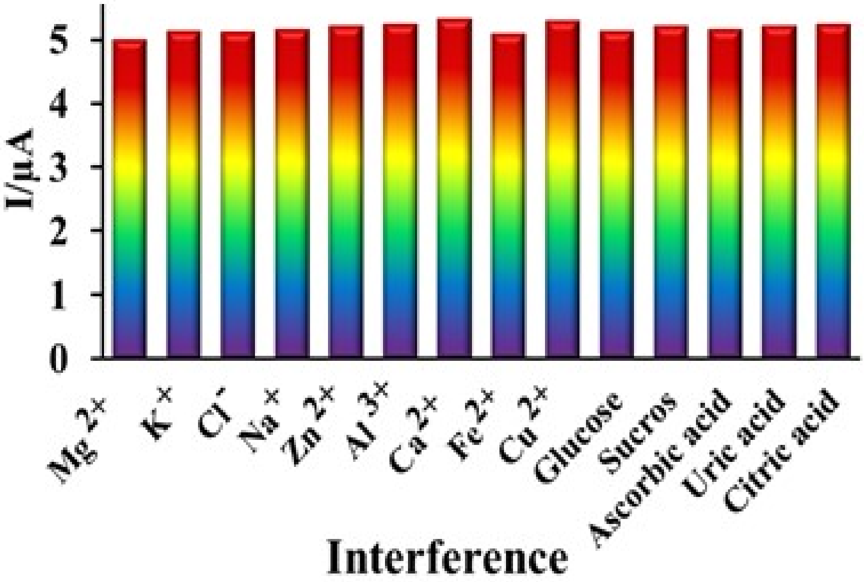


Fig. S6. Interference test of the $Ni_{0.4}Cu_{0.2}Zn_{0.4}Fe_2O_4$/CMC/GONs/GCE in 0.1 M PBS (pH 6.0) containing 4 μM OMP and other Interferences as indicated.

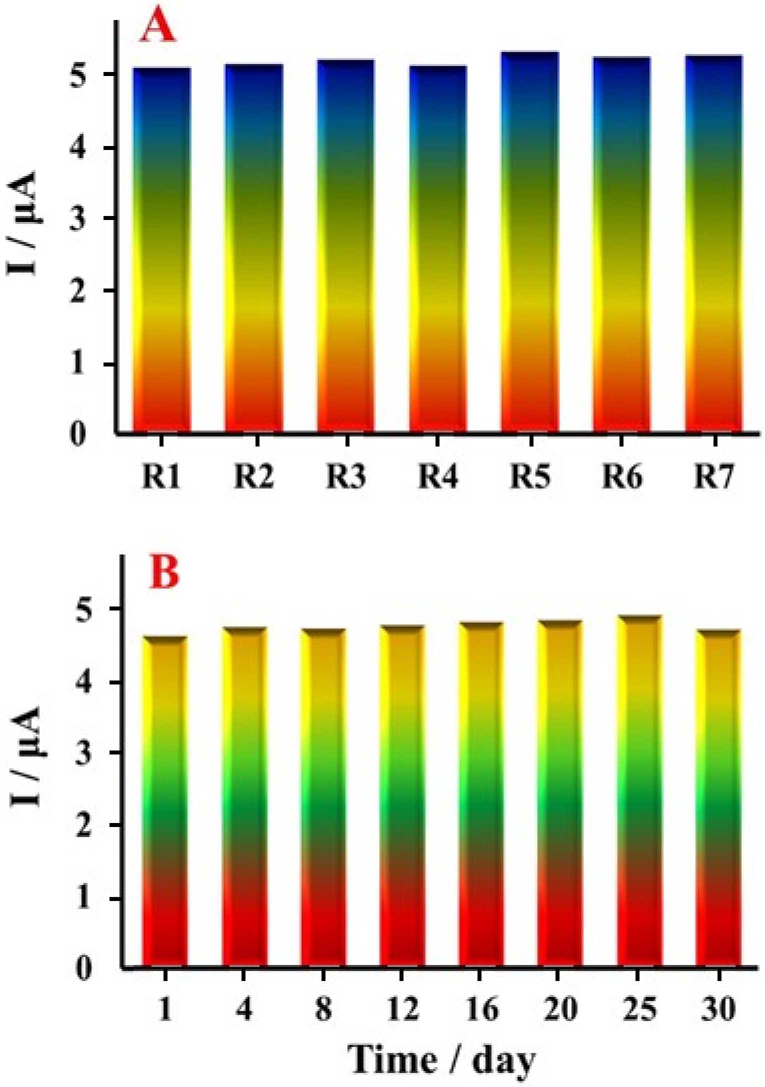


Fig. S7. (A) The reproducibility investigation of seven successive experiments (R1–R7) and (B) The storage stability of the modified electrode for determination of 4 µM OMP (in all section the currents are the I_p in DPV method).

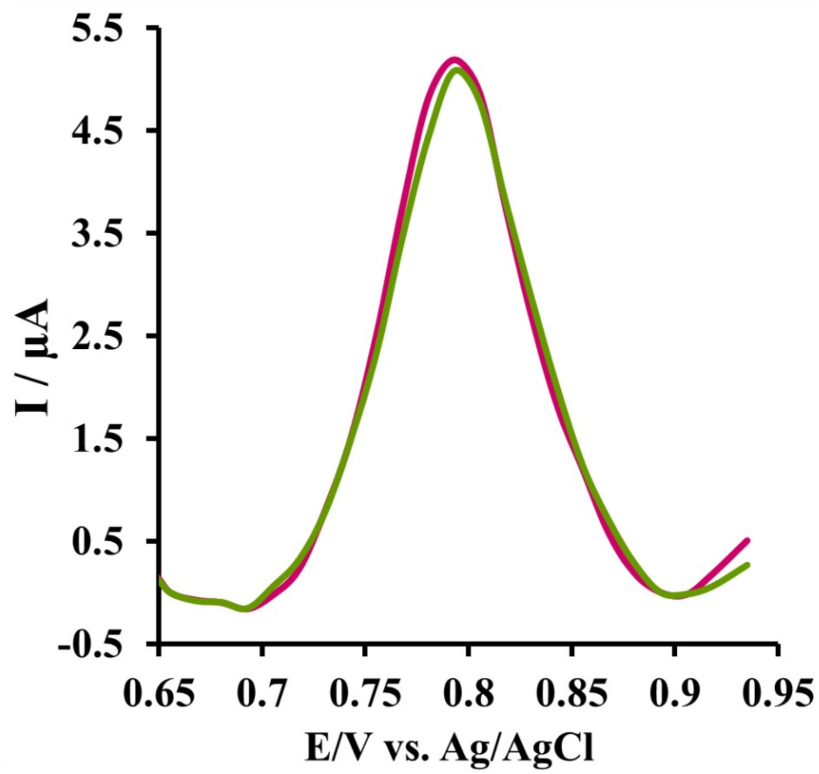


Fig. S8. DPV of $Ni_{0.4}Cu_{0.2}Zn_{0.4}Fe_2O_4$/CMC/GONs/GCE in presence of 4 μM OMP in 0.1 M PBS (pH=6.0) before (red line) and after (green line) long cycling sensing studies.