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<td>Murugan, N.; Chan-Park, Mary Bee Eng; Sundramoorthy, Ashok K.</td>
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Electrochemical Detection of Uric Acid on Exfoliated Nanosheets of Graphitic-Like Carbon Nitride (g-C3N4) Based Sensor

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A highly sensitive, selective and stable electrochemical sensor for detection of uric acid (UA) in aqueous solution has been successfully developed by deposition of exfoliated graphitic-like carbon nitride (g-C3N4) nanosheets on glassy carbon electrode (GCE). The synthesized g-C3N4 was confirmed by X-ray diffraction (XRD), Fourier-transform infrared (FT-IR) and Raman spectroscopies. Field-emission scanning electron microscopy (FE-SEM) and High-resolution transmission electron microscopy (HR-TEM) were used to investigate the crystalline structure of g-C3N4. The elemental composition was characterized by energy-dispersive X-ray spectroscopy (EDXS). Compared to bare GCE, exfoliated g-C3N4 nanosheets (NS) modified GCE exhibited higher catalytic current for UA electro-oxidation at reduced over potential in 0.1 M phosphate buffered saline solution (PBS), which is essential to discriminate interfering analytes. g-C3N4 NS exhibit a redox relationship between the electrochemical signal and the UA concentration from 100 to 1000 μM with fast response by differential pulse voltammetry (DPV). The common interferent molecules such as dopamine, ascorbic acid, folic acid, paracetamol, lactic acid, oxalic acid, cysteine, and ciprofloxacin were tested in 0.1 M PBS for the g-C3N4 NS modified GCE. It was found that these molecules did not affect the oxidation current of UA when they co-existed in the same buffer solution. Moreover, the modified sensor probe was tested for UA in urine samples with satisfactory recovery values. The proposed sensor offers high accuracy, sensitivity, simple fabrication and low cost. We suggest that g-C3N4 NS based sensor can be useful for UA analysis in medical, environmental, food and industrial applications.

Uric acid (UA) is found to have great significance in the physiology functions of living organisms and is involved in numerous biological processes.1–6 Serum UA is the primary water-insoluble end product of purine metabolism in the human body and it is an important bio-molecule present in urine and blood.7,8 Excessive, unusually low, or high time-variable UA concentration is associated with clinical disorders such as gout, pneumonia, type 2 diabetes, leukemia, toxemia during pregnancy, chronic renal disease, multiple sclerosis, hypertension and metabolic disorders.5–10 A simple and low cost method for determination of UA concentration would be useful since UA serves as a marker for the diagnosis of above conditions. Various standard analytical methods have been developed to determine UA such as high performance liquid chromatography (HPLC), a potentiometric enzyme electrode, flow-injection analysis, amperometry etc.11–16 These methods have some drawbacks such as high cost, tedious sample preparation, slow measurement, unsuitability for use outside of a laboratory setting, and requirement to be performed by skilled technicians. Among these options, electrochemical sensors (ECS) are attractive for detection of bio-molecules which exhibit electrochemical activity. ECS offers high accuracy with sensitivity, no interference, fast analysis, is user friendly and is low-cost. In order to prepare ECS, various modification strategies have been reported using bare electrodes coated with nanomaterials/electrocatalysts as the redox sites.17–20

Carbon materials such as graphene oxide (GO), carbon nanotubes (CNTs), carbon microspheres (CMP), and carbon quantum dots (CQDs) have been used for UA detection due to their excellent electro-catalytic properties.21–24 These carbon materials have some limitations such as difficulty of integration, low specific surface area and poor durability. As an emerging alternative, 2D graphic-like carbon nitride (g-C3N4) is a fascinating example of a metal-free semiconductor material with a stacked 2D structure.25–27 Recently, g-C3N4 has attracted much attention because of its remarkable structure, consisting of mainly covalent bonding of carbon and nitrogen by a π-conjugated polymeric network. g-C3N4 is two-dimensional semiconducting, layered, metal-free, easily synthesizable, nontoxic, and a biocompatible material. It is the most stable allotrope of carbon nitride with high chemical and thermal stability. g-C3N4 provides more active reaction sites (large surface area) for electron donor/acceptors with tunable electronic structure. Because of these extraordinary properties, g-C3N4 has been utilized in the fields of catalysis and sensing.28–31

It is worth to mention that as synthesized bulk g-C3N4 has poor conductivity, poor water solubility, and large particle size (low specific area), so that it is not suitable for electrochemical applications. In order to be well-utilized in the field of the sensor design, it is necessary to do further exfoliation of bulk g-C3N4 to nanosheets (NS). The exfoliated ultrathin g-C3N4 NS have higher specific surface area and provide more surface-active sites. More importantly, reports have demonstrated that the ultrathin g-C3N4 NS have better electrochemical activity and stability than bulk g-C3N4; this suggests that exfoliated ultrathin g-C3N4 NS are a promising candidate material for electrochemical applications.32–38

Electrochemical detection methods of UA were reported by both enzymatic and non-enzymatic approaches.39–46 Major drawbacks associated with enzymatic sensors include difficulties associated with enzyme immobilization on the electrode surface, limited working conditions such as humidity, pH, temperature, denaturing, lack of reproducibility and high cost.47 Nevertheless, two-dimensional (2D) nanomaterials with unique structure and physicochemical properties, have gained wide attention in electrochemical applications for sensors, energy storage and conversion.42 Various 2D materials based sensors have also been developed for UA detection using rGO-ZnO,43 Au-rGO,44 Pdop@GR/MWCNTs,44 rGO–PAMM–MWCNT–AuNP,45 MoS2–PEDOT/GCE,46 PtNi/MoS2,47 MoS2–AuNP48 and MoS2.49 These materials have some limitations such as tedious synthesis process, nanosheets easily aggregate and showed poor conductivity, relatively expensive, etc. Therefore, their application as electrocatalytic active material was limited for the detection of the small biomolecules.50 Thus, there is a demand for developing a simple sensor which can detect UA with high sensitivity and selectivity at relatively low cost.

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Herein, we demonstrated a novel and highly sensitive electrochemical sensor for UA detection using a glassy carbon electrode (GCE) modified with exfoliated ultrathin g-C$_3$N$_4$ NS. The exfoliated g-C$_3$N$_4$ NS were comprehensively characterized by various techniques. X-ray diffraction (XRD), Fourier-transform infrared (FT-IR) and Raman spectroscopies were used to analyze crystalline structure and functional groups of g-C$_3$N$_4$, respectively. Surface morphology and the crystalline nature were investigated by using Field emission scanning electron microscopy (FE-SEM) and transmission electron microscopy (TEM). The elemental and chemical compositions were characterized by Energy-dispersive X-ray spectroscopy (EDXS). Furthermore, the electrochemical properties of g-C$_3$N$_4$ NS/GCE were studied by cyclic voltammetry (CV) and differential pulse voltammetry (DPV). The new g-C$_3$N$_4$ NS probe exhibited a wide linear response over the concentration range from 100 to 1000 $\mu$M UA. Furthermore, detection of UA in a human urine sample is demonstrated with high accuracy. This new sensor offers high accuracy with sensitivity, no interferent effect, fast analysis, is user friendly, non-enzymatic and is low-cost.

**Experimental**

**Materials.—** All the chemicals and reagents (Melamine, dopamine, uric acid, ascorbic acid, folic acid, paracetamol, lactic acid, oxalic acid, cysteine and ciprofloxacin) were purchased from Sigma-Aldrich and Alfa Aesar, India. They were of analytical grade and used without further purification. The required solutions were prepared with ultrapure deionized water (Millipore water purification system).

**Synthesis of bulk g-C$_3$N$_4$.—** Bulk g-C$_3$N$_4$ was prepared by a direct decomposition method. One gram of melamine was placed on a ceramic quartz boat crucible and heated at a rate of 5°C min$^{-1}$ to 550°C in a tubular furnace and then maintained at this temperature (550°C) for 3 h under an atmospheric environment. The crucible was then cooled to room temperature, and the light-yellow colored g-C$_3$N$_4$ product was collected and grinded into a powder for further use. Synthesized g-C$_3$N$_4$ powder is referred as bulk g-C$_3$N$_4$. Fig. 1 shows schematically the formation process of g-C$_3$N$_4$ from melamine. The condensation reaction of melamine results in discrete oligomers which converted to polymers and extended networks.

**Synthesis of exfoliated g-C$_3$N$_4$ nanosheets (NS).—** Bulk g-C$_3$N$_4$ powder (0.2 g) was dispersed in 50 mL of ultrapure deionized water and then subjected to ultrasonication (probe-assisted) for 2 h (50% amplitude, pulsed for 3 seconds on and 2 seconds off). After ultrasonication, the solution was allowed to stand undisturbed for 3 h at room temperature to allow unexfoliated bulk g-C$_3$N$_4$ particles to settle at the bottom of the container. The supernatant liquid (a homogenized dispersion) of exfoliated g-C$_3$N$_4$ NS was collected and used for further studies (Fig. 2. (a) Bulk g-C$_3$N$_4$ powder and (b) exfoliated g-C$_3$N$_4$ NS dispersion).

**Preparation of exfoliated g-C$_3$N$_4$ NS modified GCE.—** The bare GCE with a diameter of 3 mm was polished on a polishing cloth pad with alumina slurry (with varied particle sizes from 1.0, 0.3 and 0.05 μm) and then successively rinsed with distilled water and ethanol several times. Finally, it was cleaned by placing the electrode in water-ethanol solution for two min under bath sonication. Then, 10 μL exfoliated g-C$_3$N$_4$ NS dispersion was drop-casted on the cleaned GCE surface and dried overnight at room temperature. The prepared...
Scheme 1. Schematic representation of sensor fabrication and UA oxidation process at g-C$_3$N$_4$ NS modified GCE.

The electrode is hereinafter referred to as “exfoliated g-C$_3$N$_4$ NS modified GCE (g-C$_3$N$_4$ NS/GCE).” This g-C$_3$N$_4$ NS/GCE was used for further characterization and applications (Scheme 1).

**Materials characterization.**—The functional groups of bulk g-C$_3$N$_4$ were characterized by FT-IR (Nicolet Impact 400 D spectrometer) in the wavenumber range of 4000–400 cm$^{-1}$. The crystal structure and phase composition of g-C$_3$N$_4$ were measured by using a powder X-ray diffraction spectrometer (X’pert powder XRD system, Malvern Panalytical) in the 2$\theta$ range of 20° to 100° with Cu K$\alpha$ radiation ($\lambda$ = 0.15406 nm). Raman spectroscopy was performed at ambient conditions with 633 nm laser excitation (LabRAM HR evolution, Horiba). The surface morphology of the samples was investigated using FE-SEM (SEM 7500F, Jeol) at an accelerating voltage 20 kV. A transmission electron microscope (TEM, JEM-2100 Plus, Jeol) operating at 200 kV and capable of Energy-dispersive X-ray spectroscopy (EDXS) was employed for surface, elemental and chemical composition analysis.

**Electrochemical measurements.**—CV and DPV were carried out in a conventional three electrode cell setup using a CHI 760 E electro-chemical workstation. 0.1 M phosphate buffered saline (PBS) solution was used as supporting electrolyte at room temperature (25 ± 2°C). Platinum wire, exfoliated g-C$_3$N$_4$ NS modified GCE and Ag/AgCl (3 M KCl) were used as counter, working and reference electrodes, respectively.

**Spiked sample analysis.**—A human urine sample was collected from a healthy volunteer (male, 22 years old). After the collection, urine was promptly refrigerated. The originally collected urine sample (10 μL) (without any additional pretreatment process) was added into 10 mL of 0.1 M PBS (pH 7.4) for the electrochemical measurements. Furthermore, known concentrations of UA (100 μM, 200 μM and 300 μM) were spiked into the above PBS (containing urine sample) and DPVs were recorded. The recoveries of the spiked UA concentrations were evaluated and ranged between 99.6 to 101.5%.

**Results and Discussion**

**FT-IR spectrum.**—FT-IR spectrum was recorded to determine the surface functional groups present on the prepared bulk g-C$_3$N$_4$. Fig. 3a exhibits a broad band at 3292 cm$^{-1}$ which can be attributed to the
stretching vibration modes of the NH2 or N–H groups. The peaks at 1242 cm\(^{-1}\), 1325 cm\(^{-1}\), 1423 cm\(^{-1}\), 1560 cm\(^{-1}\) and 1642 cm\(^{-1}\) correspond to the typical stretching vibration modes of C = N and C-N heterocycles. The small peak located at 806 cm\(^{-1}\) is a signature of the characteristic breathing vibration mode of the triazine rings present in g-C\(_3\)N\(_4\). The absorption feature at 889 cm\(^{-1}\) was associated to a deformation mode of cross-linked heptazine. All the characteristic peaks were in good agreement with the earlier reports of synthesized g-C\(_3\)N\(_4\).

XRD and Raman analysis.—The powder XRD pattern of as-synthesized bulk g-C\(_3\)N\(_4\) is shown in Fig. 3b. The strong peak at 27.62°, was assigned to the (002) plane interlayer stacking of the conjugated aromatic ring system of g-C\(_3\)N\(_4\). This characteristic peak is in good agreement with prior reports on synthesized g-C\(_3\)N\(_4\). Furthermore, Fig. 4 shows the Raman spectrum of synthesized bulk g-C\(_3\)N\(_4\) with several characteristic bands observed at 1579, 1482, 1149, 985, 705 and 473 cm\(^{-1}\) corresponding to the typical vibration modes of C-N and C=–N heterocycles.

FE-SEM, TEM and EDXS analysis.—The surface morphology of the synthesized bulk g-C\(_3\)N\(_4\) is recorded by FE-SEM as shown in Fig. 5a, which revealed the presences of agglomerated particles with average sizes of ~0.5 to 1 \(\mu\)m. Fig. 5b shows the TEM images of the exfoliated g-C\(_3\)N\(_4\) NS, where we could observe several flat layered like sheets with the dimension of ~10 nm. Inset of Fig. 5b is a HR-TEM image of g-C\(_3\)N\(_4\) NS with a lattice fringe spacing of 0.324 nm which corresponded to the (002) crystal plane of g-C\(_3\)N\(_4\). The elemental mapping (EDXS spectrum) of the sample is also revealed the presence of high intensity bands of C and N, which indicated the successful synthesis of g-C\(_3\)N\(_4\) nanosheets (Fig. 5c). The crystalline nature of g-C\(_3\)N\(_4\) nanosheets is also characterized by a SAED pattern (Fig. 5d). The SAED pattern revealed that bright continuous concentric rings attributed to diffraction from the 002 planes of g-C\(_3\)N\(_4\) and is consistent with the XRD data. We also estimated the average film thickness of the g-C\(_3\)N\(_4\) NS film was estimated to be around ~0.1 \(\mu\)m (Fig. 5b).

Electrochemical oxidation of UA at g-C\(_3\)N\(_4\) NS modified GCE.—Electrochemical oxidation of 1 mM UA was tested on a bare GCE and g-C\(_3\)N\(_4\) NS modified GCE (at a scan rate of 50 mV s\(^{-1}\)) in 0.1 M PBS, pH 7.4 in the potential range of 0 to 1 V as shown in Fig. 6. The g-C\(_3\)N\(_4\) NS modified GCE exhibited a highly enhanced oxidation peak centered at 0.45 V (red curve). Whereas, UA oxidation at the bare GCE showed a lower oxidation peak current at higher positive potential (0.53 V) (black curve). It was obvious that modified g-C\(_3\)N\(_4\) NS/GCE produced highly enhanced catalytic current of UA oxidation compared to the bare GCE. This establishes that g-C\(_3\)N\(_4\) NS exhibit high electro-catalytic activity useful for UA sensing. In addition, the UA oxidation peak was shifted to a lower potential than that of the unmodified electrode. These data indicated that electrode surface modification with g-C\(_3\)N\(_4\) NS improves the electrocatalytic UA oxidation process. A possible reaction mechanism for the oxidation of UA at the...

Figure 4. Raman spectrum of bulk g-C\(_3\)N\(_4\) (with 633 nm excitation).

Figure 5. (a) SEM images of the synthesized bulk g-C\(_3\)N\(_4\), (b) TEM images of exfoliated g-C\(_3\)N\(_4\) NS and the inset shows the HR-TEM image of the g-C\(_3\)N\(_4\) NS film from which the lattice fringes can be clearly seen. (c) EDX spectrum of g-C\(_3\)N\(_4\) NS and (d) selected area electron diffraction (SAED) pattern of g-C\(_3\)N\(_4\).

Figure 6. CVs of bare GCE (black curve) and g-C\(_3\)N\(_4\) NS modified GCE (red curve) recorded with 1 mM UA in 0.1 M PBS (pH 7.4) (Scan rate = 50 mV s\(^{-1}\)). (Inset: photographic images of g-C\(_3\)N\(_4\) NS modified GCE sensor).
Figure 7. Schematic representation of UA electro-oxidation mechanism at the exfoliated g-C$_3$N$_4$ NS modified GCE surface.

g-C$_3$N$_4$ NS modified GCE is illustrated in Fig. 7. As UA oxidation is a two-electron transfer process, uric acid (1H-purine-2,6,8 (3H,7H,9H)-trione) is converted into (1H-purine-2,6,8 (9H)-trione).$^{60,61}$ Hence, the electrochemical oxidation of UA on modified GCE takes place by direct transfer of two protons and two electrons by a chemical conversion. The effect of scan rate ($\nu$) on UA oxidation peak current ($I_{pa}$) was investigated at g-C$_3$N$_4$ NS/GCE by using cyclic voltammetry in 0.1 M PBS solution.

Fig. 8a shows cyclic voltammograms (CVs) of the g-C$_3$N$_4$ NS/GCE in 1 mM UA at different scan rates from 10 to 100 mV s$^{-1}$. According to the Randles-Sevcik formula (Equation 1),$^{62}$ it can be clearly seen that the $I_{pa}$ increases against square roots of scan rate with a linear correlation coefficient of ($R^2$) 0.9659 (Fig. 8b).

$$I_p = (2.69 \times 10^5) n^{3/2} AD^{1/2}C\nu^{1/2}$$  [1]

Where $I_p$ is the oxidation peak current (A), $n$ is the number of transferred electrons per mole, $A$ is the active surface area of the electrode (cm$^2$), $D$ is the diffusion coefficient (cm$^2$/sec), $C$ is concentration (mol/cm$^3$) and $\nu$ is the scan rate (V/s). These results indicated that the oxidation of UA on g-C$_3$N$_4$ NS/GCE is a diffusion-controlled electrochemical processes (Fig. 8b).$^{63}$

**Determination of UA by DPV.**—DPV is a highly sensitive technique that has been commonly used for electrochemical detection. Fig. 9a shows the DPV curves of different concentrations for UA on g-C$_3$N$_4$ NS modified GCE. As we recorded, the electro-catalytic oxidation peak current of UA increases linearly with concentration from 100 to 1000 $\mu$M. Fig. 9b shows a good linear relationship between the concentrations and the peak currents with a linear correlation coefficient of ($R^2$) 0.9960. This proved that the electro-catalytic oxidation of UA at the surface of the g-C$_3$N$_4$ NS/GCE is highly sensitive and dependent on the UA concentration. We have also recorded three replicate measurements and the results were reproducible. Previously, various nanomaterials have been synthesized to prepare electrochemical sensors for the detection of UA.$^{44,64-69}$ We have also compared our analytical data with some of other reported methods for electrochemical detection of UA in Table I. This proposed new method offers a number of advantages. For example, the demonstrated concentration range over which our detector response is linear from 100 $\mu$M -1000 $\mu$M compares well with the other reported methods. It also exhibits better selectivity and lower limit of detection (LOD) for UA (Table I). The LOD was calculated using the following Equation 2:

$$\text{LOD} = 3\sigma_B/S$$  [2]

Where $\sigma_B$ is the standard deviation of the current measured on a blank sample (9.0 $\times$ 10$^{-8}$ A) and $S$ is the slope of the calibration curve (2.025 $\times$ 10$^{-8}$ A $\mu$M$^{-1}$). The calculated LOD value was 4.45 $\mu$M which was better than some of the reported UA sensors (Table I).

**Determination of UA in a spiked sample.**—The proposed sensor was applied to detect UA in a spiked sample (as given in Spiked sample analysis section). As shown in Fig. 10, after each addition of UA, peak currents were increased at g-C$_3$N$_4$ NS/GCE due to catalytic oxidation of UA (Note: UA concentration in original urine sample was not determined).
Figure 9. (a) DPVs of g-C₃N₄ NS modified GCE recorded over UA concentrations range from 100 μM to 1000 μM. (b) Calibration curve of UA (I_P vs. [UA]).

Figure 10. DPVs of g-C₃N₄ NS modified GCE recorded in 0.1 M PBS with urine sample spiked with 100, 200 and 300 μM (UA). 200 μM and 300 μM were spiked into PBS containing human urine sample and analyzed by this g-C₃N₄ NS/GCE sensor to validate it suitability for practical applications. The recovery results (using Eq. 3) are provided in Table II. It indicated that this new sensor can be applied for accurate measurement of UA in real samples.

Recovery (%) = C_{found}/C_{spiked} × 100

Interference and selectivity studies.—The selectivity of the g-C₃N₄ NS/GCE sensor for UA over possible interfering molecules is an essential requirement in electro-analysis. We have recorded DPV in the absence and presence of various other molecules to investigate selectivity of the proposed sensor. Molecules such as dopamine (0.5 mM, DA), ascorbic acid (1 mM, AA), folic acid (0.5 mM, FA), paracetamol (0.5 mM, PA), lactic acid (0.5 mM, LA), oxalic acid (0.5 mM, OA), cysteine (Cy) (0.5 mM), and ciprofloxacin (Cip) (0.5 mM) were investigated in 0.1 M PBS. These molecules did not affect the oxidation current of UA when they co-existed in the same buffer solution. Only negligible current (signal change < 6.0% decreased) changes were observed as shown in Fig. 11. These results suggested that UA detection on g-C₃N₄ NS/GCE sensor is highly selective without any Table I. Analytical comparison of linear range and LODs of other modified electrodes reported for electrochemical detection of UA.

<table>
<thead>
<tr>
<th>Catalytic Material*</th>
<th>Electrode</th>
<th>Electrochemical Method</th>
<th>Detection range (μM)</th>
<th>LOD (μM)</th>
<th>Refs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pt/PAAQ</td>
<td>GCE</td>
<td>DPV</td>
<td>35–420</td>
<td>11.5</td>
<td>64</td>
</tr>
<tr>
<td>PMMA</td>
<td>GCE</td>
<td>DPV</td>
<td>20–170</td>
<td>6.38</td>
<td>65</td>
</tr>
<tr>
<td>PrGO/PB 100</td>
<td>GCE</td>
<td>CV</td>
<td>40–415</td>
<td>8.0</td>
<td>66</td>
</tr>
<tr>
<td>HNP-PTi</td>
<td>GCE</td>
<td>DPV</td>
<td>100–1000</td>
<td>5.3</td>
<td>67</td>
</tr>
<tr>
<td>Pd/CNFsc</td>
<td>GCE</td>
<td>DPV</td>
<td>50–4000</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>Pdop@GR/MWCNTs</td>
<td>GCE</td>
<td>DPV</td>
<td>20.0–320.0</td>
<td>15</td>
<td>44</td>
</tr>
<tr>
<td>Trp-GR/GCE</td>
<td>GCE</td>
<td>DPV</td>
<td>10–1000</td>
<td>12.9</td>
<td>68</td>
</tr>
<tr>
<td>Pyrolytic graphite electrode</td>
<td>GPE</td>
<td>DPV</td>
<td>21–336</td>
<td>21</td>
<td>70</td>
</tr>
<tr>
<td>MWCNT/PEDOT film</td>
<td>GCE</td>
<td>DPV</td>
<td>10–250</td>
<td>10</td>
<td>69</td>
</tr>
<tr>
<td>g-C₃N₄ NS</td>
<td>GCE</td>
<td>DPV</td>
<td>100–1000</td>
<td>4.45</td>
<td>This work</td>
</tr>
</tbody>
</table>

*Footnotes:
Poly (1-aminoantraquinone) (PAAQ),
Polymethylmethacrylate (PMMA),
Photochemically reduced graphene oxide/Prussian blue (PrGO/PB),
Hierarchical nanoporous (HNP),
Palladium/carbon nanofibers (Pd/CNFsc),
Polydopamine (Pdop), graphene (GR) and multiwalled carbon nanotubes (MWCNTs),
Tryptophan-functionalized graphene (Trp-GR).
Multi-walled carbon nanotubes-poly(3,4-ethylendioxythiophene) (MWCNT/PEDOT).
significant interference effects. Previously, g-C₃N₄ NS with graphene oxide based composite coated electrode was prepared and reported for simultaneous detection AA, DA and UA in pH 4.0. In that work, it was mentioned that GO provided a selective interface for effective oxidation of these molecules, not g-C₃N₄. In addition, g-C₃N₄ was used to enhance the electrical properties of the composite. In contrast, in this work, exfoliated g-C₃N₄ NS (single component) was tested and found that it could be useful for selective detection of UA at pH 7.4. However, further studies may be required to understand the selectivity of g-C₃N₄ NS for UA oxidation.

Conclusions

In summary, we have developed a new electrochemical sensor using exfoliated ultrathin g-C₃N₄ NS as an effective electrocatalyst for highly sensitive measurement of UA. FT-IR, XRD, Raman spectroscopy, FE-SEM, HR-TEM, and EDXS confirmed the successful synthesis of g-C₃N₄. Moreover, the material was demonstrated to be an efficient electrocatalyst for UA and showed a fast response, wide linear range of detection (100 to 1000 μM) with high sensitivity and selectivity. In addition, g-C₃N₄ NS had anti-interference ability in the presence of other biomolecules. Finally, the developed g-C₃N₄ NS based sensor was used to detect spiked UA in human urine samples with high accuracy. This sensor also offers several advantages such as easy fabrication, it is simple to operate, is highly sensitive and selective, with low cost for UA detection. We conclude that this new sensor may be suitable for UA analysis in various environmental, medical, food and industrial samples.

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Table II. Electrochemical detection of UA spiked in urine samples using g-C₃N₄ NS modified GCE as a sensor.

<table>
<thead>
<tr>
<th>Added (μM)</th>
<th>Found (μM)</th>
<th>Recovery (%)</th>
<th>RSD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>99.6</td>
<td>99.6</td>
<td>1.92</td>
</tr>
<tr>
<td>200</td>
<td>202</td>
<td>101</td>
<td>2.36</td>
</tr>
<tr>
<td>300</td>
<td>304</td>
<td>101.3</td>
<td>2.24</td>
</tr>
</tbody>
</table>

aThree number of measurements carried out (n = 3).