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# Flame synthesis of nitrogen doped carbon for the oxygen reduction reaction and non-enzymatic methyl parathion sensor

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# Abstract

Growing the concerns about economical feasibility of materials synthesis needs a simple methodology to furnish the materials. Moreover, the as-prepared materials meet a multi-functional activity is great importance. Hence, here we report the nitrogen-doped carbon nanoparticles synthesized from one-step flame synthesis by directly burning the pyrrole in room temperature and air atmosphere. The as-synthesized N-doped carbon was scrutinized as a cathode material for oxygen reduction reaction and also demonstrated towards the electrochemical sensor. Furthermore, the x-ray photoelectron spectroscopy (XPS) and Raman analysis confirms that the percentage of nitrogen content, bonding environment and the disorder of carbon. The as-prepared N-doped carbon exhibits a superior electrocatalytic activity towards the ORR as similar with the commercial Pt/C catalyst. Moreover the N-doped carbon modified glassy carbon electrode manifests a sensitive electrochemical response towards the detection of methyl parathion. The fabricated sensor was demonstrated the two linear concentrations ranging from 0.0025 to 1  $\mu$ M and 1 to 100  $\mu$ M with the lower detection limit of 0.068 nM. The proposed method is very simple, low cost and it can be utilized for practical applications to produce the carbon materials in large scale.

**Keywords:** Methyl parathion, Nitrogen doped carbon, Oxygen reduction reaction, Flame synthesis, Mechanism of parathion detection.

## 1. Introduction

Increasing the demand of energy and anthropogenic climate changes induced a need in green energy and also environmental security.<sup>1</sup> Fuel cells are the device which generates electricity by the electrochemical transformation of hydrogen and oxygen into water.<sup>2</sup> It produces energy in a greener way, however, the fuel cells are suffer from the sluggish oxygen reduction reaction (ORR) at cathode side.<sup>3</sup> So far, platinum or platinum based compounds are mostly employed as ORR catalysts by its superior activity and stability.<sup>4</sup> However, platinum has declined for fuel cells application due to the high cost and relatively low abundant of platinum. Hence, the recent studies pursued in non-precious metals and metal-free catalysts for ORR.<sup>5–8</sup> The non-noble metal catalysts reveal a better performance towards ORR, though, which are used with the carbonaceous support materials.<sup>9–11</sup> Because, the non-precious metal catalysts are lacking their lower surface area and poor electrical conductivity hence the carbons are used to reimburse the conductivity. Recent studies exhibit the carbon materials are solely engaged in ORR, which are so-called metal-free catalysts.<sup>12–14</sup> In particular, the N-doped graphenes are revealing excellent electrocatalytic responses towards ORR.<sup>15</sup>

On the other hand, to secure the environmental safety, it is necessary to remove the organic pollutants mainly carcinogenic and lethal hazardous compounds.<sup>16</sup> Especially pesticides, which are extensively used in agriculture for controlling the insects.<sup>17</sup> Methyl parathion (MP-organophosphorous compound) is one of the commonly used pesticides around the world, however, it is contaminated the soil and water bodies which affects the aquatic organisms.<sup>17</sup> Hence, it is very important to develop a viable method to detect MP in water, foodstuff and soils, etc. Several analytical techniques were employed to determine the MP such as gas chromatography (GC), high performance liquid chromatography (HPLC), gas chromatography–mass spectrometry (GC-MS) and spectrometry.<sup>18–20</sup> These methods manifest the accurate results with highly sensitivity however they are time consuming process and very expensive for the practical applications. Therefore, a rapid, selective and sensitive method still need for the detection of MP. Incidentally, an electrochemical technique offers an alternative and cost effective way to detect MP compare to the former methods.<sup>21</sup> Here, also graphene or composites of graphene are used to fabricate the sensor electrode.

Since the discovery of graphene, vast studies have been devoted to scrutinize the properties of the graphene-based nanomaterials and its composites towards the numerous electrochemical applications.<sup>22</sup> Graphene has given an advanced platform to the modern researches by its remarkable properties and versatility.<sup>23</sup> However, the synthesis of graphene or graphene based materials are lacking by their limited synthetic procedure such as mechanical exfoliation of graphite, thermal exfoliation of graphite, chemical vapor deposition on silicon wafers and the reduction of graphene oxide (GO).<sup>24–26</sup> So far, identified methods are significantly costly or questionable to safety, hence, the adaptability of graphene synthesis should be improved for practical applications. Therefore, the recent studies concentrated on activated carbons (ACs) because of the simple synthesis process, safety and economically viable.

ACs are synthesized by many sources (e.g., biomass, organic chemical and charcoal) and widely used as adsorption materials by its high porosity and high surface area. Nowadays, it is employed in heterogeneous catalysis and electrocatalysis, particularly energy and environmental applications.<sup>27–30</sup> Moreover, heteroatom (boron, nitrogen, phosphorous and sulfur) doped carbons are exhibiting excellent electrocatalytic activity when compare with undoped carbons.<sup>12–15,31</sup> In which, nitrogen doped carbon acquired tremendous interest in the field of ORR and sensors.<sup>7,8,15</sup> Among the various method, flame synthesis has furnished the carbon materials in simple one-step and very rapid.<sup>32</sup> This method has a great interest and motivated from the recently reported candle soot synthesis procedure.<sup>33,34</sup> Herein, we report the synthesis of nitrogen doped carbon nanoparticles (NCN) from the direct burning of pyrrole in air atmosphere and the resultant carbon soot was deposited on a glass plate. Furthermore, the as-prepared nitrogen doped carbon nanoparticles was characterized by various physical characterization and electrochemical characterization towards the detection of MP and ORR.

# 2. Experimental section

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# 2.1. Preparation and fabrication of Nitrogen doped carbon-modified electrode

The previously reported flame synthesis method was followed with some modifications to synthesis the nitrogen doped carbon in the form of soot.<sup>32</sup> Herein, 10 mL of pyrrole was taken in a small beaker and directly burned under air. Obviously, the aromatic organic compounds are burning with a sooty flame when igniting, afterwards the resultant soot was deposited on a glass

plate and carefully collecting the sample by scratching. In addition, the synthesis procedure was given as schematic diagram and shown in scheme 1.



**Scheme 1.** A schematic representation of the synthesis of nitrogen doped carbon from pyrrole and its voltammetric response towards the detection of MP.

To fabricate the electrode for ORR and MP sensor, the NCN (44 mg in 5 mL) was dissolved in DI water and further it is sonicated for 15 min. The homogeneous NCN solution (8  $\mu$ L) was drop casted on the well-polished glassy carbon electrode (GCE) and rotating disk electrode (RDE) dried in an ambient condition. The NCN modified electrodes were successfully used to observe the electrochemical behavior towards MP detection and ORR activity.

# 2.2. Characterization of NCN

The structure and bonding environment of NCN was analyzed by X-ray diffraction pattern analysis (XRD), XPERT-PRO (PANalytical B.V., The Netherlands) with CuK $\alpha$  radiation ( $\lambda$ =1.5406 Å) and Raman spectra (NT-MDT, NTEGRA SPECTRA). The surface morphology and elemental composition were studied by scanning electron microscope (SEM) Hitachi S-3000 H. Primary electrochemical reactions such as cyclic voltammetry and chronoamperometry were carried out in CHI 1205B electrochemical analyzer (CH Instruments, USA). The electrocatalytic

determination of methyl parathion was performed by differential pulse voltammetry (DPV) CHI 900 (CH Instruments, USA). Oxygen reduction reaction and the number of electron transfer associated with ORR were analyzed by rotating disk voltammogram AFMSRX (PINE instruments, USA). A conventional three electrode system has been employed for the catalysis where the GCE is used as a working electrode (0.07 cm<sup>2</sup>), platinum wire is an auxiliary electrode and Ag/AgCl/3 M KCl is used as a reference electrode.

# 3. Results and discussion

# 3.1. Characterization of structure and surface morphology of NCN

Fig. 1b, shows the XRD pattern of NCN, which reveals a peak at 25.82° (2θ) corresponds to the (002) plane with the interlayer spacing of 0.344 nm along the *c*-axis, which is closely matched with the interlayer spacing of pristine graphite (0.34 nm). <sup>35</sup> This result indicates that the asprepared NCN was crystallized in the hexagonal ordered unit cell. But the presence of hetero atoms such as nitrogen and oxygen moieties in the crystal lattice leads the NCN to lower grain size and disorder. Therefore, the Raman spectrum was employed to assess the disorders in NCN. Fig. 1d displays a Raman spectrum of NCN which possesses two broad bands at 1352 and 1594 cm<sup>-1</sup>, the observed peaks are corresponds to the disordered (D) band and graphitic (G) band.<sup>36, 37</sup> The ratio of the relative intensities for D and G bands provide the information about the compound's crystallinity, the lower D/G ratio of carbons showed better crystallinity. The lower D band intensity of NCN results the low distortion in hexagonal lattice and also the D/G intensity ratio of NCN reveals 0.78 which directly proportional to amount of disorder of carbon.<sup>38</sup>



**Fig. 1.** (a) Crystal model (b) XRD patterns (c) TEM image and (d) Raman spectra of as-prepared nitrogen doped carbon.

Fig. 2a displays the scanning electron microscopy (SEM) image of NCN, which shows the aggregated flake like surface morphology with the average elemental composition of 90.0, 7.1 and 2.9%, corresponding to the C, O and N respectively (Fig. 2e). These relative atomic percentages of each element distribution in NCN are further confirmed by the elemental mapping of energy dispersive x-ray analysis (EDAX) and the results shown in Fig. 2b, c & d. The local crystallinity and grain boundary of NCN was probed by transmission electron microscopy (TEM). Fig. 1c shows the TEM image of as prepared NCN, which depicts the aggregated particle like shape with distinguishable grain boundaries, however in some places it covers the particles as sheets.



**Fig. 2.** (a) SEM image of NCN, (b-d) EDAX elemental mapping of NCN which illustrates the distribution of components, carbon (b) oxygen (c) and nitrogen (d). (e) The bar diagram of atomic percentage of each elements of NCN.

X-ray photoelectron spectroscopy (XPS) is a reliable tool used to analyze the elemental composition and bonding environment of the compounds. As depicted in Fig. 3a, the XPS survey of the NCN possesses three major peaks centered at 286.5, 399.5, and 533.8 eV, which are corresponding to the C1s, N1s, and O1s, respectively. The relative elemental composition of C1s, N1s, and O1s is calculated from XPS as 89.5, 2.9, and 7.15%, respectively, this value is closely matched with EDAX analysis. The high resolution N1s, O1s, and C1s spectra are considered to understand the bonding environment of the elements. Fig. 3b shows the high resolution spectra of C1s which further deconvoluted into four peaks, the peak at 285.5 eV is related to the sp<sup>2</sup> carbon or graphitic carbon.



**Fig. 3.** (a) XPS survey of as prepared nitrogen doped carbon. High resolution XPS spectra with curve fitting for (b) C1s peak (c) N1s peak and (d) O1s peak.

The peak at 286.1 eV is related to the sp<sup>3</sup> carbon where the carbon bonding with nitrogen as C–N or in other words the graphitic nitrogen bond.<sup>39</sup> The peak at 286.9 is related to C=O and peak at 289.7 eV considerable to N–C=O bond. This observation confirms the presence of nitrogen atom into the carbon framework. Furthermore, a high resolution N1s spectrum was taken to account for the clear explanation. Fig. 3c depicts the N1s spectra of NCN, which contains three different bonding environments. The peaks at 398.73, 399.3, and 400.0 eV are assigned to pyridinic, pyrrolic, and graphitic nitrogen bonding. The crystal model of NCN is shown in Fig. 1a, which clearly illustrates the information about different environment of nitrogen in carbon framework. In which, the pyridinic and pyrrolic nitrogen atom deviates the symmetry of C=C, hence the voids are created in uniform carbon lattice. The high-resolution O1s spectra in Fig. 3d also shows the evidence for the presence of nitrogen by N–C=O bonding which is in agreement with C1s spectra. Oxygen also doped in carbon as C–O or –C=O, that is clearly observed by the peak at 532.7 eV which may play a good performance by increasing defects, disorder or local electron density around O atoms.

# 3.2. Electrochemical behavior of MP

To explain the mechanism of MP determination, cyclic voltammetry (CV) was used to characterize the electron transfer process concerned in reduction of MP. Fig. 4a shows the CVs obtained for NCN modified and bare GCE in 0.1 M PBS (pH = 7.0) in the presence of 50  $\mu$ M MP at a scan rate of 50 mV/s. These CVs were recorded only for first cycles. In the cathodic sweep, a highly intensive irreversible reduction peak (system-I, see scheme 2a) was observed at -0.55 V for NCN modified GCE corresponding to the reduction of the nitro group in MP to arylhydroxylamine<sup>40</sup> whereas bare GCE has taken 50 mV (-0.6 V) overpotential to reduce the MP. During the reverse scan, the primary reduced product (system-I, scheme 2a) at an electrode surface was oxidized into nitrosobenzene (system-II, scheme 2a) at -0.03 V, further this oxidized product was reduced in the second cathodic sweep at -0.06 V (see scan rate).<sup>41</sup> For comparison, we also recorded a CV using the same electrodes in the absence of MP, it can be clearly seen that there were no peaks arising out for bare and NCN modified GCE (Fig. 4a). In addition, the obtained CV curves for the absence of MP provide the information about the background current. Here, the bare GCE depicts the reduction behavior at -0.75 vs Ag/AgCl and provides low background current due to the low capacitance, on the other hand, NCN provides high background current by its superior high capacitance (due to high surface to volume ratio).

# 3.3. Effect of scan rate and pH

The scan rate dependence of MP reduction was evaluated to assess the electron transfer process, hence a different range of scan rate was used from 10 to 100 mV/s and the resultant CVs were shown in Fig. 4b. It is well known that the reduction peak current was increased systematically with increasing scan rate, but in our case the secondary redox product peak is observed better and well shaped. This phenomenon indicates that NCN modified GCE reduced a maximum of MP via four electron pathway. Therefore the secondary reduced product (system-I, scheme 2a) remains maximum at the electrode surface further it was produced a redox couple (system-II, scheme 2a). The peak current of the secondary product redox couple was plotted against the scan rate and shown in Fig. 4b (inset). From slope value in Fig. 4b (inset), we can find the redox process is diffusion controlled, however the decrease in primary reduction peak current indicates the adsorption process for increasing the scan rate. Thus, the present study point out that the MP reduction was both adsorption and diffusion controlled process. In which the adsorption occurs

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on electrode surface and diffusion contributes to the rate determining step.<sup>42</sup> Moreover, the adsorption of MP on to the electrode surface was confirmed from the scan rate, where a small peak potential shift was observed in the MP reduction process with increasing scan rate.



**Fig. 4.** Cyclic voltammograms of (a) bare and NCN modified GCE in presence and absence of 50  $\mu$ M MP. (b) NCN modified GCE in MP for various scan rates ranging from 10 to 100 mV/s and the corresponding plot of peak current vs. scan rate in inset. (c) NCN modified GCE in MP at various pH from 3 to 13 and inset shows the plot of pH vs. peak potential (taking for primary reduction peak). (d) Differential pulse voltammograms of NCN modified GCE in various concentrations of MP ranging from 2.5 nM to 100  $\mu$ M and inset shows the calibration plot for current vs concentration.

The electrochemical reaction is very sensitive towards the pH of the electrolyte solution which follows the linear responses for the potential versus pH with the slop of 59 mV (Nernst equation) for one electron transfer. The effect of pH on the electrocatalytic response of MP was evaluated for the NCN modified GCE in the pH ranging from 3 to 13. The NCN modified GCE exhibits the higher current response in pH at 7.0 compare to all other pH investigated (Fig. 4c). A

decrease in current response was observed for the lower pH due to the  $H^+$  ions adsorption on the electrode surface. As shown in Fig. 4c (inset) the reduction peak potential of MP is linearly varying depends on the pH in the range of 3 to 13. So, according to the electrocatalytic current enhancement, the pH 7.0 was selected for further experiments.

# 3.4. Determination of MP

Differential pulse voltammetry (DPV) is a more sensitive analytical method to determine the MP. This experiment was carried out to explore the practical viability of NCN modified GCE for non-enzymatic electrochemical detection of MP, a lethal environmentally hazardous pesticide. All DPV studies were recorded in 0.1 M PBS (pH = 7.0) by applying the potential window from -0.3 to -0.9 V with optimized pulse amplitude (0.05 V) and pulse width (0.05 s). Fig. 4d shows the DPV studies of NCN modified GCE from low concentration to high concentration of MP, it is obvious to see when increases the concentration of MP incrementally the reduction current also increases systematically. It can be observed from Fig. 4d the reduction potential of MP is shifting towards negative potential when increase the addition of higher concentrations. This factor is mainly arising from the (i) adsorption of analyte (MP) in NCN surface confinement or in other words a thin film formation of analyte on the surface ahead of diffusion layer and (ii) higher concentration of MP increases the solution resistance hence the tiny amount of ionic conductivity deviates, it may shift the peak potential. Furthermore, the determination of MP was evaluated from the calibration plot of reduction current vs. the concentration of MP (Fig. 4d (inset)) where two linear curves obtained over the concentration range of 0.0025 to 1µM and 1 to  $100 \mu$ M. From these two linear concentration ranges, the sensitivity of the fabricated sensor was calculated as 72.4 nA/µM and 10 µA/µM respectively. The fabricated electrochemical sensor exhibits a low detection limit of 0.068 nM and presents a wide linear concentration range from the two different concentration ranges of MP. This study confirms the proposed fabricated sensor was effectively determined the MP over the wide range of concentrations and displays a foremost platform to the practical applications. In order to evaluate the performance of fabricated sensor, it was compared with previous reports and provided in (Table 1).44-53 A high linear concentration range and very low detection limit was observed for the fabricated sensor when compared with previously reported materials. It can be seen that from the above studies, the

Modified electrodes	<b>Detection limit</b>	Linear concentration	References
	( <b>nM</b> )	range (µM)	
Au/MWCNTs electrode	190	1.9 to 61	44
MWCNTs-Chitosan/GCE	19	0.19 to 7.6	45
Silicate-CTAB/GCE	10	10 to 100	46
ZrO <sub>2</sub> /CPE	7.6	0.019 to 11	47
OMC/GCE	7.6	0.09 to 61	48
pSC6–Ag NPs/GCE	4.0	0.01 to 80	49
MWCNTs-PAAM/GCE	2.0	0.005 to 10	50
GdHCF/GNs/GCE	1.0	0.008 to 10	51
Au ACs/Au	0.65	0.01 to 80	42
SH-CD/AuNPs/SWCNTs/GCE	0.1	0.002 to 0.08	52
ZnO/Ag/MPTMS/OHP	0.07	0.0025 to 75	53
N-doped carbon/GCE	0.068	0.0025 to 1, 1 to 100	Present work

NCN modified GCE manifests a superior electrocatalytic performance towards the determination MP.

**Table 1.** Comparison on the performance of NCN modified GCE with other previous reported works towards the detection of methyl parathion.

# 3.5. Interference studies

To examine the selectivity of fabricated sensor, the interference studies were carried out for the potential interfering ions such as other nitro aromatic compounds and common ions. Fig. 5 depicts the interference currents for 10-fold excess of paraxon, fenitrothion, nitrobenzene (NB), p-nitrophenol (NP), nitroaniline (NA) and 100-fold excess of Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup>, PO<sub>4</sub><sup>3-</sup>, NO<sub>3</sub><sup>-</sup>, Cl<sup>-</sup> in the presence of constant concentration of 10  $\mu$ M MP. From the observed results, the fabricated sensor was showed the interference current less than 5% for other nitro compounds and no significant current changes for the common ions. The present study stated that the NCN modified GCE electrode exhibits selective detection towards MP and endorsed that the hired material for practical applications.



**Fig. 5.** Interference studies for NCN modified GCE in 0.1 M PBS containing MP in the presence of other potential interfering compounds namely (a) paraoxon, (b) fenitrothion, (c) nitrobenzene, (d) p-nitrophenol, (e) nitroaniline, (f) Na<sup>+</sup>, (g) K<sup>+</sup>, (h) Ca<sup>2+</sup>, (i) PO<sub>4</sub><sup>3-</sup>, (j) NO<sub>3</sub><sup>-</sup> and (k) Cl<sup>-</sup> in the concentration of 10 and 100-fold excess with MP for (a-e) and (f-k) respectively. 3.6. *Oxygen reduction reaction on NCN modified GCE* 

To assess the ORR catalytic activity, the NCN modified GCE was subjected to CV in  $N_2$  and  $O_2$  saturated 0.1 M NaOH. Fig. 6a exhibits the strong electrocatalytic oxygen reduction curve for NCN modified GCE at -0.147 V vs Ag/AgCl in the presence of  $O_2$  which is low overpotential compare to conventional carbon electrodes.<sup>7</sup> In contrast, the obtained ORR curve is obviously different from its background current in  $N_2$  saturated 0.1 M NaOH, where NCN modified GCE shows only double layer capacitance behavior. The performance of NCN modified GCE was compared with commercially viable and state of the art catalyst: platinum.



**Fig. 6.** Cyclic voltammograms of (a) NCN modified GCE in presence of nitrogen and oxygen saturated 0.1 M NaOH. (b) Commercial Pt/C and NCN modified GCE in the presence of oxygen saturated 0.1 M NaOH. (c) RDE voltammograms of NCN modified GCE at various rotations. (d) KL-plot for the steady current obtained from the RDE voltammograms for NCN modified GCE.

Remarkably, the NCN modified GCE reveals only 130 mV overpotential compare to commercial Pt/C catalyst and also shows the similar electrocatalytic current for ORR (Fig. 6b). The ORR activity of NCN modified GCE electrode furnishes excellent electrocatalytic current compared to the previously reported N-doped carbons.<sup>8,15</sup> Moreover, the RDE measurements were used to analyze the ORR kinetics of NCN modified GCE in O<sub>2</sub> saturated 0.1 M NaOH. Fig. 6c depicts the linear sweep voltammetry (LSV) of NCN modified GCE for various rotation rate. The NCN modified GCE reveals the one step oxygen reduction with the plateau of steady state diffusion current for all rotations. The kinetic parameters and electron transfer were evaluated by the Koutecky–Levich (KL) equation. Fig. 6d shows the KL plots for the NCN modified GCE, it follows the linearity and parallelism which suggested that obtained ORR is first-order reaction kinetics with respect to the concentration of dissolved oxygen. In addition, each rotation has an almost identical electron transfer numbers for ORR at different potentials. The number (n) of

electron transfer was calculated to be  $\sim$ 3.98 to 4.02 from the slopes of KL plots for the different potentials from 0.45 to 0.65 V. This observed electron transfer number suggested that NCN modified GCE favors a 4e<sup>-</sup> oxygen reduction process, unlike the other carbonaceous materials. Hence, it can be used as an alternative material in fuel cells for cost effective and rare earth abundant platinum.

# 3.7. Mechanisms of ORR and MP detection

The NCN modified GCE exhibits diversity of applications by its divergent properties due to the different bonding environment of nitrogen atoms in carbon lattice. As mentioned earlier, the nitrogen atoms possess two major components in NCN such as pyrrollic and pyridinic nitrogen (Fig. 1a).



**Scheme 2.** (a) Plausible mechanism for the reduction of MP. (b & c) Delocalization of the electron clouds on the carbon atoms in pyridine and pyrrole.

Commonly, pyrrole is known for electron rich aromatic ring and basic in nature which provides the ground for MP adsorption. The nitro group of MP was easily attracted by C-3 position in pyrrole, because that position is highly electron rich in pyrrole (scheme 2c). Following the

adsorption, the MP was directly reduced to arylhydroxylamine by proton coupled four electron transfer (PCET) and the as-reduced compound was further oxidized into arylnitroso group. In contrast, bare GCE also following the same reaction pathway; however, the aforementioned mechanism provides a better understanding about the reaction. In NCN, the pyrrole ring initiates the reaction, hence the activation energy has reduced, therefore NCN modified GCE reduces MP at low overpotential comparable to bare GCE.

On the other hand, the electron deficient pyridinic nitrogen furnished the bonding site for the dissolved oxygen molecule. The sp<sup>2</sup> character of nitrogen in pyridine gives the room for a localized electron hence the ortho and para position of pyridinic group in NCN attains much electropositive and welcomes the oxygen molecule (scheme 2b). The adsorbed oxygen molecule was further reduced via four electron transfer, usually un-doped carbons are well known for the hydrogen peroxide production (via two electron pathway).<sup>43</sup> The N-doped carbons manifest four electron transfer by the effective adsorption of oxygen molecules and the electrostatic interaction between the  $\pi$  –orbital and electrons of pyridinic nitrogen. This mechanistic study exhibits how the NCN modified GCE employed to a diversity of applications and suggests the possible interactions with both MP and oxygen.

# 4. Conclusions

In summary, we have demonstrated the simple and reliable method to prepare the nitrogen doped carbon for an energy and sensor applications. In described method, we follow the flame synthesis to produce the nitrogen doped carbon from the nitrogen containing organic aromatic compound namely pyrrole. Besides that, many different heteroatom doped carbons have to be synthesized from the aforementioned method by varying the precursor compounds. A meticulous evaluation of the as prepared compound (NCN) exhibits a superior electrocatalytic activity towards the detection of MP and ORR. Moreover the NCN modified GCE exhibiting the reasonable activity towards the determination of MP and acceptable level of performance compared to previous reports. Furthermore, NCN modified GCE reveals a superior electrocatalytic activity towards ORR as similar with the commercial Pt/C catalyst. Hence, the present study paves a diversity of applications handled by the single compound and also motivates the metal-free catalyst for practical applications.

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# Title of the content

Schematic representation of the nitrogen doped carbon, the action on methyl parathion and molecular oxygen by its local electron rich and deficient sites of pyrrole and pyridine.

