

 Tampere University of Applied Sciences



齊魯工業大學  
QILU UNIVERSITY OF TECHNOLOGY



# The synthesis and characterization of polyaniline nanocomposite

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Bachelor's thesis  
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Bioproducts and Process Technology

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## ABSTRACT

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Attracted by the increasing demand of batteries, sensors and supercapacitors, great efforts have been paid to the development of nanocomposite material with low cost, high energy density, high stability, easy processability.<sup>1</sup> Polyaniline(PANI) is a special kind of electroactive conducting polymer, showing great electrochemical performance, such as redox reversibility and high conductivity<sup>7</sup>. Besides, due to its environmental stability, low cost, and easy processability, PANI has been regarded as a potential material for flexible electronics and many researchers reported on it by interesting on the redox properties. However, due to the structural instability, its cycling performance is still an insurmountable challenge. Reasonably designed nanostructured conductive polymers are considered to be the most promising materials to have high electrochemical performance<sup>7</sup>. Nanocomposites of conductive polymers and metal oxides, especially transition metal oxides, can be used in catalysis, sensing, energy and other fields. Herein, PANI is combined with  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> nanoparticles by electropolymerization, and further studies on the properties of the nanocomposites are analysed by Cyclic Voltammetry(CV), UV-vis, FTIR, etc.

As a most standard electrochemical technique tool, CV described the performance of electrodes and characterize electron transfer. For CV, generally three electrodes are used to obtain accurate results. On the other hand, CV has key advantages which include quick operation time, low cost and simplicity in preparation<sup>5</sup>. This study demonstrates the synthesis and properties of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/polyaniline nanocomposite as high-performance materials in various applications. The overall analysis confirmed that the prepared  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI nanocomposite material has better performance in terms of capacitance and conductivity in supercapacitors, batteries, etc.

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**Keywords:**  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/Polyaniline; Cyclic Voltammetry; electrochemistry

## 摘要

随着对电池、传感器和超级电容器需求的不断增长，人们致力于开发低成本、高能量密度、高稳定性、易加工的纳米复合材料，此外，聚苯胺具有环境稳定性好、成本低、易加工等优点，被认为是一种很有潜力的柔性电子材料，许多研究者对其氧化还原性能进行了研究。

然而，由于结构的不稳定性，其循环性能仍然是一个不可克服的挑战。合理设计的纳米结构导电聚合物被认为是最有希望获得高电化学性能的材料。导电聚合物与金属氧化物特别是过渡金属氧化物的纳米复合材料可以应用于催化、传感、能源等领域。在此，PANI与 $\alpha$ -采用电聚合法制备了 $\text{Fe}_2\text{O}_3$ 纳米颗粒，并用循环伏安法（CV）、UV-vis、FTIR等对纳米复合材料的性能进行了进一步的研究。

CV作为一种最标准的电化学技术工具，可以用来描述电极的性能和表征电子转移。对于CV，通常使用三个电极来获得准确的结果。另一方面，CV具有操作时间快、成本低、制备简单等优点。 $\alpha$ - $\text{Fe}_2\text{O}_3$ /聚苯胺纳米复合材料作为一种高性能材料，有着广泛的应用前景。总体分析证实，该方案是可行的。 $\alpha$ - $\text{Fe}_2\text{O}_3$ /PANI纳米复合材料在超级电容器、电池等方面具有良好的电容和导电性能。

关键词： $\alpha$ - $\text{Fe}_2\text{O}_3$ /PANI, 循环伏安法, 电化学。

## 1 INTRODUCTION

Electrochemistry, as a branch of physical chemistry, is concerned with the relation of electricity and chemical change, describing the electrochemical performance of materials and is applied in many fields. Many chemical reactions involving electron transfer, some of them are used in batteries and fuel cells for energy storage and convert. Nowadays, electrochemistry is continuously innovated and it plays an increasing important role in industrial fields, such as energy storage, environmental analysis, and material science, particularly, rapid development of fuel cells and new energy vehicles opens a new approach for electrochemistry. The electro synthesis of nanomaterials is one of the cores of the development.

Typically, the first polymer which has great conductivity was polyacetylene discovered in the year of 1974 and this discovery started the development of many other conductive organic polymers in various fields. In spite of traditional organic polymers, conducting polymers obtain some special features like electrical redox activity, higher affinity, etc. Therefore, polymers with high conductivity have been synthesized in the last few decades <sup>23</sup>.

Conducting polymers are composed of monomers units with conjugated bonds under doping condition which enables the electron conductivity of the polymer. They used to be considered as good electrical insulators and have a variety of insulating applications. Researches proved that some polymers exhibit high conductivity and can be used to replace metals in various applications. <sup>7</sup>These materials include  $\pi$ - electronic skeleton controls unusual electronic properties, such as conductivity, low energy optical transition, high electron affinity and low ionization potential. In addition, such an extension  $\pi$ -conjugation system of conductive polymer has alternating single bond and double bond consistent with the polymer chain. And it is noted that the conduction mechanism of the polymer is quite complicated as their conductivity is about 15 orders of magnitude, and they show greater electrical conductivity via multiple orders of magnitude. (Recent developments in conducting polymers: applications for electrochemistry - RSC Advances (RSC Publishing)) Such properties can create beneficial utilization in diverse fields of applied electrochemistry such as supercapacitors, lithium-ion batteries, fuel cells, and solar cells. Apart from these, recently, conducting polymers are applied in electrochemical

sensors and biosensors as electrochemical cells which contained two or three electrodes for drug analysis, environmental pollution analysis, food analysis, etc. Many researches were carried out to investigate conducting polymers like (Polypyrrole) PPy, PANI, Polythiophenes(PThs), and their derivatives because of their excellent conductivity and electroactivity. Some experts also found that it is necessary to design the nanostructure. Traditionally, the advantages of polymeric material are that they can be obtained on a large scale at relatively low cost <sup>16</sup>. Thus, conducting polymer has attracted much attention.

### **1.1 Physical and chemical properties of PANI**

As a representative from the conducting polymer family, PANI is an excellent conductive functional material. In this brief explanation, PANI is used as a model material to investigate the electrochemical performance, synthesis, applications of conducting polymers <sup>16</sup>. Conducting PANI exhibits fantastic properties, such as good convertibility, and high conductivity.

Its own chemical structure is relatively unique and has good chemical and thermal stability. The economic cost is relatively low when used, and it has received extensive attention. PANI is a kind of irregular powder with low crystallinity and molecular orientation at room temperature. Similar to other conducting polymers, it also belongs to conjugated polymer. On the main chain of PANI, a chain with large electron delocalization is formed p- $\pi$  conjugate. The conductivity of the intrinsic polyaniline is very low and the conductivity can be increased by 12 times through the doping of protonic acid. The properties of PANI is highly affected by its preparation methods, PH value of electrolyte. Conducting PANI will deprotonate in alkaline or neutral conditions, and lose its electrical activity, therefore, the electrochemical properties of conducting polyaniline are generally studied under acidic conditions. PANI shows great electroactive properties, such as electrochromic, electrochemical redox behavior and catalytic activities <sup>7</sup>. It is unique because it is the only polymer that can exist in different form according to electrolyte. PANI has different oxidation states, and the most stable one is called emeraldine. Five oxidation states of PANI were proposed: Leucoemeraldine, protoe meraldine, emeraldine, nigraniline and pernigraniline, which are different in the degree of oxidation <sup>4</sup>.

The forms of PANI have different colors, stabilities and conductivities. As shown in Fig 1, when  $y = 1$ , it corresponds to the completely reduced state (Leucoemeraldine base). When  $y = 0$ , it is the highest oxidation state (Per-nigraniline base). When  $y = 0.5$ , it is the intermediate oxidation state (Emeraldine base)<sup>24</sup>.

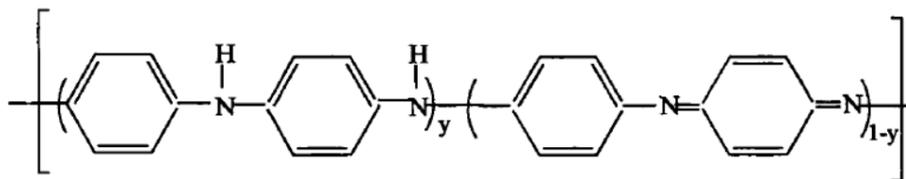


Figure 1: The Chemical Structure of Polyaniline (The value of  $y$  indicates the redox degree of polyaniline, ranging from 0-1.)

## 1.2 The application of PANI

As one of the most studied conducting polymers, PANI possesses many merits, including corrosion resistance, low cost, great environmental stability, and special proton transfer mechanism<sup>7</sup>. Due to its outstanding conductivity, storage capacity, environmental stability, high specific capacitance due to a variety of redox states and biocompatibility, and the advantage of nano size, the polymer has become an ideal candidate for high-performance environmental energy storage device<sup>15</sup> and it is widely recognized as a promising material in electronics.

In general, PANI has been extensively used in solar cells due to its outstanding conductivity, facile synthesis and low price. Microporous PANI electrode showed better electrocatalytic activity than Pt electrode because of its higher electrocatalytic activity and lower charge transfer rate of redox reaction. The porosity of PANI increases the specific surface area of solar cells, which improves the catalytic activity and trapping efficiency of liquid electrolyte. The polymerization of polyaniline on graphene surface increased the electric active region and total conductivity of polyaniline; Therefore, it improves the electrocatalytic activity of solar cell as electrode<sup>7</sup>. On the other hand, PANI is a widely studied conducting polymer for pseudocapacitors due to its low cost, easy synthesis, stable environment and high specific pseudo capacitance related to various redox states. The electrochemical characteristics of solid-state

pseudo capacitor cells show that the specific capacitance of nanotubes is the highest among all PANI forms (367F/g, 5mV/s). At high current density of 5A<sup>-1</sup>, 1000 GCD cycles can be successfully cycled in PVA / H<sub>2</sub>SO<sub>4</sub> electrolyte to maintain more than 91.5% capacitance <sup>15</sup>. It is highly recognized that PANI is optimal electrode material for stretchable energy devices <sup>5</sup>.

In addition, due to its environmental stability, biocompatibility and electron transfer mediation in redox reaction, PANI is employed as an effective material in biosensor. Diabetes is one of the biggest healthy problems which poses great threats to us, therefore, glucose control is the main issue in PANI-based biosensor construction.

The sensor based on PANI is used as electronic tongue, which is composed of six / seven sensors. It is used to detect taste, and it is as effective as human tongue to improve the product quality of food industry <sup>6</sup>.

However, the applications of PANI in various fields of engineering and electronics are limited because of its poor physical properties, more specifically, during the insertion and deinsertion process of the counter ions, the shrinkage and swelling of PANI may cause volume changes and backbone breaks, affecting the charge-discharge cycle life. When fibrillary PANI is applied to design a rechargeable battery with a specific energy on the basis of the composite material, the main drawback is the low stability during recharging process, which means higher batteries lose percentage specific energy per cycle owing to the degradation of polyaniline. <sup>2</sup>Therefore, the use of polyaniline is limited because of these weak properties and more attention has been paid to the innovative of polyaniline composite materials.

### **1.3 The application of $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI nanocomposites**

To overcome its drawbacks, scientists made great efforts to enhance the properties. For example, PANI is used more frequently to combine other materials to form a smart material, and it is recommended to fabricate PANI with carbon nanotube, transition metal oxides(TMOS) or metal oxides, which enhances electrochemical performance through increasing the strength and conductivity <sup>12</sup>. Graphite is considered as an excellent carbon substrate as it is highly conducting and having high surface area. Flexible graphene-PANI composite paper exhibits excellent supercapacitor performance with higher specific capacitance and good cycling stability. <sup>1</sup> The graphene-PANI paper as

supercapacitor electrode has better electrochemical performance than pure graphene or PANI component and possesses advantages of easy-processability, and excellent energy-storage performance. And it provides a promising and efficient way to produce high-performance for energy storage device applications<sup>1</sup>. However, as the price of graphene is expensive and the fabrication of graphite is very complex, it is not regarded as the ideal material for mass production<sup>3</sup>. Among them,  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> is one of the most competitive materials, and the theoretical specific capacity of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> is as high as 1005mAh/g. More importantly, the content of Fe in the crust is very abundant, the cost of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> is low and also environmental-friendly.

$\alpha$ -Fe<sub>2</sub>O<sub>3</sub>(hematite) nanoparticle is widely used as an electro-active material to increase electrochemical rate properties. For example, energy problems pose a great threat to the industries, and it is an urgent issue to develop high-efficiency batteries.  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> nanoparticle is proved to be an important material in Lithium batteries as it has relatively higher capacity (1005mAh/g) and can work as an efficient anode material in batteries. The application of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> nanoparticle in batteries is one of the approaches to alleviating the energy problem. As a reliable material,  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> is naturally abundant and environmental friendly, therefore, it can be easily obtained and prepared. It is informed that the combination of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI nanocomposite attracts much attention in industrial applications. In reality, the combination of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> and PANI is used in many fields. PANI based polymer is a kind of conductive sensing material because of its inherent microstructure, which makes it form stable colloid with other materials<sup>18</sup>. In recent years, Fe<sub>2</sub>O<sub>3</sub> with PANI is regarded as sensitive material for gas sensors to achieve the room temperature detection of gases with ideal sensing performance. For example,  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI nanocomposite sensor has higher response (relative resistance change of 30~70% towards 10.7 ppm of NH<sub>3</sub>) and excellent selectivity towards the detection of NH<sub>3</sub> at room temperature (20°C). The results show that the  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> / PANI nanocomposites have 50% relative resistance variation and medium selectivity for NH<sub>3</sub> with 100ppm at room temperature. It was reported that the nanocompo-

site sensors have dramatically fast response to low concentration of  $\text{NH}_3$ . Obviously, more work is needed to enhance the sensor behaviors by effective design and functional structure <sup>8</sup>.

It is known that polyaniline may suffer from limited long-term stability during cycling process due to the expansion and contraction of polymers lead to degradation in capacitance, restricting these low-cost supercapacitor electrode material from commercial point. It is generally acknowledged that supercapacitors have been widely used as an essential instrument for energy storage and could achieve higher capacitance than the conventional capacitors and better power density compared to the batteries. As an electrode material for supercapacitors, at the scanning rate of 2mV/s, the maximum specific capacitance of  $\alpha\text{-Fe}_2\text{O}_3/\text{PANI}$  is 974F/g with the current density of 0.2A/g by using CV. Furthermore, the energy density of the composite material is as high as 118Wh/kg, while the maximum power density is 9.8kW/kg and the cyclic stability is about 94% after 2000 cycles. These properties indicate that  $\alpha\text{-Fe}_2\text{O}_3/\text{PANI}$  nanocomposite is a promising electrode material for energy storage system <sup>8</sup>.

At the same time, PANI has been considered a valuable electromagnetic wave absorption material due to its high conductivity, low density and great environmental stability. As electromagnetic interference has become an urgent issue and posed threats to our health, recently, considerable efforts have been made to develop the high performance electromagnetic absorber waver, like carbon materials, magnetic materials and conducting polymers. PANI can also induce low thickness absorbing materials, which provides a research strategy for the future research of ideal absorbing materials. However, pure polyaniline has high complex permittivity and low complex permeability, resulting in poor impedance matching. In order to avoid this shortcoming, we can introduce other dielectric or magnetic materials into polyaniline to prepare high-performance electromagnetic wave absorbers. Thus,  $\alpha\text{-Fe}_2\text{O}_3/\text{SnO}_2@\text{polyaniline}$  composites were synthesized by the combination of hydrothermal reaction and emulsion polymerization route <sup>18</sup>. The composites have outstanding electromagnetic wave absorption ability with the maximum reflection loss at 2.7mm is - 50.3db. It was also found that coupling graphene nanosheets could dramatically improve its properties, and it shows that

RGO/thorns-like PANI/ $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>@SiO<sub>2</sub> nanocomposites works as a novel electromagnetic material although the use of it have not been reported yet <sup>18</sup>.

#### 1.4 The polymerization methods

$\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI can be prepared by many methods, including chemical oxidation, enzymatic method, electrochemical method, etc. Among them, electropolymerization is a relatively easy and effective technique for synthesis of polymer composites. The electropolymerization of PANI was electropolymerized in the electrolyte solution. The oxidation polymerization takes place on the working electrode and the aniline film is deposited on the electrode surface. Electrochemical synthesis methods include cyclic voltammetry (CV), Chronoamperometry, etc.

As the most standard and common method in electrochemical polymerization, CV is the most widely used technique to obtain qualitative information of electrochemical reactions and it can show the information of redox potential of the electrochemical substance <sup>19</sup>. A CV system is made of an electrolysis cell, a current-to-voltage converter, a potentiostat, and a data acquisition system. The most important part is the electrolysis cell, which consists of a working electrode, reference electrode, counter electrode and electrolyte solution <sup>7</sup>. In general, the method includes applying a potential to a working electrode immersed in an electrochemical cell also containing an electrolyte solution and having a reference electrode, a counter electrode <sup>8</sup>. In the polymerization process, the extension of PANI chain begins with the formation of nonconductive PANI, that is, the formation of fully reduced leucoemeraldine (oxidation state  $n = 1$ , which can be found in Figure 1), and ends with the formation of the most conductive PANI form of emeraldine (oxidation state  $n = 0.5$ ) <sup>8</sup>.

The polymerization is usually carried out in acidic aqueous solution, herein, H<sub>2</sub>SO<sub>4</sub> is used. Studies show that the medium of the polymerization affects the properties of the PANI. For example, the yield and conductivity of PANI in the form of emeraldine salt prepared in acidic medium can be improved by reducing the ionic strength of acid <sup>8</sup>. In fact, in acidic solution, it is founded that PANI with good quality can be formed. In aqueous salts, such as KCl, copper nitrate and sodium sulfate have been used as well. The CV curve is obtained by measuring the current at the working electrode during the scanning process and the potential of the working electrode is measured against a reference

electrode, which always keeps as a constant. The working electrode's potential is changed linearly with time while the potential of reference electrode maintains as a constant. The counter electrode is responsible for conducting electricity from the signal sources to the working electrode, while the aim of electrolyte solution is to provide ions to the electrodes during the reactions.<sup>8</sup> In this paper, the target composite film was electropolymerized on the working electrode when H<sub>2</sub>SO<sub>4</sub> worked as electrolyte and then the electrochemical properties of the composites analyzed in KCl by CV. By analyzing the variation of peak positions as a function of scan rate, and it is possible to estimate the current density and capacitance of the nanocomposites, thus, the electrochemical properties of the target material can be analyzed.

The purpose of this experiment is to synthesize  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI nanocomposite by electropolymerization, study its electrochemical performance by CV, FTIR, UV, etc. and analyze its performance to apply in industrial fields as great electrochemical materials.

## 2 EXPERIMENTAL

### 2.1 Materials

The reagents used in the experiment were aniline, H<sub>2</sub>SO<sub>4</sub>, KCl, α-Fe<sub>2</sub>O<sub>3</sub> nanoparticles. KCl, aniline and α-Fe<sub>2</sub>O<sub>3</sub> were purchased from Shanghai Aladdin Biochemical Technology Co., Ltd. Distilled water was used throughout the work.

0.01/0.1/1M H<sub>2</sub>SO<sub>4</sub> were prepared for 50ml as electrolyte in the polymerization process respectively. The concentration of aniline was 50mM, and 227ul aniline was added into H<sub>2</sub>SO<sub>4</sub>, and ultrasonic treatment for 15min to form the uniform 50 ml PANI-H<sub>2</sub>SO<sub>4</sub> solution.

α-Fe<sub>2</sub>O<sub>3</sub> nanoparticle (159.69mg) was dissolved in water (100ml) and transferred into a volumetric flask(100ml), followed by ultrasonic treatment for 15minutes. It is noted that α- Fe<sub>2</sub>O<sub>3</sub> is insoluble in water, therefore, ultrasonic treatment is necessary.

The electrochemical characterization was tested in KCL, therefore, 3.7275g KCl was weighted and 0.1M KCl was prepared in the volumetric flask(500ml).

FTIR IS 50, a fully functional material analysis workstation with special accessories and integrated software, was purchased from the company of Thermo Scientific.

Electrochemical workstation was purchased from Ivium Technologies, Netherlands. Herein, electrochemical workstation worked as the most important instrument in synthesis, analysis and measurement.

UV spectrophotometer 2800S was purchased from Shanghai Sunny Hengping Scientific Instrument Co., Ltd.

In an electrochemical experiment, electrochemical reactions are taken place in a solution in a cell, and the electrical response is measured. All electrochemical measurements were carried out at the room temperature by electrochemical workstation. SCE and Ag/AgCl were always utilized as reference electrode, the platinum and graphite rode electrode was employed as counter electrode, and glassy carbon and ITO glass were used as working electrode.

### 2.2 Electrochemical Measurements

#### 2.2.1 The setup of CV

The instrument for CV methods is electrochemical workstation, in addition to cyclic voltammetry, it can also be used for AC impedance, AC voltammetry,

current titration and potentiometric titration. In this work, the electrochemical measurements were carried out in the cell with three electrodes. The workstation can work with three electrodes at the same time. The working principle of electrochemical working station is to control the potential difference between the working electrode and the reference electrode by putting current into counter electrode.

CV is a method commonly used for the electrochemical characterization of conductive material. Particularly, this type of voltammetry is useful for electrochemical behavior studies, such as reduction and oxidation potentials. The curves of CV and peak position can show whether the reaction is a reversible or an irreversible process. However, CV is not as appropriate for qualification analysis because the limits of detection and qualification are higher than those of other types of voltammetry. Cyclic voltammetry refers that the potential applied on the working electrode starts from the original potential  $E_0$ , scans to a certain potential  $E_1$  at a certain speed  $V$ , and then scans to the original potential  $E_0$  in the opposite direction. The parameters are set according to the requirements of the experiment. Generally, the potential range, scanning rate, number of scanning cycles and current range need to be determined before the experiment. As shown in the figure, there is a cathodic reduction peak in the negative scanning direction, which corresponds to the reduction of oxidized substances. Accordingly, the anodic oxidation peak appears in the positive scanning direction, which corresponds to the oxidation of reduced substances.

Same as other voltammetric methods, cyclic voltammetry employs a three-electrode system including reference electrode, which serves as a standard, working electrode, which is the sample material being tested, and counter electrode for passing a current. Basically, in CV, a certain sweeping potential is applied to the solution containing the target compound and performed at varying scan rate, obviously, herein,  $\alpha\text{-Fe}_2\text{O}_3/\text{PANI}$  is tested. The sweeping process is repeated many cycles under different potentials and scan rates, and real-time current between counter and working electrode is recorded by the device. The generated current is the result of the electron transfer between redox species and electrode and this process is done by the ions migration

through the solution. There is no current passing between the reference electrode and working electrode and the current on the working electrode is balanced with the current passing through the counter electrode, which is required to have a larger surface area. The typically curve of CV is characterized as duck-shaped<sup>8</sup>.

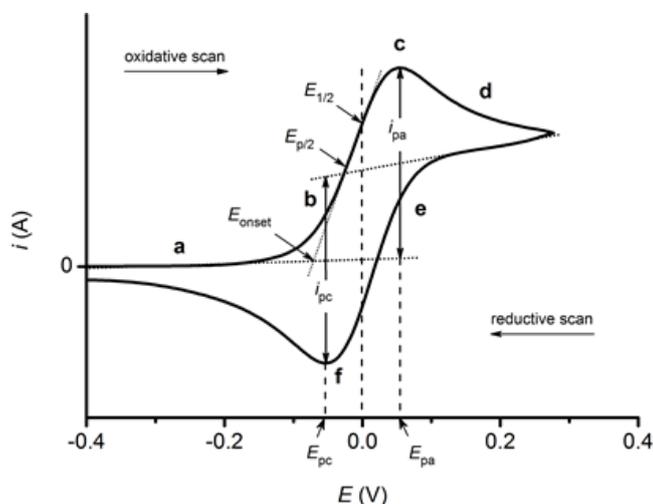


Figure 2: Duck-shaped CV curve

In Figure 2, it is obvious that the reaction is reversible, because the curve is symmetric, and if the curve is not symmetric, then the reaction is irreversible.  $i_{pa}$  and  $i_{pc}$  represent cathode peak current and anode peak current respectively, while  $E_{pa}$  and  $E_{pc}$  are cathode peak potential and anode peak potential.<sup>8</sup>

In order to have enough ionic strength for the solution, excessive inert ions are added to work as electrolyte and it is better to choose the highly purity solvent, like distilled water. In this experiment,  $H_2SO_4$  and  $KCl$  is common used as electrolyte to increase the conductivity.

The working electrode and counter electrode have to be conductive to make sure that charges move through the solution, at the same time, they cannot have any chemical reactions in the solution. Therefore, Pt and Graphite rod is chosen to be counter electrode to achieve inertness and they are required to have large surface area to ensures that the measured current corresponds to the current between the working electrode and the counter electrode. Glassy carbon and ITO glass are promising materials for working electrode. The performance of ITO/PANI and Glassy Carbon/PANI was also found sensitive and reproducible by using CV.

The reference electrode is arranged in the cell to make sure that it is in the circuit opposite to the reference electrode and the working electrode. And the reference electrode must have a known and stable potential. Its high stability is achieved by using an oxidation-reduction system, which must contain a saturation concentration in each solution involved in the reaction. Reference electrode can be divided into aqueous, calomel, non-aqueous and self-assembled reference electrode. The most common used reference electrodes are the standard calomel electrode(SCE), Ag/AgCl electrode and normal hydrogen electrode. Herein, SCE and Ag/AgCl is used frequently. ([Cyclic Voltammetry Explained: Basic Principles & Set Up | Ossila](#))



Figure 3: Three electrode cell as used in CV.

### 2.2.2 FTIR spectrum

Spectral analysis is a kind of optical analysis methods based on the absorption and emission of different wavelengths of lights. FTIR spectrum is one of the most common tools in spectral analysis. FTIR stands for Fourier transform infrared, which is used to identify material's components, quality, consistency, etc. The principle of is the unique combination of each atom. Because each material has different components and structure, an infrared spectrum represents the fingerprint of a sample and the absorption peaks correspond to the vibration frequency between the atomic bonds of the materials. Thus, FTIR can definitely identify each material with qualitative analysis by modern software algorithms. FTIR uses a beam splitter to divide the incident infrared beam into two pieces of beams. A beam of light is reflected from a plane mirror fixed in place. And another beam is reflected from a flat mirror on a mechanism that

allows the mirror to move a short distance (usually a few millimeters) from the beam splitter. The two beams are reflected from their respective mirrors and recombined when they meet at the splitter. Because the propagation path of one beam of light is fixed length, and the other beam of light changes with the movement of its mirror, the signal leaving the interferometer is the result of mutual interference between the two beams of light. The resulting signal is called interferogram, which has a unique characteristic, that is, each data point (a function of the position of the moving mirror) of the signal has information of each infrared frequency from the source. <sup>22</sup>

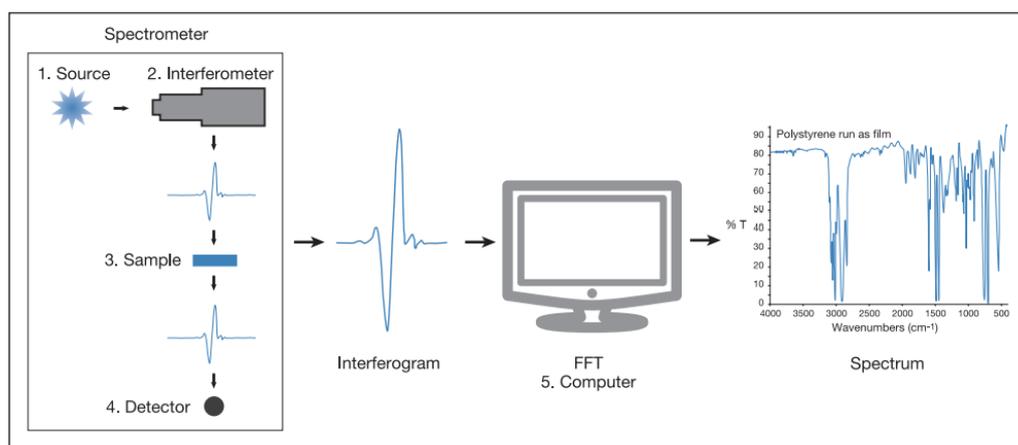


Figure 4: The sample analysis process

The advantages of FTIR is that, firstly, the measurements are made in a few of seconds instead of several minutes, which is faster than other methods; secondly, the detectors are very sensitive, so that accurate results can be obtained; finally, FTIR employs a HeNe reference laser as an internal wavelength calibration standard, and it can be calibrated by itself <sup>15</sup>. Herein, the nanocomposites were analyzed by FTIR and the chemical structure of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> can be confirmed by FTIR.

### 2.2.3 UV spectrum

UV-visible spectrophotometry is widely used in chemistry for the analysis of the species and process study. It is mainly a quantitative analysis technology, involving the absorption of near ultraviolet (180-390nm) or visible (390-780nm) radiation by chemical substances in solution. Under controlled conditions, the absorbed radiation is directly related to the concentration of substance in the solution and it can be used to quantify organic and inorganic species. The

principle is that ultraviolet light causes the transition between quantized energy levels in matter, resulting in the change of wavelength and intensity of emission, absorption or scattering radiation.

Ultraviolet visible absorption method is mainly used for the quantitative analysis of atoms. Based on the absorption peak, the component of the substance can be analyzed.

What is more, here, UV Spectrophotometer and electrochemical workstation was combined, generally, this method is called spectroelectrochemistry. As it implies, spectroelectrochemistry is simply the combination of spectroscopy and electrochemical analysis methods. The UV spectrum test and electrochemical performance test were carried out at the same time. The principle is that the spectrum changes under CV measurements scanning can be obtained and the components of substance in the detection solution changes with the change of redox reaction. The instruments is assembled and this system meet the requirements of conventional experiments, and have good performance. (Spectrophotometry - an overview | ScienceDirect Topics) The absorption of the ultraviolet visible region in the spectrum makes the electrons in the outermost occupied orbit of the atom or molecule

### **2.3 The preparation of $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI nanocomposites**

The very beginning step of the preparation is the pretreatment of the electrode. A simple electrochemical pretreatment has been developed to remove the contaminants from the electrode surface. Take Pt electrode as an example, before using the electrode, 0.3 and 0.05 micro Alumina particles should be used to polish the electrode with the shape of 8 for 2-3 minutes. After polishing, the electrodes are usually rinsed with a large amount of water. At the same time, the cell and electrolyte should be clean, and the reference electrode should be stable. In the process of using the electrode, pay attention to protect the electrode surface, and it is necessary to avoid forming scratches. It has to be considered that oxygen must be removed from the solution, generally, high purity of N<sub>2</sub> is injected into the solution for at least 15 minutes. The electrochemical performance of PANI should be first studied and PANI material was synthesized by chemical oxidative polymerization by the method of CV. The setup of the parameters in the electrochemical workstation, like potential, scan rate, etc. need to constantly adjust according to the graphics displayed in the

electrochemical workstation window. The experiment was reacted in 0.01M, 0.1M, 1M H<sub>2</sub>SO<sub>4</sub> as electrolyte with the different potential range. The scan rate was 50 mV/s for 20 cycles. PANI was synthesized on the working electrode and working electrode was rinsed with a large amount of water. Then, the electrode was scanned in 0.1M KCl for 3 cycles with the scan rate 10, 20, 50, 100, 200mV/s to test the electrochemical properties. Herein, H<sub>2</sub>SO<sub>4</sub> is able to enhance the conductivity of the electrolyte and it does not cause any side reactions, what is more, the potential measurement range of H<sub>2</sub>SO<sub>4</sub> is large. Thus, H<sub>2</sub>SO<sub>4</sub> works as an ideal electrolyte in the process of electropolymerization.

The electropolymerization of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI nanoparticles were synthesized in a similar way. The volumetric ratio of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> nanoparticle and PANI-H<sub>2</sub>SO<sub>4</sub> solution was determined by the formula: 1: 2<sup>n</sup>(1≤n≤6). For example, in the first group, the volume of PANI-H<sub>2</sub>SO<sub>4</sub> solution is 7.5ml, and the volume of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> nanoparticle should be 7.5ml. 15ml of the whole solution can be a reference.

$\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI nanocomposite was synthesized in 0.01M,0.1M,1M H<sub>2</sub>SO<sub>4</sub> solution respectively, at the scan rate of 50 mV/s for 20 cycles, following the volumetric ratio of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> nanoparticle and PANI. After electropolymerization in H<sub>2</sub>SO<sub>4</sub> solution, electrodes were rinsed with distilled water for a while, and continued scanning in 0.1M KCl for 3 cycles, with the scan rate: 10, 20, 50, 100, 200mV/s under the same potential range. It is noted that the volume of KCl should be approximately equal to the electrolyte to ensure that the same amount of electrons pass through the working electrode. Basically, it was tested on the glassy carbon and ITO glass as working electrode respectively.

It is worthy to mention the operation of UV spectrophotometer and workstation. In this study, the absorption of the composite was measured. First of all, the  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI nanocomposite was synthesized on platinum mesh as working electrode with potential range of 0-1V for 20 cycles. Then it was scanned in KCl for 3 cycles to determine the position of peaks. Secondly, the parameters of UV spectrophotometers were set. Generally, the absorption wavelength is 200-900nm and the absorption is 0-10 (adjustable). Before measuring the target composites, calibration had to be taken by using distilled water. Herein, quartz cell was used to as it does not absorb UV light and has no influence on the sample. The solution had to reach two-thirds of the quartz

cell. After calibration, three electrodes were moved to quartz cell and the reference electrode (Ag/AgCl) needed to slightly insert to the solution to prevent the absorption of UV light. It was necessary to scan for one cycle to stop short circuit as the room for three electrodes was limited and the whole experiment had to be carried without light.

Then UV spectrophotometer and electrochemical workstation worked together. Chronoamperometry is a simple and widely used electrochemical detection technology. Its working principle is that a step potential is applied between the working electrode and the reference electrode as the excitation, and the response current generated by the redox reaction changes with time flows through the working electrode and the counter electrode, and the initial value of the current is larger and gradually decreases with time. Chronoamperometry was used by applying potential step (based on the CV curves) for 300 seconds when the absorption of UV light was measured.

As a widely used testing method, FTIR has the characteristics of high detection sensitivity, high measurement accuracy, high resolution, fast measurement speed, low astigmatism and wide band.<sup>22</sup> Here, nanocomposites which were synthesized on the ITO glass were analyzed. The testing steps are as following: the first step was to have a blank sample as reference spectrum for calibration; then the samples were put into the middle of sample rack in the spectrometer sample bin to make sure that the infrared light hits the sample; next, after measurement, spectrum had to be adjusted by removing the blank sample. During the whole working process, the sample bin had to be closed tightly. Based on the spectrum, the characteristics and peaks was analyzed.

### 3 RESULTS AND DISCUSSION

#### 3.1 Electropolymerization of PANI and $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI nanocomposite

In order to explore the electrochemical performance of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI nanocomposites, first of all, PANI was electropolymerized in H<sub>2</sub>SO<sub>4</sub> under the potential of 0-1 V. In this experiment, the GC and ITO glass were used as working electrode and Ag/AgCl was used as reference electrode.

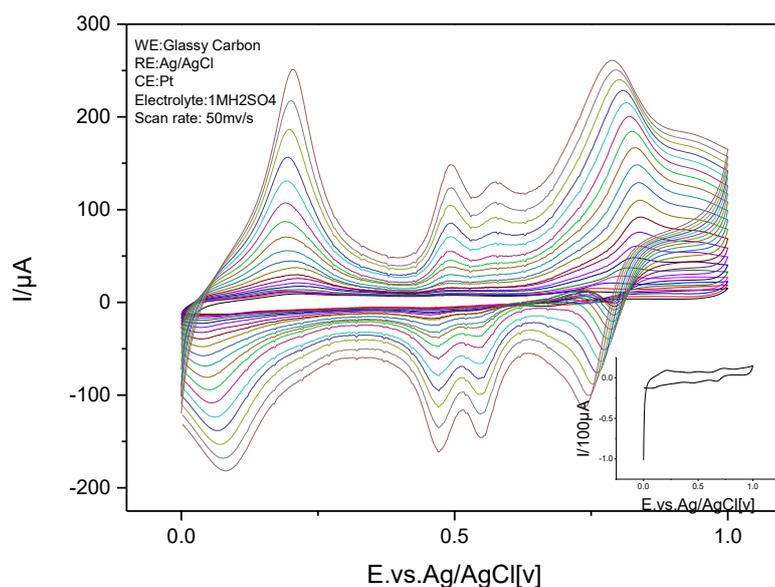


Figure 5: CV of PANI in the electrolyte of 1M H<sub>2</sub>SO<sub>4</sub>, potential range: 0-1V, 20 cycles

It can be obviously found in Figure 5 that four peaks in both reduction and oxidation directions and the current ranged from -200 $\mu$ A-250 $\mu$ A. With the increase of the number of scanning cycles, it can be seen that the capacitance is increasing.

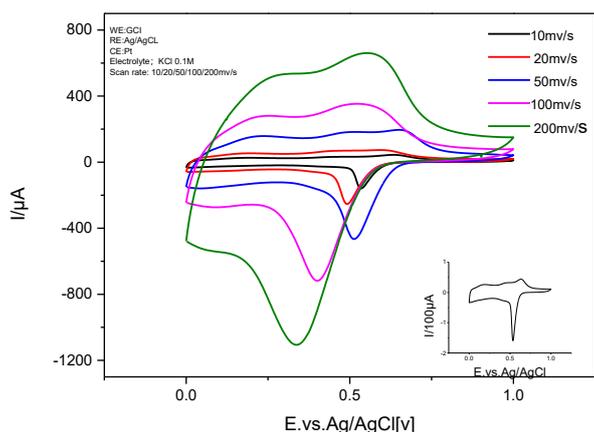


Figure 6: CV of PANI in electrolyte of 0.1M KCl potential range: 0-1V.

The electrochemical properties of pure PANI were tested by CV in 0.1M KCl. It was shown that when the capacitance was increasing with scan rate, which means higher scan rate, bigger capacitance. And the peak current was also increasing with the scan rate.

The specific capacitance of the electrode materials was calculated using the following formula (1) <sup>5</sup>.

$$C_{sp} = \frac{1}{rW (\Delta V)} \int_{V_D}^{V_C} iV dV \quad (1)$$

Where  $\gamma$  is the scan rate,  $W$  is active mass of material(g) and  $\Delta V$  is potential window(V).

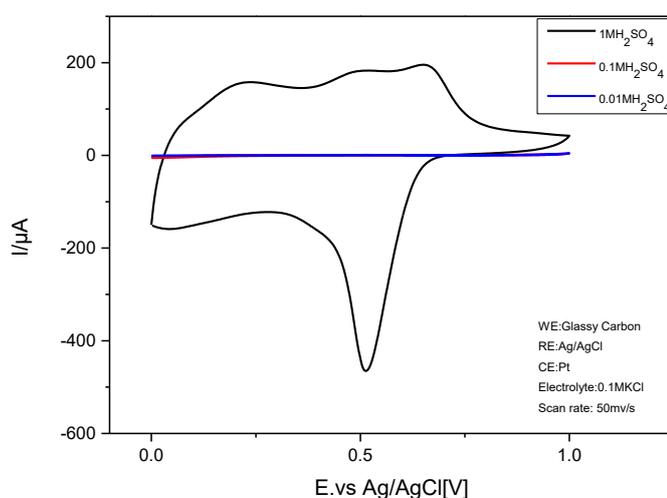


Figure 7: CV of PANI in the electrolyte of 0.1M KCl after electropolymerization in 0.01/0.1/1M H<sub>2</sub>SO<sub>4</sub>, potential range:0-1V.

The electrochemical properties of PANI was analyzed by CV in 0.1M KCl after polymerization, and based on Figure 7, PANI which was polymerized in 1M H<sub>2</sub>SO<sub>4</sub> exhibits higher current and apparent redox reaction, indicating better capacitive behaviors and high reversibility. The current in 1MH<sub>2</sub>SO<sub>4</sub> ranged from -300μA-200μA, while in 0.1M and 0.01M H<sub>2</sub>SO<sub>4</sub>, the current cannot be reserved. There are obvious redox peaks in the curve of 1MH<sub>2</sub>SO<sub>4</sub> while the other two curves, no peak was shown. It can be seen that the specific capacitance increased with an increase in concentration of H<sub>2</sub>SO<sub>4</sub>. The electrochemical performance of PANI in 1M H<sub>2</sub>SO<sub>4</sub> in terms of specific capacitance is better than in 0.01 and 0.1M H<sub>2</sub>SO<sub>4</sub>. At the same time, more peaks in 1MH<sub>2</sub>SO<sub>4</sub> solution compared with 0.1M and 0.01MH<sub>2</sub>SO<sub>4</sub>, which indicates that the presence of redox reactions and better polymerization in 1M H<sub>2</sub>SO<sub>4</sub>. In a word, 1M H<sub>2</sub>SO<sub>4</sub> works better as electrolyte in the polymerization process of PANI.

α-Fe<sub>2</sub>O<sub>3</sub>/PANI nanocomposite was electropolymerized in H<sub>2</sub>SO<sub>4</sub>, and the volumetric ratio of α-Fe<sub>2</sub>O<sub>3</sub> nanoparticle and PANI-H<sub>2</sub>SO<sub>4</sub> solution was determined by the formula: 1: 2<sup>n</sup>(1≤n≤6).

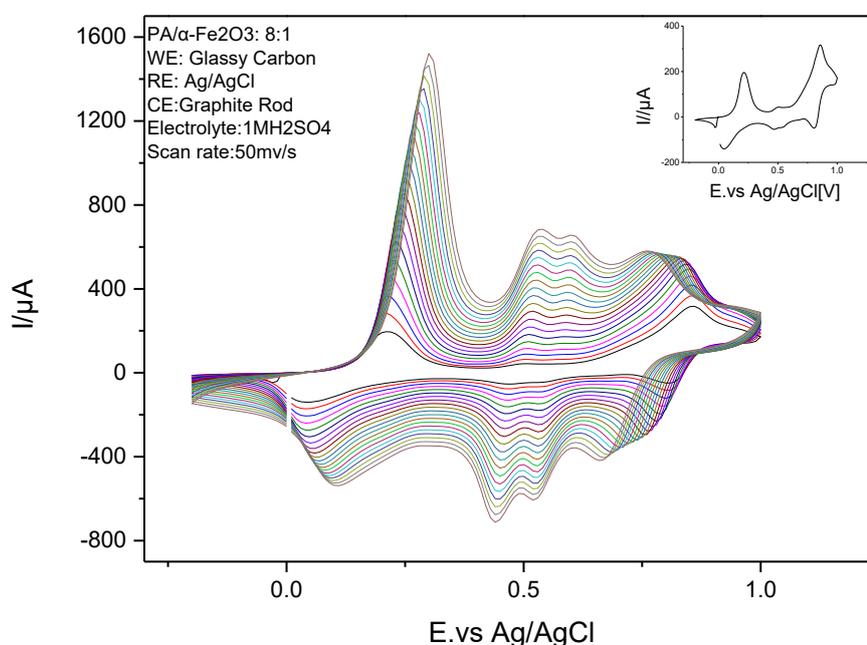


Figure 8: CV of α-Fe<sub>2</sub>O<sub>3</sub>/PANI in the electrolyte of 1M H<sub>2</sub>SO<sub>4</sub> when the volumetric ratio was 8:1, potential range: -0.2-1V.

Herein, it was found that when the volumetric ratio of PA and  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> was 8:1, the electropolymerization of composites had better performance, where the current ranged from -0.8mA-1.6mA. In this study, the volume of the solution is 15mL, so there was 1.71mL of 0.1M  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> and 13.33ml of PANI. It was noted that 15ml of solution should be used as a standard to reduce the impact of volume changes. Compared with Figure 6, the position of the peak moves to the direction of high voltage and there is a dramatic increase in terms of current and capacitance, suggesting that the  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> nanocomposites enhanced the performance of the composites.

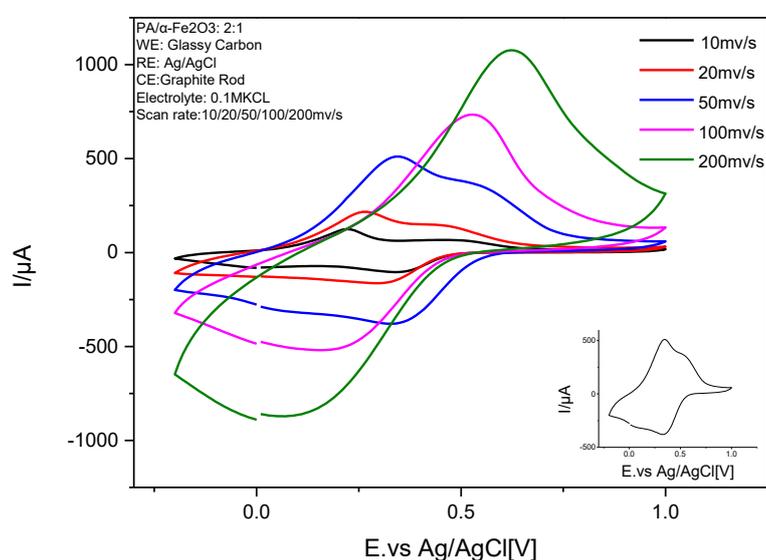


Figure 9: CV in 0.1M KCl after polymerization in 1M H<sub>2</sub>SO<sub>4</sub>, when the volumetric ratio was 2:1, the potential range: -0.2-1V.

From Figure 9, It can be seen that the specific capacitance increases with the increase of the number of scanning cycles, and the peak current moves to the direction of high potential. Some literatures have documented that at a higher scanning rate, the deviation of the shape and redox peak of the CV is due to the effective interaction between the ions and the electrode, which is greatly reduced with the increase of the scanning rate.<sup>9</sup>The current was relatively higher, ranging from -1mA-1mA.

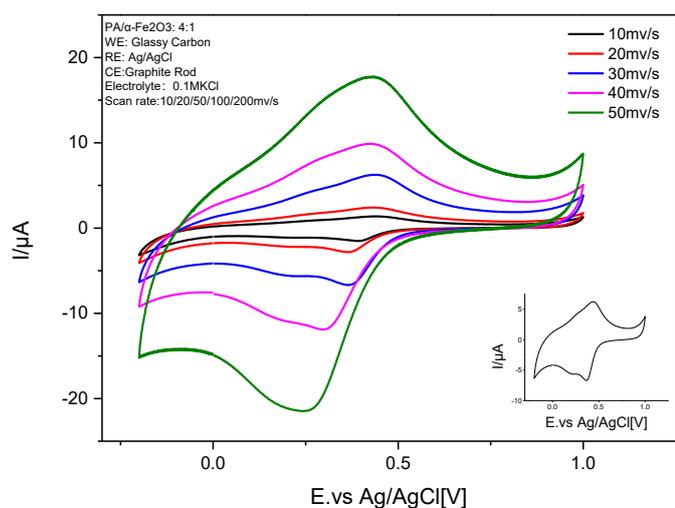


Figure 10(a): CV of PANI in the electrolyte of 0.1M KCl after polymerization in 0.1M H<sub>2</sub>SO<sub>4</sub>, when the volumetric ratio of PA and α-Fe<sub>2</sub>O<sub>3</sub> was 4:1, the potential range: -0.2-1V.

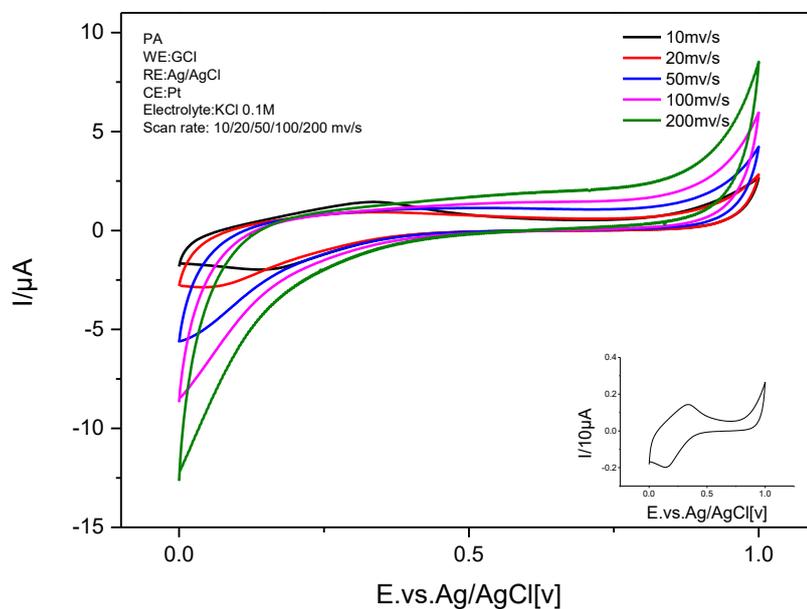


Figure 10(b): CV of PANI in the electrolyte of 0.1M KCl after polymerization in 0.1M H<sub>2</sub>SO<sub>4</sub>, the potential range: 0-1V.

In the Figure10 (a) and Figure10(b), CV curves of pure PANI and  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI were compared. It further demonstrates that the electrochemical performance of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI nanocomposites was enhanced by incorporating  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> nanoparticles as compared with that of individual PANI. Based on the curves, it apparently showed a peak in Figure10 (a) while the potential was about 0.5V, and no obvious peak appeared in Figure 10(b) when only PANI was synthesized. This result clearly shows the importance of the combination of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>, which can be seen from the current increase and capacitance enhancement, greatly improving of electrochemical activity of the nanocomposites. At the same time, the capacitance increased with an increase in scan rate from 10mv/s to 200mv/s for both pure PANI and  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI nanocomposites.

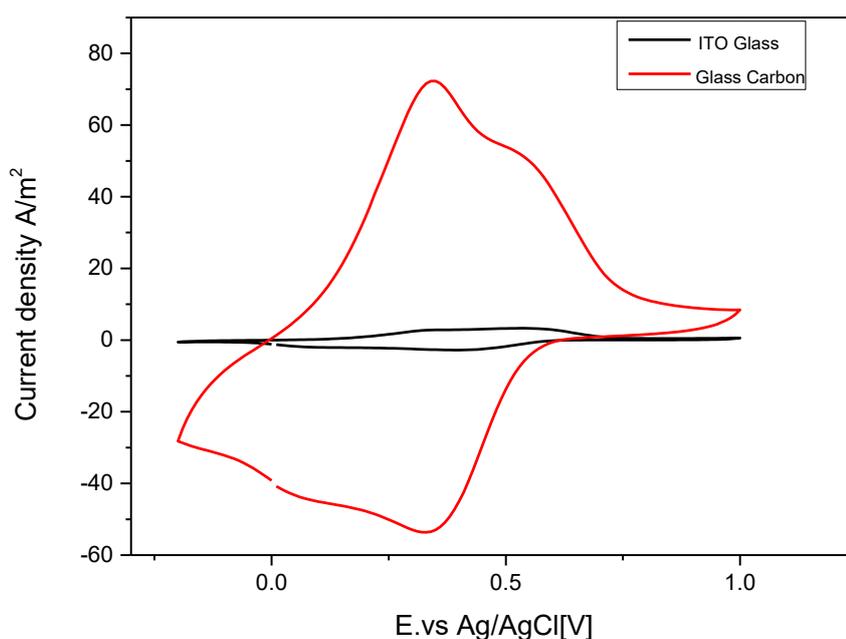


Figure 11: CV of PANI in the electrolyte of 0.1M KCl when ITO and Glassy Carbon were working electrode respectively, scan rate: 50mV/s.

Herein, it was noted that the current density was an important parameter for the comparison of ITO glass and glassy carbon. As the name suggests, literally, current density is the measurement of an electric current(A) per cross-sectional unit area(m<sup>2</sup>).

The formula for current density( $J$ ) is:

$$J=I/A. \quad (2)$$

This formula shows the magnitude of the current density, which is a vector. In this experiment, the diameter of glass carbon electrode is 3mm while the length and width of glass are 0.6 cm and 1cm respectively. Based on the parameter, the surface area of the working electrode could be calculated.

In Figure 11, the CV curves of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI nanocomposites were compared in 0.1M KCl after polymerization with ITO glass and glassy carbon as working electrode at a scan rate of 50mv/s. It is worthy to note that the  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI nanocomposites on glassy carbon exhibits a much higher current density than on ITO glass at the same scan rate, indicating that the former one has better specific capacitance and glass carbon is better than ITO glass in the process of electropolymerization of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI.

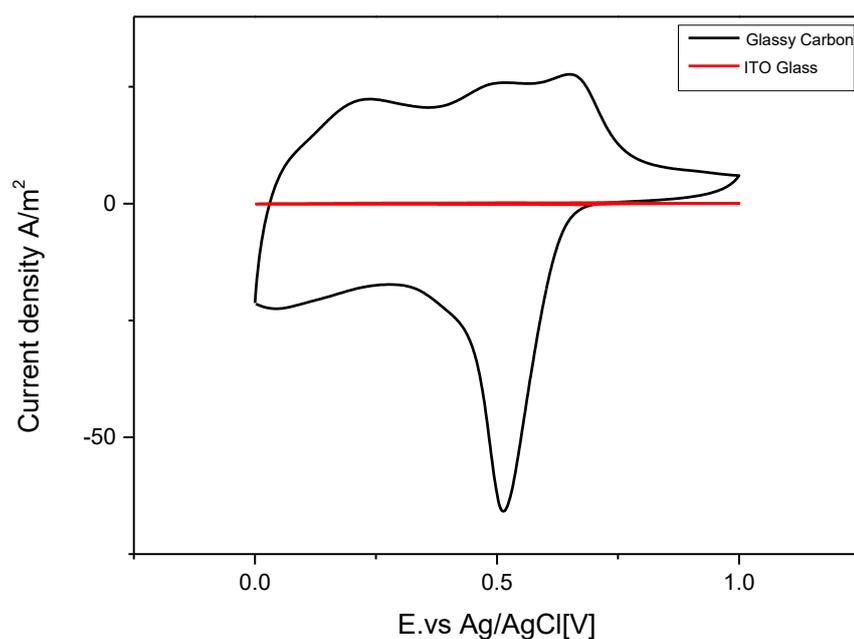


Figure 12: CV of PANI in the electrolyte of 0.1M KCl when ITO glass and Glass carbon were working electrode respectively, potential range: 0-1V.

In Figure 12, the current density of pure PANI in 0.1M KCl after polymerization in Glassy Carbon and ITO glass was compared at a scan rate of 50mv/s respectively.

PANI was firstly polymerized in 1M H<sub>2</sub>SO<sub>4</sub> for 20 cycles, and then was scanned for 3 cycles in 0.1M KCl. Based on the CV curves, it is same with the  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI nanocomposites that glassy carbon was better material than ITO glass in terms of capacitance and current. Moreover, it is obvious that compared with pure PANI, the function of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> nanoparticles cannot be ignored as the current density and capacitance increased significantly. Therefore, it is of great importance to combine  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> nanoparticle to increase the electrochemical performance of PANI.

### 3.2 UV spectrum of nanocomposites

The UV spectrum can characterize the transition of electrons in substances and helps to determine the structure and characterize the properties of compounds. The UV spectrum of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI nanocomposites was obtained while different potentials were applied by ChronoAmperometry in a certain period(300s).

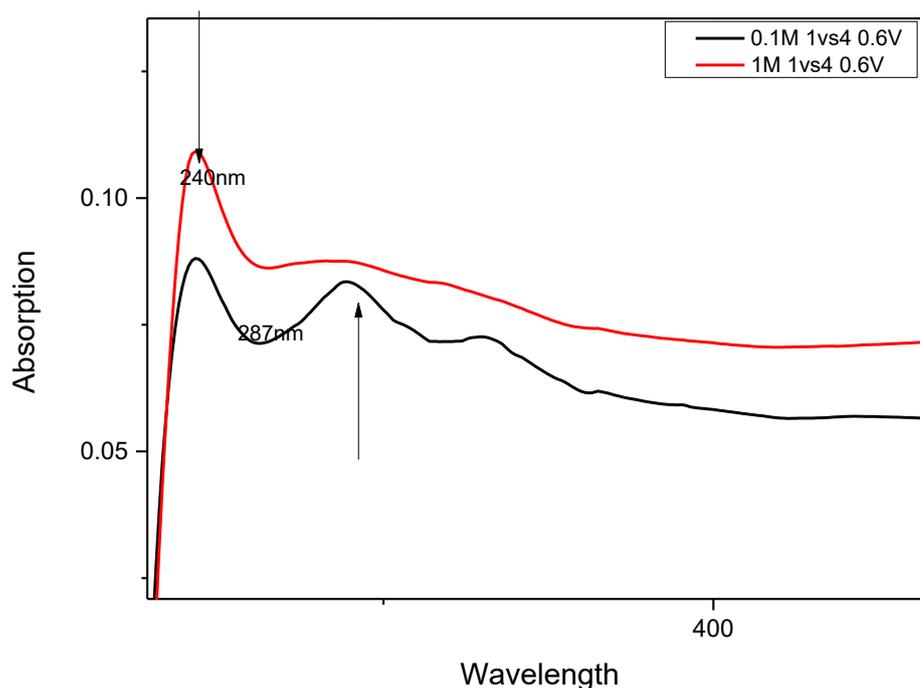


Figure 13: UV absorption spectra of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI nanocomposites, potential: 0.6V

Figure 13 shows the UV absorption spectra of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI nanocomposites which were synthesized in 0.1M H<sub>2</sub>SO<sub>4</sub> and 1M H<sub>2</sub>SO<sub>4</sub> with volumetric ratio 1:4.

The analysis of UV spectra is based on the principle of Lambert-Beer's Law:

$$A = -\lg T = \epsilon b c \quad (3)$$

$\epsilon$  represents molar absorption coefficient and it is related to the wavelength of the incident light, the properties of the component to be measured and the temperature, and is the characteristic constant of the material to be measured under certain conditions.

The relation between energy and wavelength:

$$E = \frac{hc}{\lambda} \quad (4)$$

The intense is appeared at 240nm and 287nm. The first peak (at 240nm) is attributed to  $\pi \rightarrow \sigma^*$  transition. Generally,  $\pi \rightarrow \sigma^*$  transition requires more energy, therefore, it occurs when the wavelength is small. The presence of second peak (287nm) is related to  $\pi \rightarrow \pi^*$  on benzenoid rings, characteristic of the leucoemeraldine form of PANI (Figure 1). Compared with two curves, it can be observed that nanocomposite which was synthesized in 1M H<sub>2</sub>SO<sub>4</sub> has higher absorptivity. It was supposed that the performance of 1M H<sub>2</sub>SO<sub>4</sub> was better than 0.1M H<sub>2</sub>SO<sub>4</sub>.

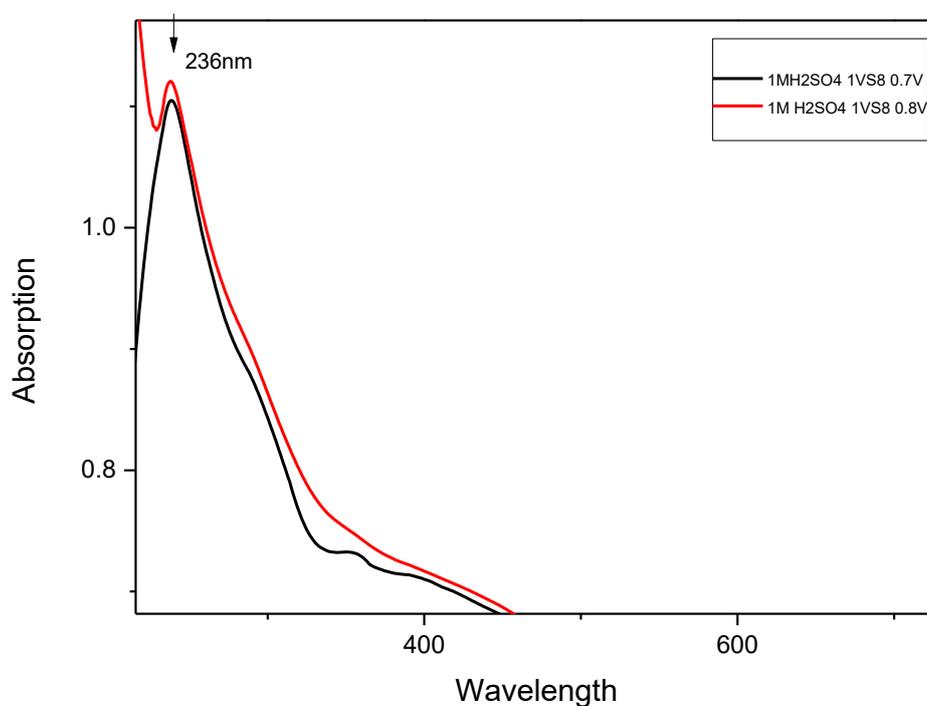


Figure 14: UV absorption spectra of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI nanocomposites with two different potentials.

Figure 14 shows that the UV spectra of nanocomposites which were synthesized in 1M H<sub>2</sub>SO<sub>4</sub> under 0.7V and 0.8V. There is a peak at 236nm, attributed to  $\pi \rightarrow \sigma^*$  transition. By applying different potentials to the nanocomposites, it is shown that the absorptivity decreased with the increase of potential.

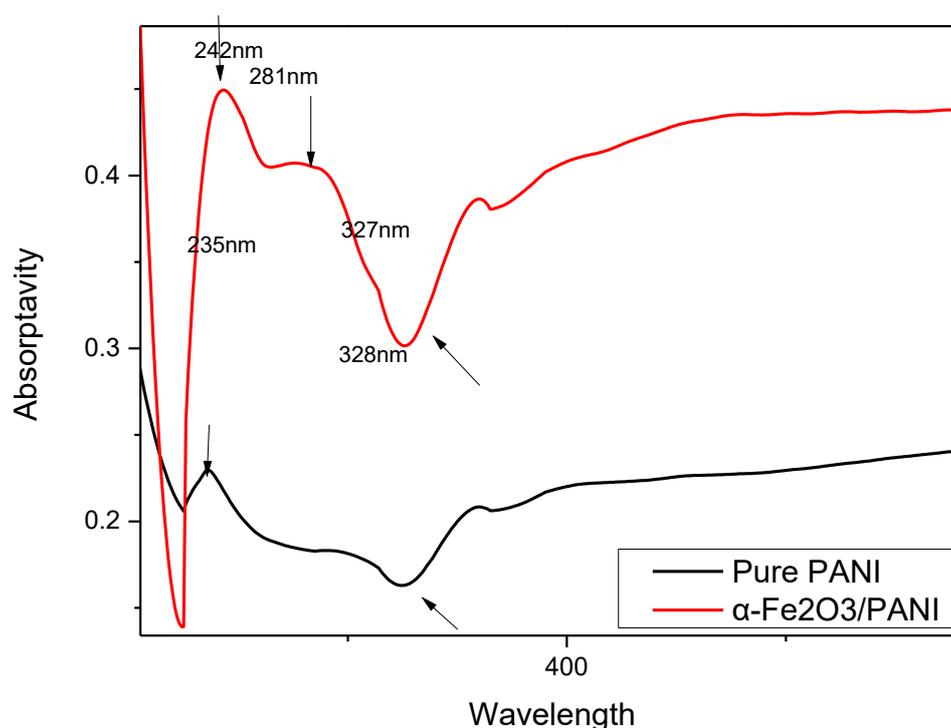


Figure 15: UV spectrum of pure PANI and nanocomposites.

Herein, PANI and nanocomposites were synthesized in 0.1M H<sub>2</sub>SO<sub>4</sub> under 0.4V potential by Chronoamperometry. PANI and the nanocomposites showed absorption bands around 235-300nm corresponding to the transition allowed in the benzenoid ring. There is a peak at 281nm in  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI, which was supposed by the presence of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>, indicating the good conductivity of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI. It is noted that the peak at 327 and 328nm was caused by the instrument and can be ignored during the measurement.

### 3.3 FTIR spectrum of nanocomposites

FTIR performed as an auxiliary technique to determine the composition of material. The chemical structure of the prepared material after polymerization was characterized using FTIR spectra in the range of  $4000\text{cm}^{-1}$ - $400\text{cm}^{-1}$ . The vibration frequency of the same group in different molecules is very close and they have same absorption bands in a certain frequency range, therefore, if the frequency and displacement law of each functional group is known, it can be determined the groups in compounds and their positions by infrared spectrum. Infrared spectrum is based on that compounds with different structures have unique infrared spectrum.

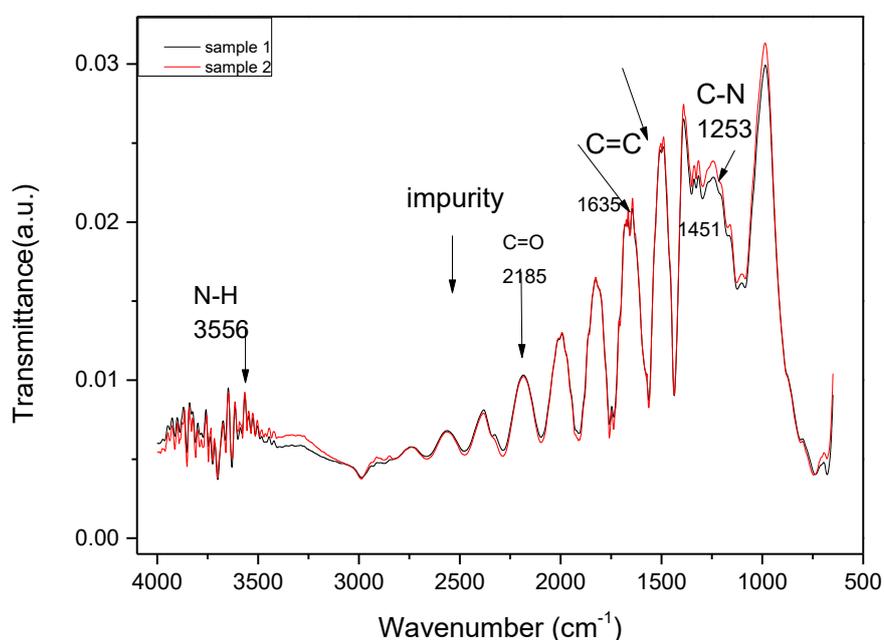


Figure 16: FTIR of  $\alpha\text{-Fe}_2\text{O}_3/\text{PANI}$  nanocomposites on ITO glass.

Figure 16 shows two  $\alpha\text{-Fe}_2\text{O}_3/\text{PANI}$  nanocomposites samples which were synthesized in  $1\text{M}\text{H}_2\text{SO}_4$ , while the volumetric ratio of  $\alpha\text{-Fe}_2\text{O}_3$  and PANI in sample 1 and sample 2 is 1:4 and 1:8 respectively. Some characteristic peaks in Figure 16 were marked, and the corresponding detail implications were assigned below: The peaks at  $1451$  and  $1635\text{ cm}^{-1}$  are attributed to C=C. The absorption peak at  $3556\text{ cm}^{-1}$  is due to N-H stretching vibration, and the peak at  $1253\text{ cm}^{-1}$  is attributed to C-N for stretching mode for benzenoid ring. Due to the  $\text{CO}_2$  in the air, C=O can be detected at  $2185\text{ cm}^{-1}$ .

And it is supposed there was impurities on the ITO glass, therefore, peaks at 2554  $\text{cm}^{-1}$  represents the presence of impurities.<sup>20</sup>

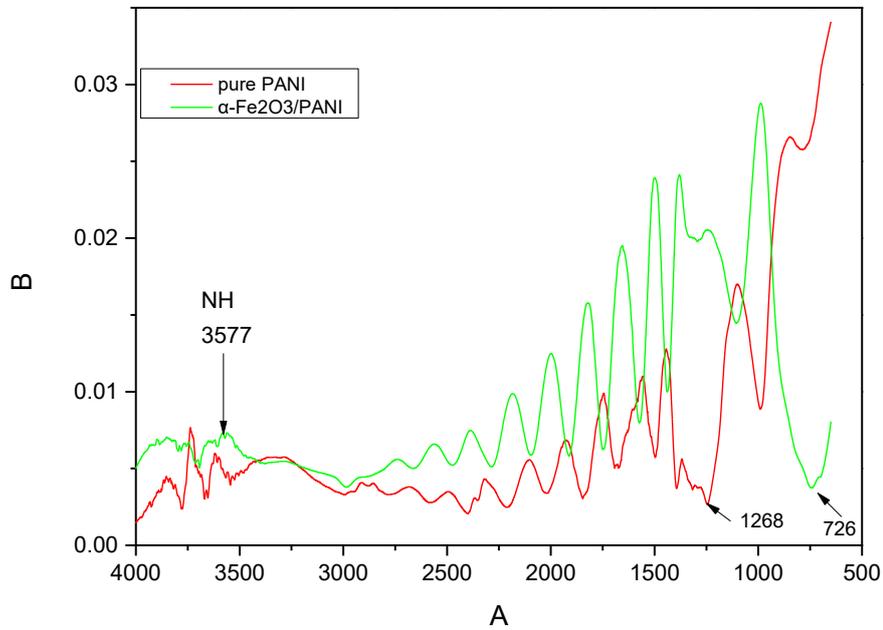


Figure 17. FTIR of pure PANI and  $\alpha\text{-Fe}_2\text{O}_3/\text{PANI}$  nanocomposites.

Figure 17 shows the comparison of FTIR spectrum of pure PANI and  $\alpha\text{-Fe}_2\text{O}_3/\text{PANI}$  composites, and it can be taken as evidence of the presence of  $\alpha\text{-Fe}_2\text{O}_3$  based on the peak at 726  $\text{cm}^{-1}$ . It is supposed that the peak at 726 is due to the Fe-O vibration and the peak at 1268 might be caused by impurities.

#### 4 CONCLUSION

In this paper, in order to explore the performance of nanocomposites,  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI nanocomposites were prepared by using electrochemical synthesis. The comparison of the CV curves between pure PANI and  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI confirmed the effective influence of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> on the properties of nanocomposites. The introduction of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> in the composites provides high conductivity as well as large capacitance, which can be used for supercapacitors, batteries and other electronics. The current density and capacitance of nanocomposite has significantly increased by combining  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> nanoparticles. At the same time, the volumetric ratio of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> and PANI was figured out by Cyclic Voltammetry. It is supposed that the nanocomposite which was synthesized 1MH<sub>2</sub>SO<sub>4</sub> and 0.1M H<sub>2</sub>SO<sub>4</sub> has better properties by analyzing its CV curves and in the cell, glassy carbon has better performance than ITO glass working electrode.

Therefore, the combination strategy of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>/PANI nanocomposite could be a promising material in electrochemical applications.

## **5 ACKNOWLEDGEMENT**

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Last but not least, I would like to give my best wishes to everyone mentioned above. I wish that we all have a bright future and may all our dreams come true.

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