Electrospun Polyetherimide-Graphene Oxide Nanofiber Electrodes for Enhanced Conductivity

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Abstract: Polyetherimide (PEI) is recognized as a potential candidate for electrochemical sensor matrix which can be used for heavy metal ion and reactive chemical substance sensing applications. However, the relatively low conductivity of PEI material limits its usage of electrochemical sensor applications. Modifying PEI membrane considerably improve the electron conductivity and electrochemical property of polymer. Conductive polyetherimide-graphene oxide (PEI-GO) composite nanofiber membrane was synthesized via electrospinning technique in order to modify electrochemical sensor electrodes. In order to optimize the electrospinning process protocol such as viscosity, surface tension and conductivity and obtained smooth electrospun fiber, PEI were electrospun from two different solvents namely n-methyl-2-pyrrolidone (NMP) and combination of NMP/ dimethylformamidem (DMF). Physical and electrical properties of the nanofiber were analysed in terms of its hydrophobicity, porosity and conductivity by manipulating the concentration of PEI from 20 wt% to 30 wt% and GO loading from 0.1 wt% to 0.5 wt%. Electrospun of 25 wt% PEI in NMP/DMF produced the highest porosity and liquid uptake of 97.81% and 2846.23% respectively. The addition of GO at 0.5 wt% into 25 wt% of PEI (NMP/DMF) improved the porosity and liquid uptake up to 98.83% and 5400%, respectively, while the conductivity increases to 32.71 µS/cm which is 10 folds higher than GO free PEI fiber. When the conductivity of drop-casted PEI-GO modified electrodes was compared to the electrospun PEI-GO fiber modified electrodes, the latter showed 2-3 folds higher. Proposed PEI-GO electrospun fiber with the enhanced conductivity, porosity and hydrophobicity along with high chemical stability can be used as an efficient conductive matrix for electrochemical electrode applications such as heavy metal ion sensing and reactive chemical sensing application.

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1. Introduction

Polyetherimide (PEI) is an amorphous polymer with great thermal and chemical stability [1,2] as it is widely used in gas separation processes such as separation of He or H2 from other gases[1,3]. PEI also shows excellent chemical resistance in presence of highly reactive chemicals (such as H2O2 and CO2) and heavy metal ions. This attribute confers great potential to PEI-based materials to be used as a sensor matrix for the electrochemical sensing of heavy metal ions [4] and reactive substances [5–7]. Herein, PEI matrixes excellently protect the electrodes from any reaction defacement and improve the sensitivity, selectivity and durability of electrodes. Although PEI shows excellent chemical stability, the relatively low conductivity of PEI material limits its usage in modern electrochemical sensing applications. However, modifying PEI membrane as one-dimensional nanofibers with highly porosity will
considerably improve the electron conductivity and electrochemical property of polymers [7]. In this regard, electrospinning technology is known as low cost, simple and versatile method to produce nanofiber material with one dimensional structure, high porosity and high surface area [8].

In electrospinning process, electric field is utilized to control the deposition of polymer fiber from polymer solution on a grounded target substrate, with nanometer scale diameters ranging from few microns down to 100 nm or less [9‒11]. Electrospun nanofibers have been successfully used in fabricating numerous number of polymer composite for recent electrochemical applications in sensor [12‒14], fuel cell [15,16], solar cell [17,18], battery [19], as well as other research field [10,20] due to unique characteristics including a large surface area to volume ratio, nanosized pore distribution, flexibility in surface properties and superior mechanical. Fabrication of electrospun membranes from PEI solutions has been also studied by few works. Han et al. [21] reported formation of porous electrospun polyetherimide (PEI) fibers through thermal degradation of blend fibers at 210°C. Moon et al. [22] produced continuously aligned nanofibers from PEI solution using both a stationary and a rotating grounded target under variable parameters. Fashandi and Karimi [23] demonstrated the optimization of the morphology of PEI electrospun fibers by utilizing various nonvolatile solvents such as dimethylformamide (DMF), Dimethylacetamide (DMAc) and n-methyl-2-pyrrolidone (NMP). They proposed a phase diagram of a nonsolvent/solvent/polymer system that can be considered a powerful and promising tool to provide insight into morphology evolution during electrospinning. As another notable work, Oğulata and İçoğlu [24] demonstrated the effect of temperature and relative humidity (RH) on morphology of the electrospun PEI/NMP solution. However, PEI electrospun fibers are yet to be fully explored for electrochemical electrode applications.

Other than morphology, electrical conductivity of electrospun nanofiber is one of the main research interests. Conductive materials such as graphene [25], reduced graphene oxide (rGO) [7], graphene oxide (GO) [13,26,27] and halloysite nanotubes (HNTs) [28] are normally added into polymer composite for various applications including sensors, coating, and tissue engineering [14]. Polymer nanocomposites with GO as a filler have shown dramatic improvements in electrical conductivity [13,26]. Moreover, the improvement is often observed at low loadings of filler evidently due to the large interfacial area and high aspect ratio of these materials, requiring small amounts of filler to achieve percolation. Graphene oxides (GO) is rich in hydroxyl groups and carboxyl groups [29] where it can bind enzyme molecules through electrostatic interactions [30] thus avoiding the leaching of enzymes from modified electrodes. Therefore, it is quite significant to introduce GO into electrospun nanofibers to construct a novel and facile hydrophilic-based membrane.

This study aims to fabricate PEI-GO electrospun nanofiber with optimum morphology such as smaller diameter, bead free structure, and high porosity, which further enhance the conductivity of PEI-GO composite material for electrochemical sensing applications. To address the optimum electrospinning protocols for producing fine and bead free PEI-GO composite electrospun nanofiber with optimum properties, electrospun PEI-GO nanofibers prepared in two different solvent systems, namely NMP and mixture of NMP and dimethylformamide DMF, at constant temperature and humidity. Eventually, improved conductivity of the proposed PEI-GO electrospun composite nanofiber matrix was investigated by comparing it with the performance of conventional drop-casted PEI-GO composite coating.

2. Material and Methods

2.1 Materials

Purified graphite powder, 30% hydrogen peroxide (R&M Chemicals), 37% hydrochloric acid (Merck), potassium permanganate (MW=158.03 g/mol, R&M Chemicals) and 98% sulphuric acid (R&M Chemicals) were used as received for the synthesis of GO. PEI beads were purchased from Sigma-Aldrich. Solvents n-methyl-2-pyrrolidone (NMP) (99.0%) and dimethylformamide (DMF) (99.8%) were purchased from R&M Chemicals.

2.2 Experiment procedures

2.2.1 Synthesis of Graphene Oxide

Graphene oxide was synthesized from graphite using modified Hummer’s method [31]. A mixture of 5 g graphite powder in 200 ml of concentrated sulfuric acid (H2SO4) was stirred for 1 hour at low temperature (in ice bath condition). Then, 30 g of potassium permanganate (KMnO4) was slowly added into the mixture within 2 hours to avoid the temperature from exceeding 15°C. The mixture was continuously stirred.
for another 2 hours. Next, the ice bath was taken out and the stirring of the mixture was continued for another 20 hours at room temperature. The mixture was then heated up to 70°C and stirred for 2 hours. Later, 100 ml of distilled water (H₂O) was added slowly into the mixture and stirred about 10 minutes. The mixture was then sonicated for 30 minutes by using ultrasonic at temperature 70°C. Again, the mixture was heated to 90°C and kept stirred for an additional 1 hour. After that, another 100 ml of H₂O was slowly added and kept stirred for 1 hour. The mixture was then sonicated again for about 30 minutes at 70°C before adding 30 ml of hydrogen peroxide (H₂O₂) to stop the reaction. The solution was then continued to stir until the temperature cool down around 25°C. After that, sonication process was conducted at room temperature for 1 hour followed by washing with 1 M hydrochloric acid (HCl) and DI water to remove impurities until the pH was neutral. The mixture was then centrifuged at 10,000 rpm for 10 minutes at 4°C. The slurry was then poured into a petri dish and dried in an oven at 60°C for 24 hours.

### 2.2.2 Preparation of PEI-GO precursor Solution

PEI solution was prepared in with different concentrations of 20, 25 and 30 wt% in 5 mL of solvents. The solutions were prepared by dissolving crushed PEI beads into NMP, and a mixture of NMP and DMF solvents under vigorous stirring at room temperature for 24 hours. The volume ratio of 4.55:5 of NMP to DMF was used for preparing 5 ml of solvent mixture.

Graphene oxide (GO) was dispersed into 5 ml of both NMP and DMF solvents separately by ultrasonication. The concentration of GO used was varied from 0.1, 0.3, and 0.5 wt%. The volume ratio used for preparing GO solution to PEI polymer solution was 1:1. The GO solution was dispersed into the polymer solution using magnetic stirrer for 1 hour.

### 2.2.3 Electrospinning procedure

The prepared solution was transferred to a 5 ml disposable plastic syringe. A 23 G stainless steel needle was attached to the syringe and the set-up position to the syringe pump as shown in Fig. 1. The tip to collector distance was set to 20 cm. The flowrate of the solution was set at 0.8 ml/hr and the applied voltage supplied to the needle was -20 kV. The electrospinning process was carried out under constant temperature and humidity. The electrospun nanofiber was dried at room temperature to remove the trace solvent and stored in a desiccator.

![Fig. 1 Schematic diagram of electrospinning setup for PEI nanofiber.](image-url)

### 2.3 Characterization

#### 2.3.1 Viscosity measurement of polymer solution

The viscosity of the PEI solutions in the different solvents and various concentrations were measured using a viscosity meter (Brookfield viscometer LVDV-11). The spindle was dipped into the polymeric solution and allowed to rotate until a static reading of the viscosity was reached. The viscosity reading was recorded.

#### 2.3.2 Porosity and Liquid Uptake Analysis

The porosity of the electrospun nanofiber membrane was analyzed by following n-butanol soaked-up method [32,33]. In this method, the nanofiber mat was cut into small rectangular shapes (2 cm × 2 cm), individually weighed, and soaked into n-butanol for about 2 hours at room temperature. The nanofiber film was then removed from the solution and wiped with tissue to remove excess solvent on it before weighing it. Eventually, the porosity of the nanofiber membrane was calculated using the following equation (1) [33,34]:

\[
\text{porosity} = \frac{(m_p - m_b)}{(m_b/\rho_b + m_p/\rho_p)} \times 100\%
\]

Where, \(m_p\) represents the weight of the electrospun nanofiber membrane as obtained by weighing the small rectangular shape of nanofiber membrane before it was soaked into n-butanol, while \(mb\) represents the weight of the nanofiber membrane after soaked into the n-butanol. \(\rho_b\) and \(\rho_p\) represent the density of n-butanol and the separator respectively.

n-butanol uptake of the membrane was
calculated by the following equation (2) [34]:

\[ \text{uptake} = \frac{m_b - m_p}{m_p} \times 100\% \]  

Whereby \( m_b \) represents the weight of the nanofiber membrane that was soaked with n-butanol, while \( m_p \) represents the weight of the dry nanofiber membrane.

2.3.3 Hydrophobicity and Wettability Analysis

The hydrophobicity of the electrospun nanofiber membrane was determined by measuring the water contact angle using a goniometer (VCA 3000, AST products Inc.). The goniometer utilized an optical subsystem to capture the profile of a water droplet on a solid surface. In this test, the glass syringe was filled with distilled water and placed on syringe dosing system. The illumination lamp and charge coupled device (CCD) camera were then turned on. Then, the sample was placed on the sample stage. The syringe knob was then opened to allow the water to drop onto the sample and the contact angle between the liquid droplet and fiber surface was measured.

2.3.4 Electrospun Fiber Morphology

The morphology of the electrospun fiber was investigated using field emission scanning electron microscope (FESEM) at an accelerating voltage of 5 kV. The samples were sputtered-coated with a thin layer of 15 nm gold prior to the FESEM measurement. ImageJ software (open version is available on worldwide web) was used to determine the fiber size diameter. The mean and standard deviation values were obtained by selecting 150 fibers.

2.3.5 Conductivity Analysis of Electrospun PEI-GO Nanofibers and drop-casted PEI-GO fibers

The electrospun nanofiber conductivity was determined using frequency response analysis (FRA) in electrochemical impedance spectroscopy (EIS) (Autolab, pgstat 204). The PEI-GO solution was electrospun onto the working electrode of the screen-printed carbon electrode (SPCE). The SPCE was carefully covered with aluminum foil except the working electrode area. The EIS characterization of PEI-GO thin film on the working electrode of SPCE was carried out in acetate buffer solution of pH 4.6 as the electrolyte. The frequency was varied from 100 mHz to 100 kHz. The bulk resistance, \( R_b \), of the fiber was recorded to determine the conductivity of the nanofiber membrane using the following equation [35]:

\[ \sigma = \frac{d}{R_b S} \]  

Where, \( \sigma \); conductivity of the nanofiber membrane (S/cm), \( d \); the thickness of nanofiber membrane (cm), \( R_b \); the bulk resistance of the nanofiber membrane (\( \Omega \)), \( S \); the area of symmetrical electrode (cm²) (0.1257 cm²).

100 \( \mu \)L of the polymeric solution was dropped onto the surface of the SPCE working electrode. The solution was left to dry to form a thin membrane layer. Analysis was conducted using FRA in EIS potentiating using acetate buffer as the conducting electrolyte to complete the circuit (refer section II).

3. Results and Discussion

3.1 Physical Properties of PEI Solutions

In this study, 20 wt% of PEI was chosen as the initial polymer concentration, wherein the electrospun fibers were produced free from entangled beads or polymer clots [36]. 20 wt%, 25 wt% and 30 wt% of PEI in NMP solution was more viscous than PEI in the mixture of NMP/DMF solution (as shown in Table 1). In electrospinning of very high viscous polymer solution, jet is difficult to be expelled from the electrified nozzle and that lead to droplet formation (electrospray) or larger size of fiber [37]. Besides, high boiling point of the NMP solvent may results low solvent evaporation rate from the fiber which lead less thinning and larger size of fiber formation. To overcome these problems, NMP was mixed with DMF to increase the electrospinnability of the polymer solution. The physical properties of DMF such as boiling point and density is lower as compared to NMP, contributing to the better electrospinnability. Lower boiling point and density increases the drying rate of the nanofiber membrane. Low boiling point of DMF enhanced the solvent’s evaporation rate and thus allowing it to evaporate easily during their transport to the grounded collector [38].

Table 1 Viscosity of the various weight percentage of PEI dissolved in NMP solvent and NMP/DMF solvent mixture.

| Concentration of PEI (wt %) | in NMP solvent | in NMP-DMF solvents |
|----------------------------|----------------|---------------------|
| 20                         | 482.6          | 275.5               |
| 25                         | 1379           | 1107                |
| 30                         | 2622           | 1667                |

3.2. Porosity and Liquid Uptake Properties of PEI and PEI-GO Electrospun Nanofiber

Table 2 shows the results of calculated electrolyte uptake and resultant porosity measurement of the merely PEI electrospun fiber mat.
produced using NMP and DMF solvents. According to Table 2, the calculated liquid uptake percentages are about 1663.93, 2846.23 and 1793.65 % for 20, 25 and 30 wt% of PEI in NMP/DMF solvent mixture respectively. The electrolyte uptake values in NMP/DMF mixture are higher than electrolyte uptake in merely NMP solvent, which are 461.70, 941.00 and 748.06 % for each concentration of PEI solutions. Herein, high percentage of electrolyte present in the fiber is due to the high percentage of porosity [39,10]. Therefore, the porosity of PEI produced by NMP/DMF solvent mixture were 96.31, 97.81 and 96.57 % whereas similar amount of PEI in merely NMP solvent produced PEI fiber with 87.88, 93.66 and 92.15% of porosity respectively. The electrolyte uptake and porosity of the PEI fiber in the mixture of NMP/DMF solvents was higher compared to merely in NMP solvent at all concentration of PEI. Furthermore, the highest porosity and liquid uptake were obtained at 25 wt % of PEI in NMP-DMF solvent mixture which is the optimum condition to load GO to electrospun PEI fiber. Based on the results of porosity and liquid uptake, the optimum concentration for producing PEI nanofiber with highest porosity was chosen as 25 wt% in NMP-DMF solvent. Additionally, the experiment proceeded with the addition of 0.1 to 0.5 wt% of GO into the optimum concentration of PEI solution in order to improve the conductivity of the electrospun fiber.

The calculated porosity and liquid uptake profile of GO introduced in the electrospun PEI nanofiber membrane are shown in table 3. Table 3 shows the porosity of the electrospun fiber mat of 25 wt % PEI with the addition of GO. 97.81, 97.62, 97.74 and 98.83% porosity were obtained from 0, 0.1, 0.3 and 0.5 wt% of GO loading respectively. Herein, the liquid uptake and resulted porosity of the PEI membranes increase with increasing wt% of GO. It had been reported that the addition of GO enhances the influx rate of the solvent, therein more solvent was absorbed by the fiber and resulted in high porosity [40]. However, the rapid improvement in porosity (98.83%) is obtained at 0.5 wt % of GO which is the optimum concentration for producing highly porous conductive electrospun PEI membrane.

### Table 2: Porosity and liquid uptake of the electrospun 20, 25 and 30 wt% PEI nanofiber membrane produced in NMP solvent and NMP/DMF solvent mixture.

| Concentration of PEI (wt %) | Porosity (%) | Liquid Uptake (%) |
|-----------------------------|--------------|-------------------|
|                             | NMP solvent  | NMP/DMF solvent   | NMP solvent  | NMP/DMF solvent   |
| 20                          | 87.88        | 96.31             | 461.70       | 1663.93           |
| 25                          | 93.66        | 97.81             | 941.00       | 2846.23           |
| 30                          | 92.15        | 96.57             | 748.06       | 1793.65           |

### Table 3: Porosity and liquid uptake of the 25 wt% PEI electrospun fiber loaded with 0, 0.1, 0.3 and 0.5 wt% GO concentration.

| Concentration of GO (wt %) | Porosity (%) | Uptake (%) |
|----------------------------|--------------|------------|
| 0                          | 97.81        | 2846.23    |
| 0.1                        | 97.62        | 2613.33    |
| 0.3                        | 97.74        | 2760.00    |
| 0.5                        | 98.83        | 5400.00    |

#### 3.3 Fiber Size Distributions

Fig. 2 shows the FESEM micrographs and size distribution of electrospun PEI fiber mat produced by different concentration of PEI in NMP and NMP/DMF solvent mixture. In both NMP and NMP/DMF solvent mixture, 20 wt% of PEI polymer produced amorphous fiber structures that contained entangled bead structure. Low viscosity resulted by the low concentration of polymer solution mitigate the viscoelastic force to counteract with electrostatic force and results in bead formation [41]. However, higher number and larger size of beads structure are produced by 20 wt% PEI dissolved in NMP solvent whereas numbers and diameter of beads significantly decreased in fibers produced by NMP/DMF solvent mixture. On the other hand, 25 wt% of PEI in NMP and NMP/DMF solvent mixture produced electrospun fiber with the mean diameter 882 ± 262.20 nm and 1356.48 ± 369.23 nm respectively. However, the beads still exist at 25 wt% PEI-NMP whereas beads free fiber are produced at 25 wt% PEI-NMP/DMF system. In addition, the size distribution of the PEI fiber prepared by using NMP solvent is broader than the fiber prepared using NMP/DMF solvent. The disappearance of beads and narrow size distribution of 25 wt% PEI/NMP system are attributed to the combination of low surface tension, optimum viscosity and increasing conductivity of the system [42]. 30 wt% of PEI in NMP and NMP/DMF solvent mixture produce fiber with the diameter of 3420 ± 95 nm and 1778.49 ± 268.17 nm respectively which is larger than the previous concentrations of PEI in both solvents. This increasing fiber size may have been obtained due to the high viscosity of polymer solution which is not optimum for electrospinning process.

Fig. 3 shows the FESEM images and size
distribution of 25 wt% PEI electrospun fiber as a function of different concentrations of GO loading (0.1 to 0.5 wt%). 25 wt% PEI dissolved in NMP/DMF produced nanofibers with 1004.71 ± 332.53 nm, 637.85 ± 239.26 and 271.13 ± 52.06 nm mean diameter from 0.1, 0.3 and 0.5 wt% of GO loading, respectively. It can be clearly seen that the fiber diameter decreases with increasing weight percentage of GO. This may be attributed to the rise of solution conductivity by addition of GO that resulted in smaller fiber. Eventually, 0.5 wt% percentage of GO loading was the optimum condition for producing conductive electrospun PEI nanofiber with uniform size distribution.

3.4 Hydrophobicity of PEI and PEI-GO Electrospun Nanofiber.

The contact angle was used to determine the wettability of a surface when a liquid and solid phase are in contact. Fig. 4 shows that the water contact angles of 25 wt% of PEI dissolved in NMP/DMF electrospun nanofibers are 81 ± 2.2°, 72 ± 2.1°, 74 ± 2.7° and 80 ± 2.0° for 0, 0.1, 0.3 and 0.5 wt% of GO loading respectively. The contacts angle of GO free PEI fiber shows a higher contact angle than GO added PEI fiber, which implicit the hydrophobicity of PEI fiber decreases with the addition of GO. This result may be attributed to the hydrophilic property of GO that enhances the water absorbance of fiber [43]. However,
among GO added PEI fibers, the water contact angle of electrospun PEI fiber mat increased with increasing amount of GO and maximum contact angle was obtained at 0.5% GO addition. These results attribute to decreasing fiber diameter with increasing amount of GO. The roughness of fiber mat decreases with decreasing fiber diameter whereby the hydrophobicity improve [34]. In this study, the increasing amount of GO increases the conductivity of PEI-NMP/DMF precursor solution that improved the electrospinning performance, likely producing a smaller diameter of PEI fiber and 0.5 wt% PEI-GO produced the smallest diameter of nanofiber, which result in the highest hydrophobicity. This finding is consistent with FESEM results where the fiber diameter decreases with increasing amount of GO and smallest diameter of fiber was obtained at 0.5% of GO addition.

3.5 Conductivity of electrospun nanofiber.

Fig. 5 shows Nyquist plot graph that represents the electrochemical performance of 25 wt% PEI with 0.1 wt % to 0.5 wt% GO added for electrospun PEI and drop-casting PEI SPCE surfaces. The bulk resistance (Rb) values of the electrospun coated and the drop-casting coated electrode surface and electrolyte interface bulk resistance are tabulated in Table 4. In both electrospun and drop-casting coated SPCE, PEI electrode system without GO shows higher bulk resistance than GO loaded PEI electrodes. Also, bulk resistance of both electrospun and drop-casted system decreased with increasing concentration of GO loading. In electrochemical system, when internal electron transfer increases, the bulk resistance decreases. Therefore, this decreasing bulk resistance indicates that the GO has enhanced the electron diffusion rate through PEI nanofibers whereby the conductivity of GO modified PEI nanofiber increased with increasing concentration of GO [44]. On the other hand, electrospun PEI electrode shows about two folds higher bulk resistance than drop-casted PEI.
electrode in each concentration of GO loading. The nanofiber has lower bulk resistance since it contains a porous structure. A porous structure can hold more electrolyte which can reduce the resistance and increase the electron transfer.

The conductivities of the samples were calculated based on the $R_b$ values using equation (3). As shown in Table 4, conductivity of drop-casted PEI without GO and, with 0.1 wt%, 0.3 wt% and 0.5 wt% of GO are 1.11, 2.21, 7.06 and 15.12 μS/cm respectively, whereas electrospun PEI without GO, 0.1 wt%, 0.3 wt % and 0.5 wt% of GO showed 3.47, 3.98, 23.94 and 32.72 μS/cm respectively. Here, pure PEI electrospun fiber showed lower conductivity compared to PEI with GO addition. PEI with addition of GO showed an improvement in conductivity with the increasing amount of GO concentration. Thereby the maximum conductivity was obtained at the highest amount of GO i.e. 0.5 wt% in electrospun membrane. The same trend was observed for the drop-casted PEI membrane as well. As discussed earlier, improved conductivity of the PEI fibers attribute to the addition of GO. However, in comparison to drop-casted PEI, electrospun PEI SPCE shows 2 to 3 folds higher in conductivity. This enhanced conductivity may be attributed to the one dimensional structure of electrospun fiber that result in increasing electron diffusion coefficient [18]. Also, high porosity and surface of nanofiber may increase the electrolyte interaction and enhance electron transfer rate.

4. Conclusion

This study proves that the 25 wt% PEI incorporated with the NMP/DMF binary solvents mixture produced beads free electrospun fiber with the highest porosity, which was about 97.81%. The porosity of the PEI electrospun nanofiber membrane increased to 98.83% after the addition of 0.5 wt % of GO. Water contact angle test implied hydrophilicity of PEI electrospun fiber whereby it increases with the increasing amount of GO. Moreover, the conductivity of the nanofiber membrane showed an increasing trend with the addition of GO. About 10-fold higher in conductivity was obtained from the addition of 0.5 wt % GO than without GO in electrospun PEI SPCE. Moreover, compared to the drop-casted PEI-GO membrane, electrospun PEI-GO fiber shows 2‒3 folds higher conductivity due to the one-dimensional structure, high surface area, and high porosity of electrospun nanofibers. Consequently, this study has proven that 0.5 wt% loaded GO in 25 wt% electrospun PEI-GO membrane shows the highest conductivity and the lowest bulk resistance that make electrospun PEI-GO suitable to be used as a conductive matrix of electrodes for several electrochemical applications.
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