Performance of supercapacitor device model based on double layer reduced graphene oxides films as electrodes in KCl electrolyte

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Abstract. We report the performance of supercapacitor device model based on double layer reduced graphene oxide (rGO) films as electrode in 1 M KCl. Graphene oxide (GO) films were deposited on ITO-glass use an electrochemical deposition method using 1 mg/ml GO dispersed in water. The film’s thicknesses were controlled by number deposition cycles. rGO films were obtained by thermally reduced the GO films at 200 °C for 1 hour under argon flowing. A pair of 1 cm² rGO/ITO electrodes was employed as double layer electrodes of supercapacitor device model using a filter paper which was soaked in 1 M KCl as a separator. Performance of the supercapacitor model was investigated using cyclic voltammetry (CV) in a voltage range of 0.0 volts to +0.9 volts with varied scan rate range of 25mV/s to 125mV/s. The highest specific capacitance of 20 F/kg and specific power of 0.825 W/kg was obtained using device with rGO films that deposited for three voltage cycles.

1. Introduction
Electrical energy is a primary need of modern life. It drives significantly research activities on energy sources and energy storages. The best energy storage must be had high specific power and high specific energy. Electrochemical capacitor that also known as supercapacitor has high ratio between its capacitance and its mass. Supercapacitor has widely studied as a storage device since it has higher specific capacitance compare to the conventional capacitor. It can overcome the limit of another energy storage such battery and traditional capacitor [1]. A rechargeable battery has high specific power and low specific energy. In contrast, a capacitor has low specific power and high specific energy [2-4]. Capacitor stored energy in between 2 electrical layer as electrodes seperated by an electrolyte [2].

To overcome the disadvantage of capacitor, the material which used as electrodes has been widely investigate. Two dimensions material like graphene is a proper material as electrode, beside it has porous structure, high surface area, it is also has high electrical conductivity. Moreover, graphene has porosity and liettability that is suitable for supercapacitor storage system [3-5]. Availability of perfect graphene is still limited and could not be made easily, but it can be approached using a material which has close characteristic as graphene. The characteristics of reduced graphene oxide (rGO) can...
approach characteristics of graphene and it is easily made compare to graphene. rGO can be prepared from graphene oxide (GO) solution as a precursor and then thermally reduced to remove its oxygen functional group of GO [5].

The configuration of supercapacitor device in this experiment consist of two (2) symmetric rGO/ITO as electrode that separated by a filter paper and 1 M KCl as an electrolyte. In this experiment for investigation of device best performance it is determined the capacitance and its energy storage values based on the cyclic voltammetry (CV) data.

2. Method
2.1. Fabrication of rGO films on ITO-glass
1 mg/ml GO solution in water (Graphenea SA ES A75022608) was sonicated for an hour in room temperature. Then it was electrochemically deposited using MetrOhm Autolab on ITO-glass substrates (1 cm × 1.25 cm) using three-electrodes system. Those electrodes were Ag/AgCl as a reference, Pt as a counter electrode and ITO as a working electrode. All three electrodes are arranged in cells containing 12 ml GO solution. Deposition has been done in various voltage cycles (1 to 5 cycles) with voltage applied in the range of -1.6 V to 0 V and scan rate of 75 mV/s The samples then were dried on hotplate at temperature of 25 °C. In order to obtain rGO films, the GO thin films were thermally reduced using furnace at 200 °C for 2 hours under argon flowing.

2.2. Fabrication of rGO supercapacitor
The rGO supercapacitor device model was built using two symmetric rGO films on ITO as active electrodes and a piece of filter paper as a separator. The filter paper that soaked in 1M KCl solution then was inserted between two symmetrical rGO films. Finally, the device was covered by parafilm. The schematic model of supercapacitor device is shows in figure 1. In this experiment, we prepared five (5) devices samples that consist of varied rGO film thickness. The sample was labelled as S1, S2, S3, S4 and S5 for device using 1, 2, 3, 4 and 5 voltage cycles deposition of GO films, respectively.

![Figure 1. Schematic configuration of supercapacitor device model.](image)

2.3. Measurements
The electrochemical capacitance measurements of the rGO supercapacitors device model were carried out using CV measurement (MetrOhm Autolab). It was done by applying voltage to the device and at the same time measured its current response of the device. The CV characteristic of the device was measured at voltage range of 0 V – 0.9 V. The device’s performance was observed from their CV curve shapes for various scan rate from 25 mV/s to 125 mV/s to check its stability. The stored power in the device is calculated using equation (1) and the capacitance value is calculated using equation (2).

\[
P = \int_0^{0.9} i \, dV + \int_0^0 i \, dV
\]

\[
C = \frac{1}{2m \Delta V_s} \left( \int_{-0.9}^{0} i dV + \int_0^{0.9} i dV \right)
\]

P in the equation (1) is a power storage of device for a certain scan rate, I is a current response of device for a given applied voltages. C in the equation (2) is a specific capacitance of device, m is mass
of electroactive materials, \( \Delta V \) is the potential window (which is 0.9 volts), \( s \) is scan rate using in the CV measurement.

3. Result and Discussion

Samples in figure 2 that labelled as E1, E2, E3, E4 and E5 are five pair of rGO films on ITO-glass substrates. The samples of E1, E2, E3, E4 and E5 were obtained from GO films that thermally reduced at 200 \(^\circ\)C for 2 hours. These GO films were electrochemically deposited using five different number of voltage cycles i.e. 1, 2, 3, 4 and 5 cycles, respectively. Increasing number of voltage cycles during the deposition causes increasing of GO films thickness. As can be seen on figure 2, the samples are homogeneous with a darkness level gradually increased for samples that deposited at higher number of cycles. The film darkness is related with the films thickness, thicker film appeared more dark compare to thinner GO film. Its darkness color indicates that rGO films was dominated by carbon atom and reducing oxygen atom. In this experiment we use the rGO films that prepared from GO film as “graphene-like” material.

![Figure 2](image)

**Figure 2.** The pairs of rGO films on ITO-glass substrates that electrochemically prepared using various voltage cycle during deposition, one cycle (E1), two cycles (E2), three cycles (E3), four cycles (E4), and five cycles (E5).

Then the rGO samples were employed as a pair of electrodes for supercapacitor devices model that its device structure shown in figure 1. We built five supercapacitor devices model named as S1, S2, S3, S4 and S5 by employed pair of rGO film of E1, E2, E3, E4 and E5, respectively as electrodes.

The CV characteristic of device samples S1 to S5 measured using scan rate of 25 mV/s and 50 mV/s are shown in figure 3. From figure 3 it is obvious that device of S3 has the biggest CV. It indicates that the S3 device has better power capacity than the other sample devices.

![Figure 3](image)

**Figure 3.** Cyclic voltamogram of S1 to S5 supercapacitor devices at scanrate of (a) 25 mV/s and (b) 50 mV/s.

Furthermore, figure 4 shows characteristic of CV curves of S3 device that measured at varied scan rate i.e. 25 mV/s, 50 mV/s, 75 mV/s, 100 mV/s and 125 mV/s. The curve displays the effect of scan rate on the device capacity. All of CV curves has a similar shape but different size. It implies that the
device model was stable enough in the voltage range of applied scan rate. The CV area increases as the scan rate was increased and it indicates that power capacity of S3 device also increased.

The values of power capacity and specific capacitance of the S3 device for various scan rates were calculated using equation (1) and (2) and those results were plotted in two different graphs as shown in figure 5. The highest power density of the S3 device is 0.825 W/kg that was achieved at scan rate of 125 mV/s. At this scan rate, however, its specific capacitance is reached the lowest value i.e. 6 F/kg. The highest specific capacitance is 20 F/kg that achieved at scan rate of 25 mV/s. At that scan rate, however, its power density is the lowest i.e. 0.375 W/kg.

![Figure 4. CV curves of S3 supercapacitor device model at various scan rate.](image)

![Figure 5. Characteristic curve of S3 supercapacitor devices at various scan rate, (a) specific capacitance and (b) power density.](image)

As shown in the figure 5, the value of specific capacitance of S3 device decrease significantly at low scan rate, but in contrast, the value of its power density increased. For a voltage window of 0.9 V and scan rate of 125 mV/s, the time required to complete one loop of cyclic voltammogram is 14.4 s. Therefore, a power density of 0.825 W/kg at scan rate of 125 mV/s is equivalent to energy density of 0.003 Wh/kg.

Based on Ragone plot [1], a capacitor device is specified as a supercapacitor if its specific energy is above 0.05 Wh/kg and its power density is above 10 W/kg. From this point of view, the S3 device model could not classified as supercapacitor device. However, the device still could specify as supercapacitor from point of view specific capacitance since it has quite large specific capacitance in the range of 6 F/kg to 20 F/kg.
4. Conclusion
We have built supercapacitor devices model using rGO films as electrodes. The S3 supercapacitor device that consist of rGO electrodes, obtained from GO film that electrochemically prepared using three voltage cycles, has higher performance. The S3 supercapacitor has power density of 0.825 W/kg and specific capacitance of 20 F/kg. Although its specific energy still lower than the standard criteria of supercapacitor but its specific capacitance is large enough.

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