Testing of the charging and discharging characteristic of chitosan thick film as a capacitor dielectric

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Abstract. In this study, chitosan films were fabricated through solution casting method with a thickness of 200 μm. Testing of charging and discharging characteristics of dielectric chitosan film was done by placing a chitosan film in a capacitor system configuration. The testing used an RC series circuit with the supply voltage in DC. Testing of charging and discharging characteristics was conducted in two experimental stages, the first is by varying the supply voltage values of 1V, 3V, 5V, 10V and 15V and the second is by varying the resistance value of 100 Ω, 1K Ω, 10K Ω, 100K Ω and 1M Ω. Variation of the supply voltage was conducted to obtain the charging and discharging characteristic of chitosan film while the variation of the resistance value was conducted to find out the performance of chitosan film. Of the above experiments were obtained that the chitosan film has a very fast response to the electric field. Besides, it was obtained that the performance of chitosan film meets the general equation of capacitance in RC series circuit. Analysis of thermal properties using DSC showed that chitosan film has a low specific heat of 0.016 J/g K.

1. Introduction

The electronic waste (E-waste) is one of the causes of climate change, environmental pollution and the spread of health problems. According to data from the United Nations Environment Program, globally electronic waste has been grown to 40 million tons per year [2]. The rapid development of technology in the field of electronics followed by the rapid electronic stuff become obsolete because the emergence of a new generation of technology is the main cause of electronic stuff to switch functions into waste. Various efforts have been made by governments in many countries through e-waste sustainable management programs to reduce the value of world electronic waste, but the Environmental Protection Agency estimates that only 15 – 20% of electronic waste was recycled while the rest end up in landfills [3].

The capacitor is one of the electronics components whose the existence is required by almost every electronic circuit. The use of non-degradable dielectrics such as metallized polycarbonate, metallized polyester, tantalum and mica on the commercial capacitor is of particular concern because non-degradable dielectrics are difficult to degrade and toxic. The dielectric material is generally
distinguished based on the element material such us solids with an amorphous or non-polar crystal structure, an inorganic substance with a structure of ionic crystals and molecules of a polymeric material. Generally, solids with amorphous or crystalline structures are nonpolar and inorganic substances with ionic crystalline structures are non-degradable materials and toxic. While the dielectric of polymer material is divided into two types that is a synthetic polymer and a natural polymer. Natural polymers are typically biodegradable and non-toxic. Therefore in this research, we used the natural polymer material such as chitosan as a dielectric material which is expected to be an alternative material dielectric that can function as an environmentally friendly dielectric on commercial capacitors.

Chitosan was selected because of its biodegradable [6], biocompatible, biofunctional and nontoxic properties [9]. Moreover, chitosan is a natural polymer with the second largest amount of production volume in the wild [7]. The various literature states chitosan is the most popular natural polymer in the development of electronic devices, this is due to its unique characteristics. The presence of free amino groups and hydroxyl groups in chitosan compounds [4] making this natural polymer can be easily modified [8]. This shows that chitosan-based electronic devices can be further enhanced through the addition of other chemicals so that the application can be wider in the various field.

In this study, Testing of charging and discharging characteristics of chitosan film was conducted in two experimental stages. In the first stage, the supply voltage values were varied of 1V, 3V, 5V, 10V and 15V, it was performed to obtain the charging and discharging characteristic of chitosan film. In the second stage, the resistance value was varied of 100 Ω, 1K Ω, 10K Ω, 100K Ω and 1M Ω. It was performed to observe whether the performance of chitosan film meets the general equation of capacitance in series RC circuit. Characterization using DSC was also performed to analyse the thermal properties of chitosan film.

2. Experimental

2.1 Chitosan Film Fabrication

The sample was prepared using the solution casting technique by stirring 1.5 grammes of chitosan powder (medium molecular weight of Sigma-Aldrich production) in 50 mL 1% (v/v) acetic acid (EMD Millipore production) solution. The Stirring process was conducted using a Scilogex magnetic stirrer with rotation speed 300 rpm for 6 hours at room temperature (23 ± 20C). After stirring process, the homogenous solution was poured into Normax Petri dish and then, dried in Digital Oven (Memmert UN 55) at temperature 60°C for 12 hours. The dried chitosan thick film was cut into a smaller thick film with the dimension of 1.8 x 1.8 cm².

2.2 Testing of charging and discharging

First testing. Chitosan film with a surface area of 3.24 cm² and a thickness of 200 μm was arranged parallel between two electrodes (copper) inside a capacitor system configuration. This system was integrated into RC series circuit as C (capacitor), this RC series circuit was equipped with Regulated DC Power Supply ATTEN APS3003S as supply voltage source and a digital multimeter Hydra Series III fluke 87 V to display the result of testing. In this testing, the supply voltage values were varied of 1V, 3V, 5V, 10V and 15V. Second testing. The similar testing was conducted with the same experimental setup as in the first testing by varying the resistance values of 100 Ω, 1K Ω, 10K Ω, 100K Ω and 1M Ω at the voltage value of 5 volts.

2.3 Characterization of chitosan film

Dielectric film chitosan was characterized using Differential Scanning Calorimetry (SDT Q100), the sample was heated from room temperature up to 500 °C with a heating rate of 10 °C / min.

3. Results and discussion

Figure 1 shows the charging and discharging process of chitosan thick film as a capacitor dielectric in a system of RC series circuit. Seen that on each variation of the supply voltage, the capacitor with the chitosan film as dielectric therein experiences a transient period of less than one minute. It can be seen
through the increase in the value of the sharply increased output voltage and the decrease in the value of the output current that is very drastic when the charging process begins. This indicates that the chitosan film has a fast response to the electric field.

Shortly after the chitosan film capacitor undergoes a transient period, the chitosan film capacitor immediately enters the steady state period. This is shown by stable voltage values and output currents, it is also indicated that the transient period does not cause damage to the chemical bond of the chitosan film.

In the process of discharging, the chitosan film capacitor also shows the ability of high electrical charge transfer to the resistance. This can be seen through the graph of voltage and output current which drops very sharply after the emptying process begins. The increase of the output voltage value and a decrease of the output current value during the charging process indicates the electric field can orient the chitosan film molecule. This is because the bond strength of the chitosan film molecule does not restrain the orientation of the molecule toward the electric field.

![Graphs showing charging and discharging characteristics of chitosan film capacitor](image)

**Figure 1.** Testing of the charging and discharging characteristic of chitosan thick film as a capacitor dielectric using an RC series circuit at the supply voltage of 1, 3, 5, 10, 15 volts, respectively

Through the results obtained in the first experiment, a calculation was conducted to the value of electrical charge which saved by chitosan film capacitor using the general equation in this bellow,

$$Q = i \cdot t$$

where $i$ = The value of the stored voltage during the charging process (at $t = 3600$ seconds) per the value of resistance (10K Ω), and $t$ = The length of time the charging process (3600 seconds).

Through the calculations was obtained the ratio of the charge value which stored by the chitosan film capacitor at each value of the supply voltage variation.
Table 1. The electrical charge which stored by chitosan film dielectric at each value of the supply voltage

| No | Supply Voltage (V) | Electrical charge (C) |
|----|-------------------|-----------------------|
| 1  | 1                 | 0.065                 |
| 2  | 3                 | 0.078                 |
| 3  | 5                 | 0.304                 |
| 4  | 10                | 0.200                 |
| 5  | 15                | 0.151                 |

The above table shows at the supply voltage of 5 volts the amount of electrical charge that can store by chitosan film capacitor shows the maximum value of 0.304 C. This value is much greater when compared to the applied supply voltage ≤ 5 volts. Similarly, when the applied supply voltage value is increased. Therefore 5 volts was used as the value of supply voltage in the next testing of charging and discharging characteristics by varying the resistance value of 100 Ω, 1K Ω, 10K Ω, 100K Ω and 1M Ω.

Table 2. Changes in capacitance value along with increasing the resistance value

| No | Resistance (Ω) | Capacitance (F) |
|----|----------------|-----------------|
| 1  | 100            | 3.1725          |
| 2  | 1000           | 0.4136          |
| 3  | 10000          | 0.05379         |
| 4  | 100000         | 0.007917        |
| 5  | 1000000        | 0.001522        |

The above table shows the effect of resistance value variation on the charging and discharging process of the chitosan film capacitor to the value of capacitance. It is seen that the increase of resistance value causes the capacitance value of chitosan film capacitor to decrease. This result meets the general equation of capacitance in RC series circuit,

\[ C = -\frac{t}{R \ln\left(\frac{1}{e}\right)} \]  

where the resistance value is inversely proportional to the value of the capacitance.

The result of DSC analysis in figure 2 shows the peak value of endothermic T<sub>e</sub> is 102.866 °C while the exothermic peak value T<sub>m</sub> is 278.953 °C. A dielectric material should have high thermal resistance even though it will be adapted to the type of capacitor application. Knowing the glass transition value of the dielectric aims to determine the thermal limit of the capacitor application. It is related to the importance of knowing the value of supply energy that can be accepted by the dielectric to prevent the occurrence of electrical properties damage in the dielectric. The amount of energy supply that is acceptable to the dielectric material depends on the specific heat of the material. For that through the thermogram result of DSC analysis (figure 2), the specific heat of the chitosan film was calculated by the equation below [5],

\[ C = \frac{[DSC (T)_{Sample} - DSC (T)_{Baseline}]}{\varphi} \]  

where \( DSC (T)_{Sample} \) = The value of DSC signal at temperature glass transition of thermogram (W/g), \( DSC (T)_{Baseline} \) = The value of DSC signal at a temperature from thermogram base for phase change (W/g) and \( \varphi \) = heating rate (°C/s).
Using the equation 3, it was obtained the specific heat of the dielectric chitosan film is 26,003 J/g °C or 0.016 J/g K. This value is relatively small compared to dielectric type of polymers such as Polypropylene with a specific heat value of 1571 J/g K and Polystyrene with a specific heat value of 927 J/g K [1]. If to raise the temperature of one gram of chitosan film material of 1 °C required the energy of 26,003 joules, then to make one gram of its substance reach the glass transition temperature is 2,674 joules. Therefore it is concluded that the amount supply energy which is acceptable to the chitosan film dielectric is ≤ 2,674.5 J.

![Figure 2. DSC analysis of chitosan film](image)

Table 3 below shows the value of energy applied during the charging process of the chitosan film capacitor at each variation of the supply voltage value. The value of supply energy was calculated using the equation below,

\[ E = V I t \]  

(4)

where \( V \) = The value of supplied voltage (V), \( I \) = The current value in the circuit (µA) and \( t \) = The length of time the charging process (3600 seconds).

Through the table 3, it can be seen that the variation of the supply voltage values was used in this study is the voltage value that can still be accepted by chitosan film dielectric, where the amount of energy applied is below of the acceptable energy limit of the dielectric material.

**Table 3. The amount of energy supply in each supply voltage variation**

| No | Tegangan supply (V) | Energi supply \(\times 10^{-3}\) J |
|----|---------------------|-----------------------------------|
| 1  | 1                   | 2.985                             |
| 2  | 3                   | 29.059                            |
| 3  | 5                   | 108.412                           |
| 4  | 10                  | 390.388                           |
| 5  | 15                  | 861.562                           |

**4. Conclusion**

Testing of charging and discharging characteristics shows that the chitosan film dielectric has a fast response to the electric field. Besides, obtained that the performance of chitosan film meets the general equation of capacitance in series RC circuit. Analysis of thermal properties using DSC showed the chitosan film has a low specific heat of 0.016 J/g K. Therefore, chitosan film can be applied as an environmentally friendly dielectric capacitor with low voltage consumption.
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