Analysis characteristic of cholesteryl acrylate conductivity with the addition of the PE-b-PEG doped ITO-nanoparticle in the development of liquid crystal technology

M Ismail*, A Afrizal, D I Syafei and M A Puspita
Department of Chemistry, Faculty of Mathematics and Natural Science, Universitas Negeri Jakarta, Jl. Rawamangun Muka, Jakarta, Indonesia

*mikanimochinus@gmail.com

Abstract. The study of liquid crystal material is very interesting and has the opportunity as a smart material such as cholesteryl acrylate. Liquid crystal cholesteryl acrylate can be made synthesized by Acryloiloxy Butyloxy Benzoate (ABB) precursor and cholesterol. Cholesteryl acrylate was polymerized by the ultraviolet curing (UV-Curing) method to keep the crystal structure stable. During the polymerization process some ingredients are added which can increase and regulate the formation of liquid crystal structure phases. Cholesteryl acrylate can be doped by adding conductive oxide in the form of nano particle scale Indium Tin Oxide (18 nm). The optimum conductivity results were 5.70 x 10^{-7} S/m with the addition of ITO 10% w/w. The structure of the crystal phase formed can be directed by the addition of Polyethylene-block-Polyethylene Glycol during the UV-Curing process. The hydrophobic part of PE block will interact with hydrophobic liquid crystal molecules, while the hydrophilic part of the PEG block has a high affinity for the hydrophilic ITO electrode substrate. The added PE-b-PEG varies from 0.001 to 0.005 percent by weight of polymer cholesteryl acrylate composite. Conductance data is measured using LCR meters from a frequency of 50 Hertz to 5000 kHzertz. The average conductance data for ITO is 0.09597838 S, cholesteryl acrylate is 5.20635 x 10^{-6} S, the polymer cholesteryl acrylate composite with doped ITO is 4.58284 x 10^{-6} S. When added PE-b-PEG 0.003 percent composite weight is obtained the highest average conductance data is 1.24234 x 10^{-5} S with an average conductivity value of 6.09 x 10^{-5} S/m. The varies composition of PE-b-PEG content is very influential to regulate the arrangement of crystals formed in electrical conductivity.

1. Introduction
Liquid crystal is a unique material and has very broad potential in various aspects of today's technology. A number of studies related to liquid crystalline material have been widely studied following the needs of the times. The researchers continue to strive to find new formulas in developing quality improvement materials such as liquid crystals. Today, liquid crystal material has been widely studied in the development of display technology [1]. Applications of liquid crystalline material can be used as biosensors such as temperature sensors, sensors that detect radiation-prone areas [2], and as an electro-optical material in a Liquid Crystal Display device [3]. This is because the properties of liquid crystals can polarize light, form thin, have an effective electric field response, and have low energy and voltage requirements [4]. In addition, liquid crystal material also has several advantages, namely when it wants...
to be synthesized, the material needed is easily obtained, and is more environmentally friendly because it comes from organic material [5].

Liquid crystalline cholesteryl acrylate material is a material that can be made by reacting it using Acryloiloxy Butyloxy Benzoate (ABB) and cholesterol precursors. The ABB precursor react with cholesteryl acrylate to form a collosteric structure [6]. Each layer in a colonic structure has a helical molecular structure on a regular basis. The layer in the collosteric structure also has a high level of stability. The value of the distance between the crystalline molecular liquid molecules which is twisted is called the pitch value in one full twist 360° [7]. The distance between the crystals can be inserted by the Indium Tin Oxide (ITO) nanoparticle dopant which serves to increase the conductivity value [8]. In addition to direct the arrangement of phases, Polyethylene-block-Polyethylene Glycol (PE-b-PEG) can be used which has hydrophobic and hydrophilic properties [9].

Further studies related to the liquid crystalline cholesteryl-acrylate when added PE-b-PEG have not been carried out. The results of the last study of liquid crystalline cholesterol acrylate were cholesteryl acrylate polymerized and coupled with ITO nanoparticles. The combination of nematic liquid crystals with a dopant of ITO nanoparticles can reduce the resistivity value from $7.73 \times 10^{11}$ to $1.21 \times 10^{11}$ Ω/m [10]. The ITO nanoparticle dopant used as a dopant from liquid crystalline cholesteryl acrylate gave the highest conductivity value of $5.70 \times 10^{-7}$ S/m with an ITO concentration of 10% w/w [11]. The addition of PE-b-PEG arranged as a block copolymer is expected to be able to interact with liquid crystal molecules assembling helical arrangements to form a phase of coloesteric structure [9]. Cholesteric phase is a mesophase structure condition from liquid crystalline cholesteryl acrylate which can conduct electric current [12].

The results obtained from this study are conductance data. Conductance data is very important as a reference to determine whether this material is a conductor, semiconductor, and insulator. Conductance is the ability of an object to deliver an electric current from a material and in SI units it has siemens (S) units. Where high conductant values indicate that the material is able to condition electric current well, a low conductance value indicates that the material cannot flow the charge perfectly [13]. Some metal conductive dopants that can modify the conductivity properties of coloesteric liquid crystals are shown in Table 1.

### Table 1. List of several conductive dopants in a polymeric liquid crystal [14].

| Dopant                        | Particle Size | Density (kg/m³) |
|-------------------------------|---------------|-----------------|
| Carbonyl Iron                 | 1.1 μm        | 7000            |
| Indium Tin Oxide-ITO          | 3.38 μm       | 1200            |
| Metal splinters of Aluminium  | 12 μm         | 2700            |

1.1. Electrical conductivity

In the intrinsic semiconductor, the electron concentration in the conduction energy band (n) equals the hole concentration in the valence energy band (p) so that with index i expressing "intrinsic", $h$ is the Planck constant, $m^e$ and $m^h$ are mass respectively. Effective electrons and holes and Eg are energy gaps [15]. Based on the formula from Kittel, conductivity can be calculated by equation:

$$n_i = p_i = 2 \left( \frac{2\pi k_B T}{\hbar^2} \right) ^{3/2} \left( m^e m^h \right)^{3/4} e^{-E_g/(2k_BT)}$$  \hspace{1cm} (1)

Electrical Conductivity ($\sigma$) in semiconductor material is strongly related to electron mobility ($\mu_e$) and hole mobility ($\mu_h$), the equation is:

$$\sigma = e(n\mu_e + p\mu_h) = e n_i(\mu_e + \mu_h)$$  \hspace{1cm} (2)

Equation (2) shows that conductivity depends on the concentration of the electric charge carrier. Each semiconductor material has a different gap energy. Silicon has an energy gap of 1.1 eV, germanium has a gap energy of 0.7 eV, and the dopant of ITO nanoparticles has an energy gap of 0.2 eV to 2.5 eV.
because it is a semiconductor material [16]. Calculations for gap energy can be formulated by Jorena with:

\[ E_g = \ln \sigma_o / \sigma - 2kT \]  

(3)

Where \( \sigma_o \) has constant 2.173913043, \( \sigma \) as the conductivity value, k is the Boltzman constant value (8.62 x 10^{-5} eV), and T is the temperature value. In addition to that the electrical conductivity produced can also be formulated:

\[ \sigma = G \frac{L}{A} \]  

(4)

Where G is the conductance value (S), L is the thickness of the plate (1.96 x 10^{-3} m), and A is the cross-sectional area of the plate (4 x 10^{-4} m). Permittivity can also be measured through equations:

\[ \varepsilon = \frac{C \times L}{A \varepsilon_0} \]  

(5)

Where C is the sample capacitance value (F), and \( \varepsilon_0 \) is the relative permittivity value in vacuum which is equal to (8.85 x 10^{-12} C^2/Nm^2), L is the sample plate thickness and A is the cross-sectional area of the sample plate.

2. Methods

The steps carried out in this study were started by making Acryloiloxy Butyloxy Benzoate (ABB) precursors which were reacted with cholesterol to form a cholesteryl acrylate monomer. In order to maintain the structure of cholesteryl acrylate in order to remain stable photopolymerization process was carried out using the in situ method by providing ultraviolet light radiation at a certain time. During the photopolymerization process a number of supporting materials were added which consisted of Indium Tin Oxide (ITO) and Polyethylene-block-Polyethylene Glycol (PE-b-PEG). The fixed variable is the cholesteryl acrylate monomer and ITO nanoparticle dopant, while the independent variable is a variation of PE-b-PEG which consists of a variation range of 0.001 to 0.005. Furthermore, the photopolymerization samples measured their electrositivity using LCR Meter type Hioki 3532-50.

3. Results and discussion

The conductance value obtained can be measured using equation (4) and the permittivity value can be measured using equation (5). The frequency range used is starting from the smallest frequency of 5 Hz to the largest frequency of 5 MHz.

Based on Table 2, it can be seen that the cholesteryl acrylate is an organic material can be increased the conductivity value if it is given an ITO nanoparticle and PE-b-PEG material. ITO nanoparticles are conductive oxides which have a large conductivity of 0.47 S / m. The addition of PE-b-PEG can increase the value of conductivity because the helical twisted molecular structure forming the colesteric phase can form its own structure directed by PE-b-PEG. The addition of ITO nanoparticles dopants and PE-b-PEG material can increase the conductivity value. Therefore, the polymeric acrylate material that has been made in such a condition is classified as a semiconductor material. The smallest energy gap of the liquid crystalline polyester acrylate material is 0.135 eV derived from the addition of PE-b-PEG 0.003. The smaller the energy gap a material makes it easier for electrons to move from the valence band to the conduction band. A material if given an external electric field through an electrode, it can be seen the electrical phenomenon that appears (conductance and capacitance). Changing voltage frequency can cause a change in direction of electric dipole moment. If the material's dipole moment is more uniform, then this condition will reduce the external electric field.
Table 2. Conductance data, capacitance, conductivity, and permittivity of liquid crystalline cholesteryl acrylate.

| Sample                     | Conductance (S) | Capacitance (F) | \( \sigma \) (S/m) | \( \varepsilon_0 \) |
|----------------------------|----------------|-----------------|---------------------|-----------------------|
| Cholesteryl Acrylate       | 5.20635 x 10^{-6} | 9.46 x 10^{-11} | 2.55111 x 10^{-5} | 52.35858236          |
| ITO                       | 0.095978        | 2.75 x 10^{-6}  | 0.470294062        | 1,520,613.148        |
| PE-b-PEG                  | 2.47611 x 10^{-5} | 2.1 x 10^{-7}  | 0.000121329        | 116,079.5419         |
| CA + ITO                  | 4.58284 x 10^{-6} | 5.37 x 10^{-11} | 2.24559 x 10^{-5} | 29.71871593          |
| CA + ITO + PE-b-PEG 0.001 | 1.16643 x 10^{-5} | 1.80 x 10^{-10} | 5.71551 x 10^{-5} | 99.8316056           |
| CA + ITO + PE-b-PEG 0.002 | 1.18222 x 10^{-5} | 1.03 x 10^{-10} | 5.79286 x 10^{-5} | 56.9674339           |
| CA + ITO + PE-b-PEG 0.003 | 1.24234 x 10^{-5} | 2.69 x 10^{-10} | 6.08745 x 10^{-5} | 148.9783775          |
| CA + ITO + PE-b-PEG 0.004 | 8.06323 x 10^{-6} | 7.65 x 10^{-11} | 3.95098 x 10^{-5} | 42.33352619          |
| CA + ITO + PE-b-PEG 0.005 | 8.15005 x 10^{-6} | 7.5 x 10^{-11}  | 3.99352 x 10^{-5} | 41.50156322          |

The ability of the liquid crystalline cholesteryl acrylate material on delivering the largest electric current occurs when giving frequencies around 4 MHz to 5 MHz. Liquid crystalline cholesteryl acrylate material added with 0.003 PE-b-PEG material obtained greater conductance data compared to the addition of other PE-b-PEG materials. The average conductance data of cholesteryl acrylate dopant ITO nanoparticles under PE-b-PEG 0.003 is 1.242 x 10^{-5} S with conductivity values of 6.087 x 10^{-5} S/m. The optimum condition does not significantly influence the increase in the value of the electrical conductivity produced (Figure 1). The conductance value is influenced by the movement of the ion charge, the density of the charge, and the strength of the electric field produced.

The addition of PE-b-PEG did not have a significant effect on the conductivity value of liquid crystalline cholesteryl acrylate. The biggest percentage is only giving effect as much as 58% when adding PE-b-PEG 0.003 (Figure 2). This is because PE-b-PEG only functions as a material that directs the formation of a collesteric structure in a polymeric cholesteryl acrylate.

![Figure 1. Relationship between conductance and frequency.](image-url)
Figure 2. Percentage of influence of PE-b-PEG on conductivity.

The size of the amount of electric charge stored for an electric potential can be measured based on capacitance data (Figure 3). The highest average capacitance value is obtained when the addition of PE-b-PEG 0.003 which is equal to $2.69 \times 10^{-10}$ F. In the frequency condition of 0.387 MHz there is a significant increase in capacitance, namely from $5.6616 \times 10^{-12}$ to $2.2704 \times 10^{-11}$. The polymeric acrylate polymer dopant ITO nanoparticles at a frequency of 2.488 MHz has a large conductance with PE-b-PEG 0.003 compared to other PE-b-PEG. This explains that the liquid polyester crystalline acrylic can store a good electrical charge especially with the addition of PE-b-PEG 0.003 that at high frequency conditions there has been a change in the direction of the external electric field.

Figure 3. Relationship capacitance to frequency.

The energy gap of liquid crystals is very influential on the nature of liquid crystals. The smaller of energy gap, the electrons is easier from the valence band to move to the conduction band because the gap between spaces is narrow. Based on table data (3) the smallest energy gap is obtained for the composite sample of polymeric acrylate polymer dopant ITO nanoparticles with PE-b-PEG 0.003 of 0.135 eV. The narrow distance between gaps will facilitate electron mobility so that it can increase the conductivity value.
Table 3. The energy gap of the liquid crystalline cholesteryl acrylate in addition to the variation of PE-b-PEG.

| Sample                        | Energy Gap (eV)  |
|-------------------------------|------------------|
| Cholesteryl Acrylate          | 0.146793         |
| ITO                           | 0.019795         |
| KA + ITO + PE-b-PEG 0.001     | 0.136363275     |
| KA + ITO + PE-b-PEG 0.002     | 0.136189472     |
| KA + ITO + PE-b-PEG 0.003     | 0.135548091     |
| KA + ITO + PE-b-PEG 0.004     | 0.141137292     |
| KA + ITO + PE-b-PEG 0.005     | 0.140998807     |

4. Conclusion
Composite polymer liquid crystal polymer composites were successfully obtained by synthesis of ABB precursors and cholesterol. Next is the photopolymerization to keep the structure of the structure stable, with ultraviolet radiation. During the UV-Curing process, the colloid acrylate monomer was mixed with ITO nanoparticles and PE-b-PEG materials with several variations. The addition of PE-b-PEG does not significantly increase the conductivity value, which only affects 58%. Based on the experimental results, the highest conductivity and capacitance data were obtained with the variation of PE-b-PEG of 0.003. In addition, the variation of PE-b-PEG 0.003 also has the lowest energy gap value which indicates that electron mobility can take place more smoothly.

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