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Potential solar cells material using Chlorophyll-Ferrocene complex

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ABSTRACT

Solar cells based on organic materials have many benefits compared to the conventional inorganic cells. Although theoretically, the capability of chlorophyll in producing electricity is high, the current situation shows limited stability and ability to produce electricity. This paper gives a comparison between pure chlorophyll and stabilized material of chlorophyll-ferrocene complex in terms of the UV absorbance wavelength and infrared absorption spectrum. The results show promising future for a new material for solar cells.

1. Introduction

Among the most effective way to produce electricity is by harvesting the solar irradiance directly from the sun using photovoltaic (PV) technology. There are several methods to increase the collection of solar irradiance. Some focus on aligning the panels with the sun (Ahmad et al., 2013a; Ahmad et al., 2013b) while others directly increased the efficiencies of the solar cells through improving the structure and chemical interaction within the material (Lim et al., 2015; Min Nam et al., 2010). They are many types of solar panels available in the market, ranging from inorganic to organic based solar cells. Inorganic PV has a few drawbacks such that it is costly, less efficient in high temperature ranges and its disposal can negatively impact the environment. Besides harmful to the environment, the inorganic silicon based PV are expensive due to the high cost of silicon. Currently, inorganic PV technologies were intensively studied to be widely used in converting sunlight to electricity. As a result, low cost organic solar cells have been explored over the years and over recent years, studies in organic and hybrid solar cells have increased with the recent achievement of 14.1% efficiency. However, this value is still low compared to the inorganic ones. One of the most important criteria to look after in organic PV is the interface must allow charge carriers, either holes or electrons, between an electrode material and an organic semiconductor active layer to easily pass with minimal resistance (Greiner and Lu, 2013). The low efficiency of organic material is worsen by the instability of the material which can reduce its efficiency through an extended disclosure to light and ambient air (Jørgensen et al., 2008; Dalal et al., 2012; Kawano et al., 2006).

This research explores the ability of chlorophyll to transform sunlight into another form of energy, electricity. Generally, plants transform the sunlight to sugar for food. Particularly, the chlorophyll content in the plants leaves makes all this possible, where it captures the coherent light and transforms it to another form of energy through the process called the photosynthesis. As the sunlight touches the leaves, photons of varying wavelength are absorbed; where Chlorophyll a and b as in Fig. 1 properly absorbed almost the entire light spectrum of the visible solar spectrum between 430nm to 700nm wavelengths as in Fig. 2. As photons of varying wavelength are absorbed; they produce an excited state of the electron called the exciton. Proteins in the chloroplast of the plant channel this energy to produce their own food as sugars.

However, our purpose is to produce electric instead of sugar. In order to do this, the function of protein in leaves is to be mimic and use in a solar cell application. In theory, once the electron excites, a suitable acceptor is needed to channel the electron to the electrodes mimicking the function of proteins. The current scenario, however, shows a very low efficiency, this may due to the fact that the electrons are confined within the chlorophyll structure thus the energy cannot be transferred out. Although chlorophyll is known as an excellent n-type semiconductor but without a suitable p-type acceptor it is impossible to transfer out the energy

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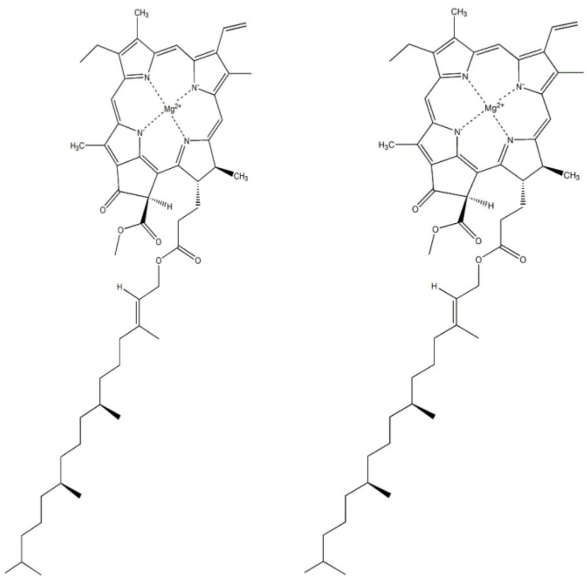
(Würfel, 2007). The main reasons are; photon absorption does not directly lead to free charge carriers and exactions with large binding energies are difficult to dissociate. Although, if the right combination of materials can be found, the organic solar cells can be as efficient as the inorganic one (Würfel, 2007).



a b

Fig. 1: Structure of chlorophyll

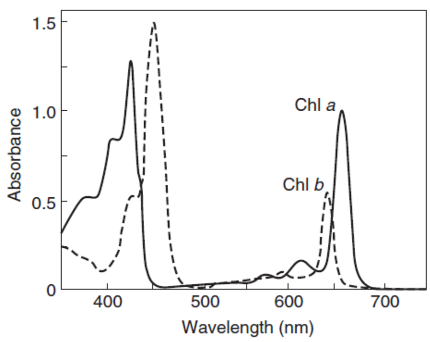


Fig. 2: Absorption spectra of Chlorophyll a and b (Lichtenthaler and Buschmann, 2001)

1.1. Function of ferrocene

Once the electron excites, a suitable acceptor is needed to channel the electron to the electrodes. In this case, the electron resonance inside the chlorophyll's structure has to be channeled onto other organic material called the ferrocene. The ferrocene molecular structure is shown in Fig. 3. The function of ferrocene is to mimic the plant's protein and stabilizes the chlorophyll structure. Theoretically, once the chlorophyll is bonded to the iron of the ferrocene, it allows the electron movements into the ferrocene and thus bridging the movement of electrons to the electrodes of the solar cell. Ferrocene was also used by many researchers in dye-sensitized solar cell as an electrolyte to increase the efficiency of the organic solar cell including in a research by Sonmezoglu et al. using Fe^{2+}/ Fe^{3+} (ferrocene) as its liquid electrolyte (Sonmezoglu et al., 2012).

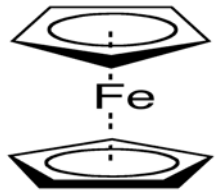


Fig. 3: Ferrocene molecular structure

2. Methodology

2.1. Extraction of chlorophyll

Spinacia oleracea or spinach is used for obtaining chlorophyll a and b since it is easily available and are among the richest chlorophyll contained leaves. The extraction of chlorophyll is done using column chromatography as depicted in Fig. 4 and thin layer chromatography. This process produces green dry powder of chlorophyll a and b.

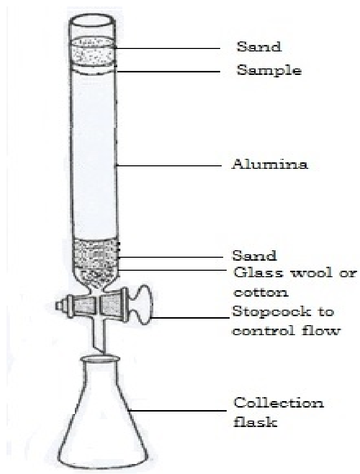


Fig. 4: Column chromatography

2.2. Chlorophyll- ferrocene structure

The combination of Ferrocene and Chlorophyll are dissolved in solvent. The color changes indicated by the solution show that a chemical reaction has occurred. A bond formation reaction is needed to occur between both materials and the bonding could be detected using Fourier Transform Infrared Spectroscopy (FTIR) equipment.

2.3. Infrared absorption

An analysis of the light absorbing activity comparing between the new materials formed and its original form is done by studying the light absorption under UV and visible light. A comparison and improvement in absorption wavelength are observed.

2.4. Resistivity test

The resistivity directly affects the solar cell performance where it is directly related to the conductivity of the material. Four point probe method is used to determine the resistivity of the sample. Then the conductivity can be calculated using these given equations:

$$R_S = 4.532 \times V/I \quad (1)$$

$$\sigma = 1/R_S \quad (2)$$

3. Results and discussion

3.1. FT-IR structural analysis

Three samples were used for the structural analysis. This will provide sufficient information of the material in its original form; the chlorophyll and the ferrocene in comparison to its new material formed which is the chlorophyll-ferrocene complex. To confirm that the chlorophyll extracted from this experiment is in its purest form, a comparison of its properties through the vibrational mode obtained from the experiment and literature are compared. The values are given in Table 1 and from the values obtained, all of the readings show similar values to the one from the literature.

In Fig. 5, on the other hand, shows a comparison between these three samples. Various information is observed from the graphs, including on the properties that needed to be retained and also the improvement needed in the new material. Firstly, a comparison between pure chlorophyll and chlorophyll-ferrocene complex graphs show that the pattern of peak values for both materials is still the same. This shows that the complex formed still retain its chlorophyll properties which shows a good sign in the complex formation. Secondly, a shift in peak from 2924.03 cm^{-1} in chlorophyll to 2917.90 cm^{-1} in the chlorophyll-ferrocene complex is observed. This shows that a chemical reaction had occurred and possibility of electrical conduction in the material is detected. Lastly, a comparison between the ferrocene and chlorophyll-ferrocene complex graphs shows that the peaks in ferrocene of 1105.45 cm^{-1}, 999.8 cm^{-1} and 814.86 cm^{-1}, are neutralized and are no longer visible in the complex form. This is a positive sign, where it proves that the chlorophyll has already formed a complex with the ferrocene.

Table 1: Comparison of chlorophyll's IR spectrum analysis (Holt and Jacobs, 1955, Shanmugam et al., 2015; Neault and Tajmir-Riahi, 1999)

Entry	Wavelength (cm^{-1})		Vibrational mode
	Literature	Experimental	
1	3392	3400	N- H stretching vibrations
2	2924	2924.03	C-H stretching vibrations
3	1705	1709.8	C= O ketone band
4	1610	1610	C =C vibrations
5	1000.96	1043.8	Chlorophyll peak
6	1664	1665	C= O aldehyde band

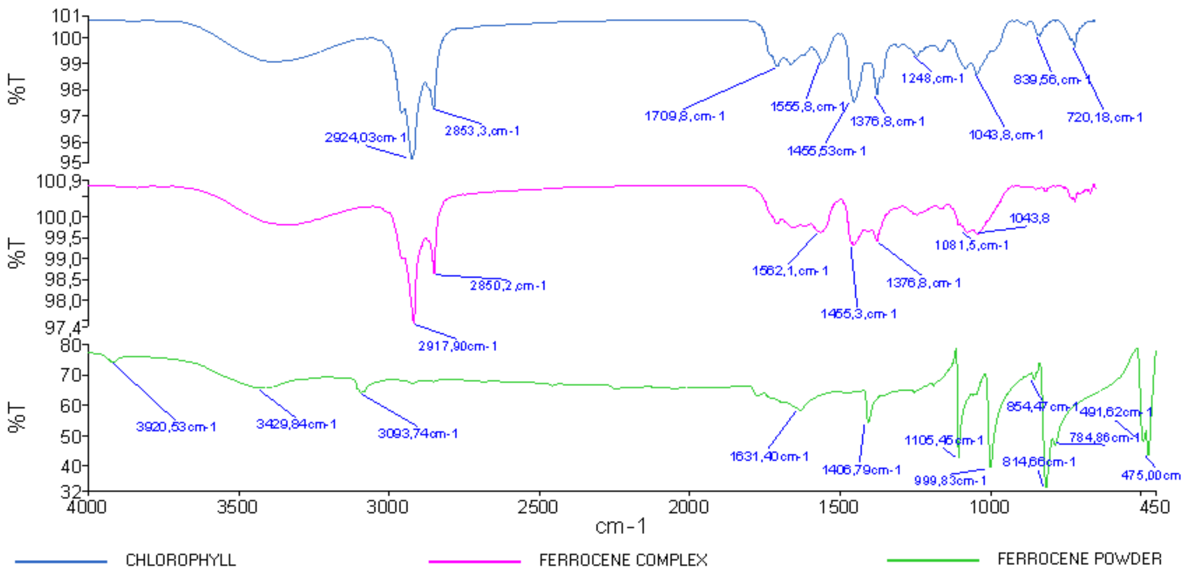


Fig. 5: FT-IR Result

3.2. Infrared absorption analysis

In general, there are 2 major absorption bands in the visible region for chlorophyll, the red and blue. Based on the result obtained from the UV-VIS analysis, between the absorption spectra of from the chlorophyll, the absorption spectra obtained from chlorophyll-ferrocene complex demonstrates longer shift in wavelength for both red and blue bands. Both peaks show an increment of 11% and 33% compared to its original form as shown in Fig. 6.

3.3. Conductivity

Based on the resistivity measured, it can be concluded that the material is conductive with the value of within the range of a semiconductor.

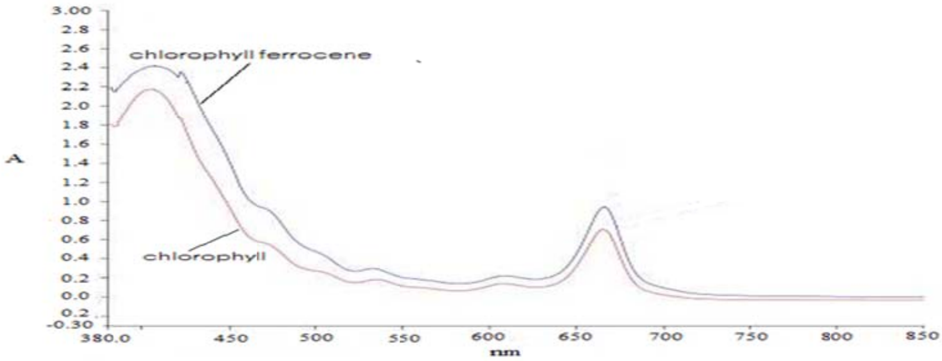


Fig. 6: UV-VIS Results

4. Conclusion

The experiment shows positive result based on the formation of the chlorophyll-ferrocene complex. Firstly, a complex formed provides stability to organic material, which in this case, the chlorophyll will have, more resistance against prolonged exposure to environmental factors. Next, higher and wider absorbency wavelength could provide higher output in producing electricity. In conclusion, chlorophyll-frozen complex form shows a high potential for solar cell material and further investigation is needed to prove its ability to produce electricity.

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