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Nonlinear Optical Properties of Clitoria Ternatea Dyes Using Z Scan Method

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Abstract: Nonlinear material has recently attracted in last decades which is very useful in optical application, but it comes with the issues of high cost, hazardous and complex synthesized methods of inorganic material. This study is aimed to determine and analyze the nonlinear absorption coefficient of the organic dye extracted from Clitoria Ternatea by using the Z-scan technique. It is measured through the open aperture of Z scan measurements to analyze the nonlinear absorption coefficient, β, on three different dye concentrations (0.004g/ml, 0.008g/ml and 0.016g/ml) at different powers. It was found that there is a decreasing trend in the value of nonlinear Absorption when the concentration increases in same power, showing that the CT dye exhibits saturable Absorption (SA). Based on these results, CT dye is a prospective competitor for building different photonics and optoelectronics equipment such as passive mode locking and Q switching of lasers due to these enticing properties.

Keywords: Z Scan Method, Clitoria Ternatea, Nonlinear Optical Properties, Nonlinear Organic Material, Anthocyanins

1. Introduction

Rapid developments of laser and optical fiber has greatly helped in the practical development of optical communications and optical devices [1]. Non-Linear Optical (NLO) materials have become the centre of many optical electronic warfare (EW) systems as well as other upcoming defence technologies because they can alter the wavelength and frequency of laser light, allowing operation in previously inaccessible parts of the electromagnetic spectrum (EMS) [2]. It has remarkable achievements in the photonic industry. Nonlinear optical properties have become the most important elements in optoelectronic devices such as solar cells as they maximize the efficiency due to their additional sensitivity, broadband spectral responses, etc. [1].

Inorganic nonlinear optical materials have made great strides since discovering laser oscillations in inorganic compounds in the 1960s [3]. By definition, inorganic material refers to mineral compounds that do not contain any carbon in the components and do not come from living beings, while any of the carbon-based substances discovered in nature are considered organic materials [4-5]. In addition,

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organic nonlinear optical materials have been researched due to its effective NLO properties, and fast response based on highly mobile electrons [6]. Nonlinear optical materials are crucial for high-capacity communications [7].

Clitoria ternatea, also widely recognized as butterfly peas, is a type of perennial herbaceous plant from the legume family [8]. It has received much attention lately due to its potential use in contemporary health and agriculture, and as a source of natural food colourants and antioxidants. This flower is native to India and Southeast Asia, and it can be cultivated for a reasonable price. The flower's petal is a vibrant blue because of the richness of polyphenols, primarily ternatin anthocyanins. Anthocyanins are pigment compounds that absorb a lot of light in the visible spectrum, giving them a red, blue, or purple appearance. They quickly emerge as a particularly promising component for electrochromic purposes [9].

Many methods are used to determine the nonlinear optical properties of materials, such as nonlinear interferometry, degenerate four-wave mixing, nearly degenerate three-wave mixing, ellipse rotation and beam distortion measurements [10]. However, among the techniques used in the previous research, the Z scan method has been chosen to conduct this experiment as it is the most sensitive, easiest, and most straightforward way to carry out [11]. This method is a popular method developed and invented by Sheik-Bahae et al. (1989-1990) who saw it as a straightforward approach to determining the nonlinear optical characteristics of materials [12]. Sheik-Bahae's Z-scan approach employs the notion of spatial beam distortion to measure both the magnitudes and the signs of real and imaginary parts of complicated nonlinear refractive indices [13-17].

Nonlinear material has recently attracted in last decades, which is very useful in optical applications [6]. A well-known problem with this type of material is that it does not consider the issues of high-cost, hazardous and complex synthesized methods [9]. Besides that, there is a further problem with using inorganic material that might possess potentially toxic substances such as lead and cadmium [18]. One approach to solve these issues involves the use of organic materials, which are easily obtained and eco-friendly. Characterization of Clitoria Ternatea dye is important for increased understanding of how to apply the organic dyes into optical devices due to its additional benefits. However, there are very few publications of studies on the nonlinear optical property of Clitoria Ternatea dye [9].

This paper was designed to determine and analyze the nonlinear optical properties of the Clitoria Ternatea dyes, such as the nonlinear absorption coefficient for three different concentrations, using the Z scan technique in distilled water and comparing its nonlinearity with two different powers, 74º and 78º.

2. Experimental Details

2.1 Preparation of Clitoria Ternatea dye solutions

The Clitoria ternatea plant was chosen to extract its dye in this study. The blue-colored flowers were first heated in a microwave oven for one hour. After that, the flowers were ground using the mortar and pestle to homogenize the samples in three different amounts of petals; 0.2g, 0.4g, and 0.8g. The petals were extracted using an aqueous technique, which involved dissolving each quantity in 50ml of distilled water. Each of the concentrations of the dyes is separated by test tubes and subsequently immersed in the water at 60ºC for 60 minutes. The resulting solution was continuously stirred. The medium was filtered out and aseptically transferred to the glass sampling bottles. Figure 1 below shows the Clitoria Ternatea dye solutions with a concentration of 0.004g/ml, 0.008g/ml and 0.016g/ml starting from the left respectively.

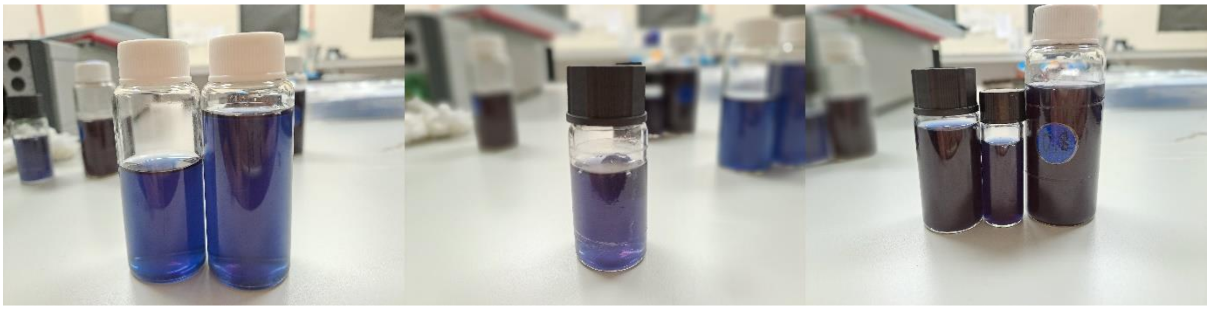

Figure 1: 0.004g/ml, 0.008g/ml and 0.016g/ml of Clitoria Ternatea dye solutions

2.2 Linear Absorption

The UV-Vis spectrometer (U-3900H) was used to determine the absorbance values of the different concentrations of CT dye solutions. The linear absorption coefficients of all dye concentrations were calculated using absorbance data from the UV-Vis spectrometer.

2.3 Nonlinear absorption characterization

Z scan technique was used to measure the nonlinear absorption coefficient of dye samples in distilled water. This study uses a femtosecond laser at 808nm of wavelength as a light source. Figure 1 depicts a schematic representation of the experimental setup. A 1mm quartz cuvette holding sample dye is mounted into a precision computerized platform and moved along the laser-beam's parallel direction. The power of the laser is adjusted from 74º to 78° to see the difference in its nonlinearity for each of the dye concentrations. The beam is fully collected by the Photodetector 1 (PD1). Transmitted signals were collected by using the oscilloscope which connected to the photodiode.

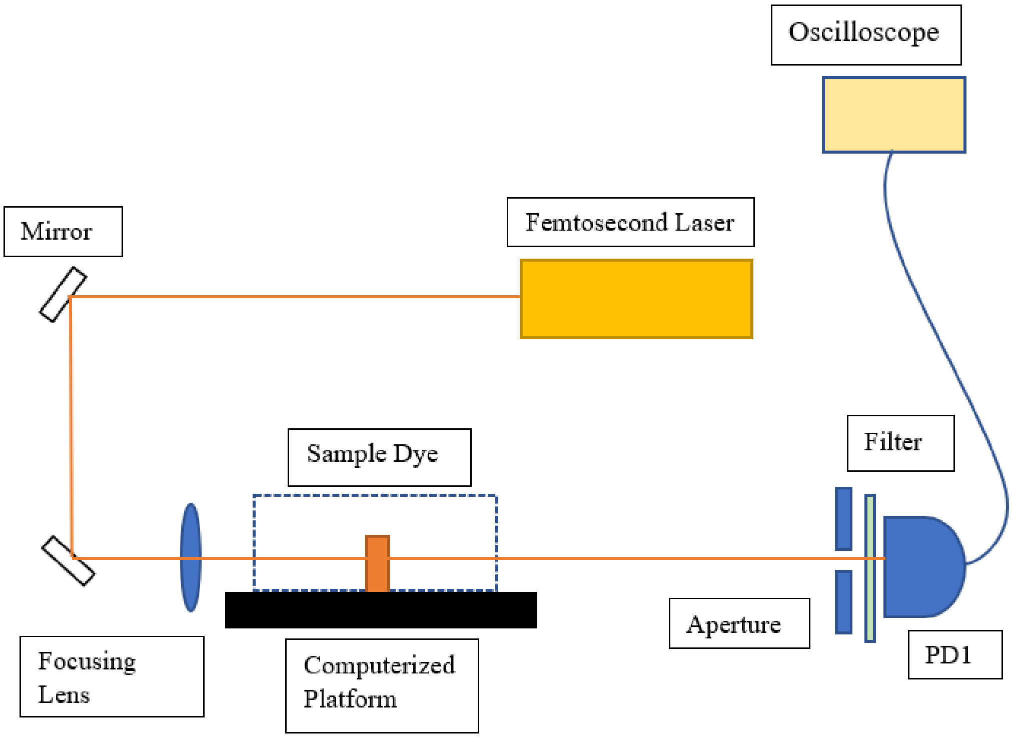

Figure 2: Z scan experiment setup

2.3 Nonlinear Optical Measurements

The nonlinear absorption coefficient can be determined by using the formula below from the open aperture z-scan technique [19]:

$$\beta = \frac{2\sqrt{2}\,\Delta T}{I_0 L_{eff}} \qquad Eq.1$$

where ΔT refers to the value of one valley from the open aperture curve, L_{eff} refers to the sample's effective thickness, and the intensity of the laser at the focal point is denoted by I_0. The formula for the calculation the effective thickness of sample is given as below [19]:

$$L_{eff} = \frac{1 - e^{(-\alpha L)}}{\alpha} \qquad Eq.2$$

where α refers to the linear Absorption and L refers to the thickness of the sample.

The change in the nonlinear absorption coefficient is referred to as the imaginary part of the third-order nonlinear susceptibility. Equation 3 below shows the formula used to calculate the imaginary part of third-order nonlinear optical susceptibility [9].

$$Im\,\chi\,3 = 10^{-4}\,\frac{\epsilon_0 c^2 n_0{}^2 n_2}{\pi}\left(\frac{cm^2}{W}\right) \qquad Eq.3$$

3. Results and Discussion

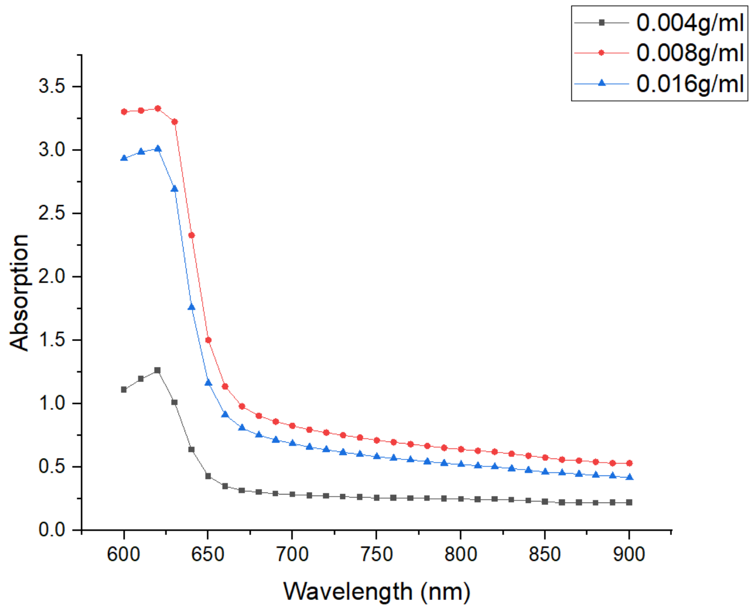

Figure 3: UVVIS optical absorbance values of various concentrations of Clitoria Ternatea dye in distilled water

Figure 3 displays the linear absorption spectra of various concentrations of Clitoria Ternatea dye. The transmittance spectrum of the CT dye was measured between 600nm and 900nm by using the UV-Vis spectrometer. From the absorption spectra of 0.004g/ml of CT dye, one absorption peak can be observed at the wavelength of 619nm with an absorption value of 1.266. The observed peak position of 0.008g/ml of CT dye is located at the wavelength of 622nm with a transmittance of 3.339. The detected peak location of 0.016g/ml CT dye is at 620nm with a transmittance of 3.014. In general, increasing the concentration of CT dye will cause an increase of the absorption values also. The observed correlation between the concentration of the CT dye and the Absorption might be explained in this way. The higher the anthocyanin concentration, the higher the Absorption as it has more particles inside the dye to absorb the light. However, this condition was except for the 0.016g/ml of CT dye. This discrepancy could be attributed to some errors during the dye extraction process. The current study's findings support the previous research from Mundzir Abdullah et al. (2022) who found that linear absorptions are particularly prominent in the ultraviolet and visible regimes, having large shoulders at 570 nm and 622 nm, respectively [9].

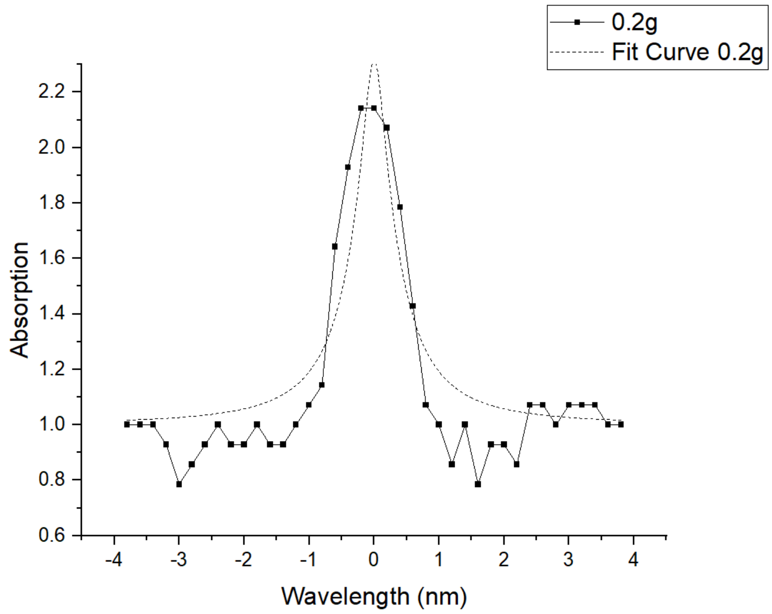

Figure 4: Open aperture Z scan curves of 0.004g/ml of CT dye at 74°

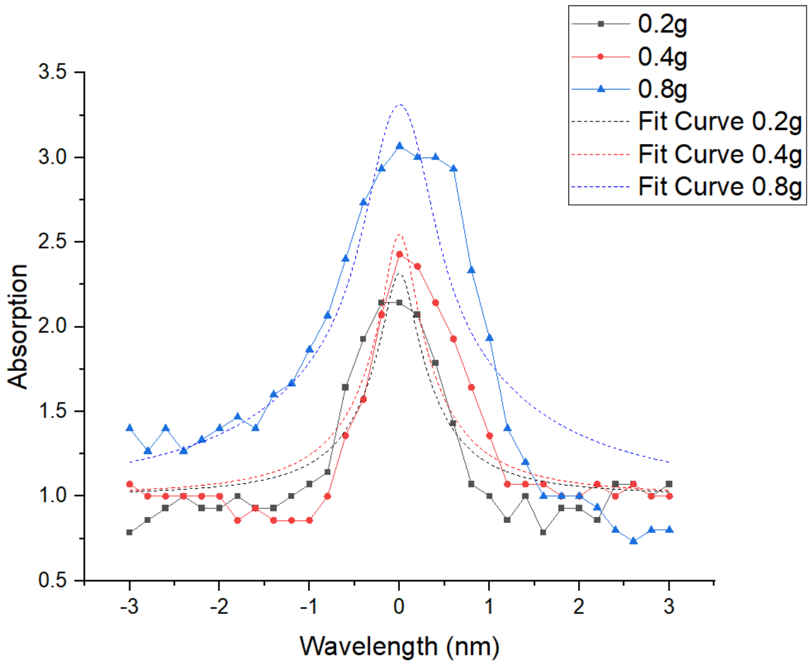

Figure 5: Open aperture Z scan curves of various concentrations of Clitoria Ternatea dye in 74°

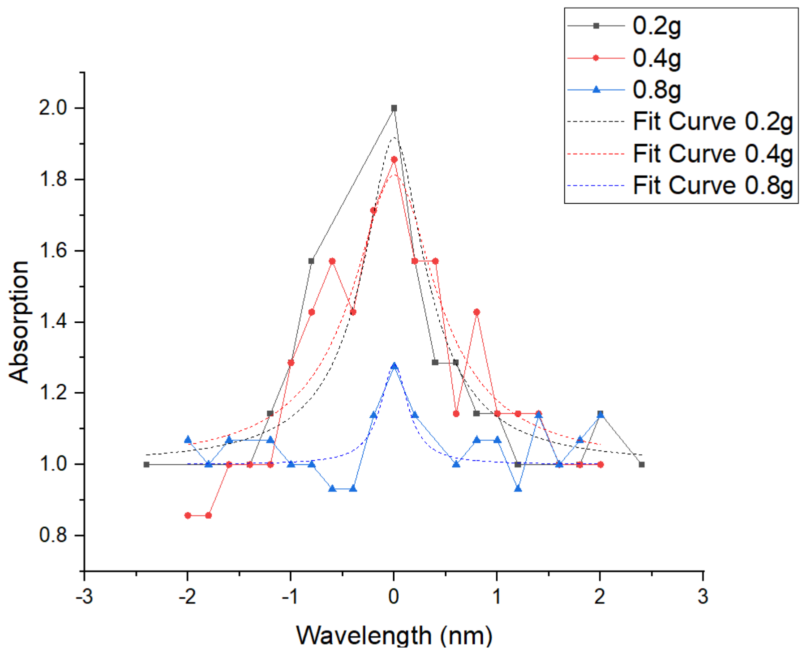

Figure 6: Open aperture Z scan curves of various concentrations of Clitoria Ternatea dye in 78°

The open Z-scan curves in Figure 4 show the presence of NLO response. The open aperture Z-scan dataset calculates the nonlinear absorption coefficient, β. The most important clinically relevant finding was the negative value of the nonlinear absorption coefficient, which implies that the particular response is saturable Absorption (SA). When the absorption cross-section of the excited state is less than that of the ground state, light absorption will be reduced when the system is strongly excited [20]. The optimal concentration range of samples has been chosen to explore its optical nonlinearity. The magnitude of nonlinear absorption was computed using the nonlinear fitting curve via Levenberg–Marquardt technique and analyzed using the OriginPro software.

Turning now to the experimental evidence on the results of the open z-scan curves of different concentrations, 0.004g/ml, 0.008g/ml, and 0.016g/ml, respectively with the comparison of varying laser power (Figure 3 and Figure 4). As seen from the images above, most of them perfectly match the curve. The results of the above figures found that the laser with lower power has a higher nonlinearity.

Figure 5 and Figure 6 show the open Z scan curves of various concentrations of CT dye in 74º and 78º. Obviously, when the dye concentration increased, the nonlinear Absorption decreased in both 74º and 78º. It seems possible that these results are due to the z-scan signal causing problems to capture at lower doses because the fluctuation was so small. And at greater concentrations, the sample was rich in colour and absorbed virtually all the incoming light. The observed increase in nonlinear Absorption when the concentrations increased could be attributed to the dye molecules aggregating more as the pigment concentration increases [20]. Nevertheless, the inconsistency of the 0.012g/ml of CT dye in the result of the open aperture z scan curves with the power of 78º (figure 7) may be due to the source of error such as the issue of handling technique, such as the inconsistent stirring rates of the samples.

Table 1 below presents an overview of the nonlinear absorption coefficient of CT dye at different concentrations, 0.004g/ml, 0.008g/ml, and 0.016g/ml at different powers. It depicts the decreasing trend of nonlinear absorption coefficient, β as the dye concentration increases when compared in the same power. However, there is an increasing trend of nonlinear Absorption when compared to the different power with constant concentration of CT dye. Contrary to the expectations, the result for the 0.016g/ml of CT dye did not follow the trend in this condition. This finding is contrary to previous studies from Mundzir Abdullah (2022), which proved that the CT dye exhibits reverse saturable Absorption (RSA).

Previous research from Mundzir Abdullah (2022) finds that the relationship between the concentrations is directly proportional to the nonlinear Absorption [6].

Table 1: Nonlinear absorption coefficient of various concentrations at different power

Sample	Concentrations (g/ml)	Nonlinear Absorption (x10^{-4}) 74°	78°
1	0.004	-0.00888 ± 1.23306	-0.00841 ± 2.92238
2	0.008	-0.01308 ± 1.2408	-0.01168 ± 3.89259
3	0.016	-0.01205 ± 7.65085	-0.00614 ± 12.2000

4. Conclusion

In this study, the aims were to assess the nonlinear absorption coefficient of the various concentrations of the Clitoria Ternatea dye at 0.004g/ml, 0.008g/ml, and 0.016g/ml and compare them with the different powers at 74º and 78º with the femtosecond laser operating at 808nm as excitation source. The results of this study show the relationship between the nonlinear Absorption and the concentrations of the CT dye solutions. Varying the concentrations of the CT dye solutions decreased the nonlinear optical parameter, β. The most obvious finding from this study is that the Clitoria Ternatea dye exhibits saturable absorption properties when conducting the open aperture of z scan experiment in various concentrations and powers. The magnitude and value of the nonlinear absorption coefficient were determined effectively. Because of these appealing qualities, CT dye is a possible contender for developing various photonics and optoelectronics equipment such as passive mode locking and Q switching of lasers. A greater focus on the nonlinear optical properties of the organic materials could produce interesting findings that account more for the contribution to the optics field.

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