Simple Investigation on the Optical Properties of Carbon Nanodots Using Lasers and a Lux-Meter

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Abstract: Carbon nanodots (Cdots) have excellent optical properties. This study aims to investigate scattering and absorption of Cdots via simple exposure of ultraviolet (UV)/violet, red, and green lasers. The experiment was conducted by preparing the Cdots from cajuput oil distillation wastes as the precursor. The solid wastes were dried under the sun, grounded into powder, filtered, and carbonized inside an oven at 250 ^{o}C for one hour. The carbonized powder was then mixed with distilled water, left for a night, and then filtered again so that the Cdots solution was obtained. Here, the mass of the precursor was varied. The Cdots samples were characterized using ultraviolet-visible (UV-Vis) and photoluminescence (PL) spectroscopies, and also particle size analyzer (PSA). The lasers were directly exposed to the Cdots samples. A digital lux-meter was used to measure the intensity of the lasers transmitted from the sample. The angle of the lux-meter was varied on a circular track. The sample was on the center of the track. The UV-Vis characterization showed two peaks at 217 nm and 270 nm, and a tail extending to the visible region. The PL characterization showed an intensity peak at 509.57 nm, which confirms the cyan luminescence of the Cdots. The PSA characterization indicated that the size of the Cdots was 1.04 nm. Moreover, at an angle of 0^{o}, the UV wavelength was strongly absorbed by the Cdots in accordance with the UV-Vis characterization result. The intensity of the green laser also dominates as it was less absorbed and strongly scattered by the Cdots.

Keywords: Cdots; laser; scattering; absorption; lux-meter

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I. INTRODUCTION

Carbon nanodots (Cdots) is a nanomaterial that is widely investigated in the world today. This is because Cdots have various benefits and are relatively easy and economical to be prepared. Moreover, Cdots have excellent properties, such as excellent luminescence [1], biocompatible [2], and non-toxic [3]. So far, Cdots have been widely applied in various fields, such as electronics [4], health [5], and optics [6].

Cdots can be obtained from organic materials because organic materials contain carbon [7]. Several studies have utilized organic wastes to be prepared into Cdots. Some of these wastes include watermelon peel [8], cornhusk and corncobs [9], and bagasse [10]. Hence, this has inspired a similar study using cajuput oil distillation wastes from Sendang Mole Cajuput Oil Factory Yogyakarta, which are still mounting around the factory and have not been used for preparing Cdots. An initial observation at the factory indicates that the amount of solid wastes from the distillation of leaves and twigs from the cajuput plants reaches 2,492 tons in 2019, which produces 22,821 liters of cajuput essential oil.

As Cdots have excellent luminescence property, their optical properties should be fully studied. The optical properties can be investigated via interactions between electromagnetic radiation and the Cdots sample, which is known as spectroscopy. Many spectroscopy characterizations can be used for the investigation of Cdots' optical properties, *e.g.* ultraviolet-visible (UV-Vis), Fourier transform infrared (FTIR), photoluminescence (PL), time-resolved PL (TRPL), and dynamic light scattering (DLS). These characterizations use electromagnetic radiation sources, *e.g.* laser and/or tungsten lamp, and expose the sample with the radiation source. A detector then measures the remaining radiation transmitted from the sample.

In this study, we use a similar principle to that of the spectroscopy above but with simpler arrangement and apparatus. We use unpolarized lasers with different wavelengths to be exposed to the Cdots sample. The transmitted laser intensity is then detected by a digital lux-meter. To the knowledge of the authors there has been no reported studies on this simple optical investigation of the Cdots with variation of the mass of the Cdots' precursor and the angle of the lux-meter's position. A study in relation to this is conducted in [11] where an instrument is design to detect the peroxide content in cooking oil using light dependent resistor.

This study offers a simple characterization of Cdots with simple arrangement and apparatus. Furthermore, this study may also be used for pedagogical purposes in high school and/or undergraduate levels. Hence, this study aims to investigate scattering and absorption of Cdots by exposing them to ultraviolet (UV)/violet, red, and green lasers. The UV/violet, red, and green lasers are chosen as they are inexpensive and easily available as laser pointers suitable for simple experiments and pedagogical purposes. The intensity of the laser

FIG. 1: (a) The powder after being heated in the oven. (b) The obtained Cdots sample.

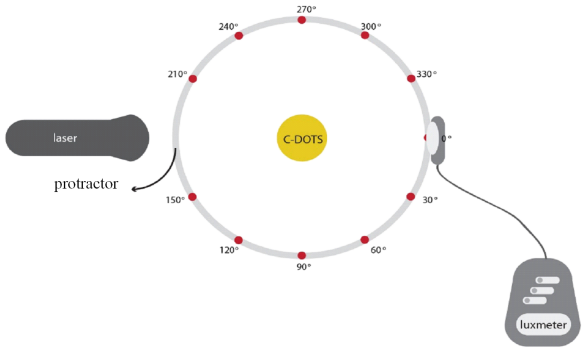

FIG. 2: The experiment arrangement.

transmitted from the Cdots is measured by a digital lux-meter.

II. METHOD

The experiment was conducted to investigate the scattering and absorption of the Cdots solution, which was exposed by the lasers. The transmitted intensity of the lasers was then measured by a digital lux-meter. The variables being varied in this study were the mass of the precursor and the angle of the lux-meter's position.

The materials utilized in this study were distilled water and cajuput oil distillation wastes. The equipments used were vials, a digital scale [Hario], a digital lux-meter [LX 1010B], filter papers, an oven [Kirin HBO-190LW], a grinder, aluminium foil, a glass funnel, a ruler, a protractor, an UV/violet laser pointer [max output power < 5 mW; wavelength 405 ± 10 nm], a red laser pointer [max output power 1 mW; wavelength 640-660 nm], a green laser pointer [Fx-009; max output power 5000 mW; wavelength 532 nm], UV-Vis spectrophotometer [Shimadzu 2550], PL [Laser picosecond 420 nm from Picoquant; spectrometer MAYAPro2000 from Ocean Optics; and Photon detector: TCSC PicoHarp 260 from Picoquant], and particle size analyzer (PSA) [Microtrac Nanotrac Wave II Particle Size and Zeta Potential Analyzer].

The main experimental steps in this study were i) preparing the Cdots samples, ii) characterizations of the Cdots samples, and iii) data collecting of the transmitted laser using the digital lux-meter. Each of the experimental steps can be explained as follows. The Cdots were prepared with the following steps: 1) drying the cajuput oil distillation solid wastes for 12 hours under the Sun; 2) grinding the dried solid wastes into powder form; 3) filtering the powder using a sieve to obtain homogenous powder; 4) heating the powder in an oven with a temperature of 250 ^{o}C for one hour so that carbonized powder was obtained as shown in Fig. 1(a); 5) mixing 0.2 gr of the carbonized powder with 10 ml distilled water, stirred, and then left for a night; 6) filtering the mixture that had been left for a night so that the Cdots solution was obtained as much as 7 ml as shown in Fig. 1(b). The above procedure was repeated for the powder mass variation of 0.4; 0.5; 0.6; 0.8; 1.0; and 1.5 gr.

The next step was the characterizations of the Cdots samples. The characterizations used were UV-Vis, PL, and PSA. In this case, the characterizations were conducted on the Cdots solution obtained from 0.2 gr powder sample. The UV-Vis test was conducted in the Integrated Chemistry Laboratory, Chemistry Education Department, Universitas Negeri Yogyakarta. The PSA was conducted in the Integrated Laboratory, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta. Finally, PL characterization was done in Indonesia Science Institute.

The data collecting steps were given as follows: 1) arranging the equipment as shown in Fig. 2; 2) placing the Cdots sample (starting with 0.2 gr powder) in its position, *i.e.* at the center of the circular track; 3) placing the UV/violet laser opposite to the lux-meter; 4) measuring the transmitted intensity for the angle of 0^{o}; 5) rotating the lux-meter around the sample by following the circular track and recording the transmitted intensity for each angle provided in Fig. 2; 6) repeating steps 2) to 5) for Cdots samples with powder masses of 0.4; 0.5; 0.6; 0.8; 1.0; and 1.5 ; and finally 7) repeating steps 1) to 6) for the green and red lasers.

Finally, the data analysis in this study was done using the graphs obtained. The data of the graphs were obtained from the experiments and plotted using Microsoft Excel 2010 software. The graphs were then analyzed in order that the objective of this study is achieved.

III. RESULTS AND DISCUSSION

The Cdots sample under sunlight is observed as a yellow-brownish solution as depicted in Fig. 1(b). Exposing the Cdots sample using UV/violet laser produces cyan (blue-greenish) luminescence that may be observed in Fig. 3. Moreover, the result of the UV-Vis characterization seen in Fig. 4 produces two absorption peaks at 217 nm and 270 nm, and a tail extending to the visible region. This is in accordance to the Cdots UV-Vis spectrum in [12] where a peak is obtained at around 293 nm. The peak is due to the π-π* electronic transition of the C = C functional group of the Cdots core.

The cyan luminescence in Fig. 3 is further supported by the PL characterization result. This can be observed in Fig.

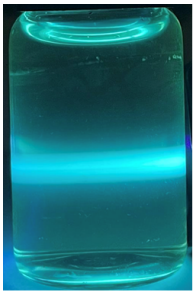

FIG. 3: The luminescence of the Cdots sample exposed by UV/violet laser.

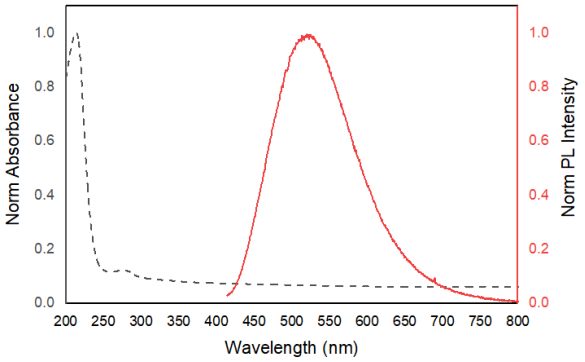

FIG. 4: UV-Vis and PL spectra of the Cdots sample.

4. It may be observed in Fig. 4 that there is an intensity peak at a wavelength around 509.57 nm. This means that the Cdots sample emits luminescence radiation with a wavelength of 509.57 nm. This wavelength corresponds to the cyan color, which has wavelengths of 490 nm to 520 nm.

The sizes of the Cdots are estimated using the PSA characterization. This can be observed in Fig. 5. The PSA characterization indicates a peak at 1.04 nm, which is the mean diameter of the Cdots sample and smaller than 10 nm satisfying the definition of Cdots. It is worth noting also that the diameter of the Cdots is quite small compared to commonly obtained Cdots sizes of around 2 nm to 5 nm in [12–15].

The optical properties of the Cdots samples obtained via lasers and a digital lux-meter can be observed in Fig. 6. The lasers used are UV/violet, green, and red. The initial intensities measured by the digital lux-meter without the present of the Cdots solution for the red, green, and UV/violet lasers are 5 lux, 4310 lux, and 318 lux, respectively. It can be observed that the green laser produced the highest intensity, followed by the UV/violet and red lasers. This is in accordance to the power specified on each laser.

The general feature of the intensity of the lasers detected by the lux-meter for the UV/violet, green, and red after being exposed to the Cdots samples are similar for variations of the lux-meters angle and mass of the powder. The highest intensity measured by the lux-meter is obtained for the angle of 0°. In this case, the laser, Cdots sample, and lux-meter are in

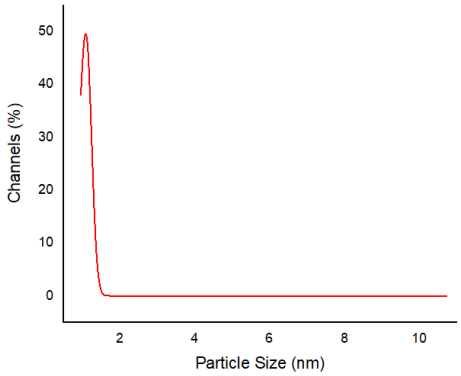

FIG. 5: Particle size distribution obtained from the PSA characterization.

a straight line, which means that most of the transmitted and scattered beam for all lasers are detected by the lux-meter. It can also be observed that at this angle, the highest transmitted intensity is obtained for the green laser, followed by the UV/violet and red lasers. This is of course in accordance with the initial intensities of the transmitted lasers measured by the digital lux meter without the Cdots sample. However, rotating the lux-meter produces a sudden intensity decrease from 30° to 300°. The intensity then rises again at 330°. The low intensities at the angles of 30° to 300° are the scattered (and luminescence) part detected by the lux-meter.

Increasing the mass of the powder means that the Cdots sample obtained becomes darker as more Cdots are produced. The effect of the powder mass towards the transmitted intensity of the lasers may be observed in Fig. 7. Here, we take the lux-meters angles of 0°, 90°, and 330°. There are significant differences concerning the interactions between the lasers and the Cdots samples as the mass of the powder is varied. For an angle of 0°, the intensity of the lasers tends to increase as the powders mass increases, except for the UV/violet laser, which decreases. This shows that the Cdots absorb UV wavelength, which is in accordance to the existence of the peaks of the UV-Vis characterization above. At an angle of 90°, the UV/violet and green laser intensities fluctuate as the mass of the powder increases. However, the red laser has zero intensity. This means that the lux-meter is unable to detect the scattered beam of the red laser, as it is very low. Finally, at an angle of 330°, the intensities fluctuate and tend to decrease for the UV/violet and red lasers, while the intensity of the green laser tends to increase.

We can also compare the effect of the lasers towards the transmitted intensity. This is shown in Fig. 8. At an angle of 0°, it is clearly seen that the UV/violet laser is being absorb by the Cdots sample as the mass of the powder increases. This does not happen for the green and red lasers as the intensities tend to increase as the powder mass is increased. At an angle of 90°, the transmitted intensities of the green and UV/violet lasers are higher compared to the red laser. This is because shorter wavelengths tend to be scattered more than longer ones. Finally, at an angle of 330°, the transmitted in-

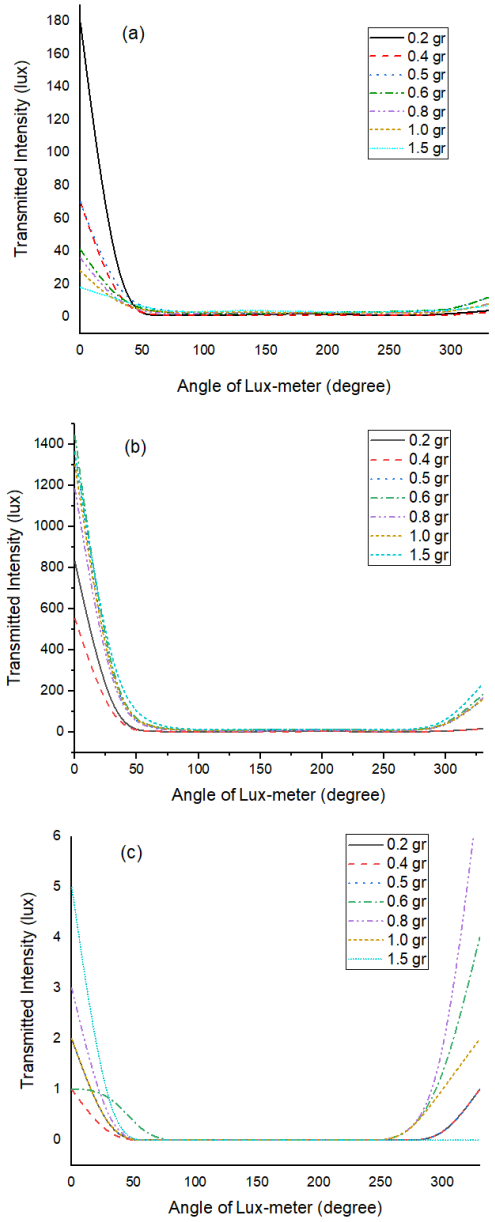

FIG. 6: The intensity of the UV/violet (a), green (b), and red (c) lasers detected by the lux-meter after being exposed to the Cdots sample.

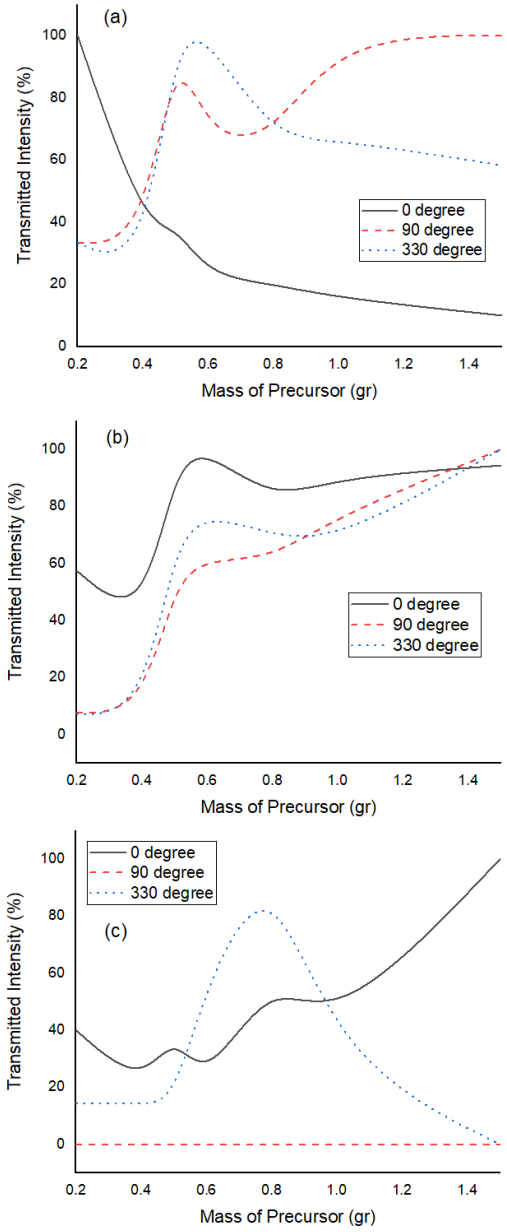

FIG. 7: The intensity of the UV/violet (a), green (b), and red (c) lasers as a function of powders mass and the angles of the lux-meter.

tensities of all lasers show an increase for the precursor mass less than 0.8 gr. However, for higher precursor mass, only the transmitted intensity of the green laser increases, whereas the transmitted intensities of the UV/violet and red lasers decrease.

IV. SUMMARY

Cdots from the wastes of cajuput oil distillation factory have been produced via low carbonization using an oven. The UV-Vis characterization shows two peaks at 217 and 270 nm, and a tail extending to the visible region. The PL characterization indicates cyan luminescence of the Cdots sample, which is in accordance with the luminescence of the Cdots sample exposed by the UV/violet laser. The PSA characterization indicates that the size of the Cdots particle is 1.04 nm. The highest transmitted intensity measured by the lux-meter for each laser is obtained at the angle of 0°. The transmitted intensity then undergoes a sudden drop at angles of 30° to 300°, and increases again at an angle of 330°, for each laser. At an angle of 0°, increasing the mass of the powder increases the transmitted intensities of the green and red lasers, except for

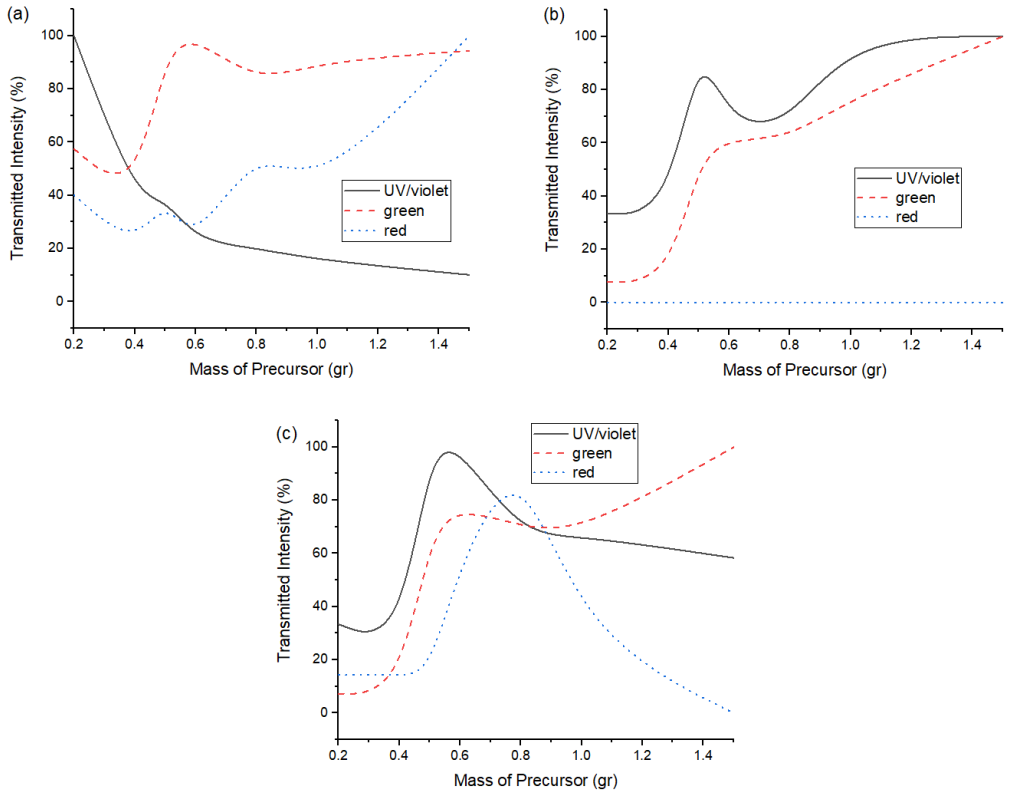

FIG. 8: The intensity as a function of the powders mass and the lasers at angles of (a) 0°, (b) 90°, and (c) 330°.

the UV/violet laser, which decreases. This shows that the UV wavelength is absorbed by the Cdots solution in accordance to the result of the UV-Vis characterization. Moreover, the intensity of the green laser measured by the digital lux-meter dominates as it is less absorb and strongly scattered by the Cdots particles.

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