# JOICHE

Journal of Industrial Process and Chemical Engineering

Jurnal homepage : ejurnal.itats.ac.id/JOICHE

## The Influence of the Ratio of Citric Acid and 4-carboxy-3-chlorobenzene boronic acid on the Quantum Yield of Graphene Quantum Dots

*Adi Permadi*[*1], *Mutiara Wilson Putri*[2]

[1-2]*Jurusan Teknik Kimia, Universitas Ahmad Dahlan, Yogyakarta, Indonesia*

**INFORMASI ARTIKEL**

**Halaman:**
29-3 6

**Tanggal penyerahan:**
25 Maret 2025

**Tanggal diterima:**
09 Desember 2025

**Tanggal terbit:**
09 Desember 2025

**EMAIL**

[1*]adi.permadi@che.uad.ac.id

[2]2300020037@webmail.uad.ac.id

1* **corresponding author**

***ABSTRACT***

*This study investigates the effect of citric acid (CA) and 4-carboxyl-3-chlorobenzeneboronic acid (CBBA) ratio on the Quantum Yield (QY) of Graphene Quantum Dots (GQDs). The hydrothermal synthesis method was employed with various CA/CBBA molar ratios, and the optical properties were analyzed using UV-Vis and photoluminescence (PL) spectroscopy. The results show that increasing the CBBA ratio enhances fluorescence efficiency, with the highest QY of 5.075% obtained at a 1:5 ratio. The addition of CBBA improves surface passivation and reduces non-radiative recombination sites, thereby optimizing the photoluminescence properties. Furthermore, precursor ratio variation influences particle size and functional groups, affecting the solubility and stability of GQDs. These findings highlight the role of CBBA in controlling exciton recombination, making GQDs more efficient for optoelectronic, bioimaging, and biomedical applications. Further studies are needed to explore the long-term effects of CBBA doping on fluorescence stability.*

***Keywords:*** *Graphene Quantum Dots, Quantum Yield, Citric Acid, CBBA, Fluorescence Efficiency*

## INTRODUCTION

Graphene Quantum Dots (GQDs) are carbon-based nanomaterials derived from two-dimensional graphene, typically measuring less than 20 nanometers in size. These materials possess a non-zero band gap and exhibit luminescence when stimulated. GQDs are highly valued for their unique properties, including low toxicity, good solubility, stable fluorescence, and chemical inertness, in addition to their capacity to be functionalized with various chemical groups. These characteristics make them exceptionally useful for applications like biological imaging, light-emitting diodes, and the absorption of pollutants. Structurally, GQDs form a honeycomb lattice where carbon atoms arrange into six-membered rings. This structure facilitates electron delocalization within the p-orbitals, which is crucial to their distinct optical and electrical characteristics. Furthermore, GQDs display photoluminescence, a result of the quantum confinement effect. Their band gap energy is tunable, ranging from 0 to 6 electron volts, which can be precisely controlled by modifying the chemical groups present on their surface [1], [2].

Graphene Quantum Dots (GQDs) have diverse applications, owing to their unique properties such as biocompatibility, high solubility, and ease of functionalization. In the biomedical field, GQDs are utilized for bio-imaging and targeted drug delivery. Furthermore, their attractive optical absorption properties make them suitable for use in optoelectronic devices, photodetectors, and various sensing applications. The peroxidase-mimicking activity of GQDs also allows for their application in the electrocatalytic detection of hydrogen peroxide ($H_2O_2$), while their high surface area makes them ideal for electrode modification. With these significant advantages, GQDs hold immense potential for developing technologies across various fields [3], [4].

Quantum Yield (QY) is a crucial parameter in Graphene Quantum Dots (GQDs) applications because it measures the efficiency of photon emission [5]. A high QY indicates that more absorbed photons will be re-emitted as fluorescence, which is essential for applications in bio-imaging, sensors, and optoelectronic devices [6]. The photoluminescent properties of GQDs, influenced by their unique structural and optical characteristics, make them suitable for these applications due to their high fluorescence activity and stability. Furthermore, variations in QY can provide insights into the electronic environment and particle size distribution within the GQDs, which is critical for optimizing their performance in specific applications [7].

The bottom-up approach in the synthesis of Graphene Quantum Dots (GQDs) involves forming GQDs from small molecular or atomic precursors. This method of synthesizing Graphene Quantum Dots (GQDs) involves creating them from small molecules or polymers using techniques such as microwave, molecular carbonization, and electron beam irradiation (EBI), each with its own set of advantages and limitations. Generally, this approach utilizes starting materials like citric acid, amino acids, phenyl compounds, or small molecule sugars, and may also involve doping with different elements to synthesize GQDs. In one such process, elephant grass is crushed and heated in an autoclave along with ethylenediamine (EDA), which serves as the nitrogen doping agent, yielding N-GQDs with high fluorescence properties. This approach offers the benefits of inexpensive starting materials, a simple synthesis route, and a high yield, making it highly promising for industrial applications [8], [9].

In the synthesis of Carbon Dots (CDs), precursors such as citric acid and 4-carboxy-3-chlorobenzeneboronic acid (CBBA) play a vital role in determining their final properties. Citric acid is frequently used because it can produce CDs with controlled sizes through carbonization and can be modified with boronic acid ligands to inhibit viral replication. Meanwhile, CBBA is used to modify CDs to confer additional properties, such as inhibiting virus interaction with target cells through the formation of a cyclic boronate diester complex. The combination of these precursors allows for the customization of CDs properties for biomedical applications or enhanced fluorescence [10], [11].

The optical characteristics of Graphene Quantum Dots (GQDs) are influenced by surface conditions, particle size, synthesis methods, and surface functionalization. Oxygen-rich functional groups and edge effects impact photoluminescence (PL), while particle size determines the band gap energy, with small GQDs exhibiting quantum confinement effects [12]. The appropriate synthesis method can yield uniform size distribution, while surface functionalization allows for band gap tuning and increased solubility. These factors collectively determine the efficiency and stability of GQDs photoluminescence, which is crucial for applications in optoelectronics and bioimaging [13]. Citric acid is utilized as the primary carbon source in the synthesis of Carbon Quantum Dots (CQD) [14]. In a study by Yuniarti (2021), citric acid was mixed with urea and dissolved in deionized water to form a solution, which was then subjected to microwave irradiation. This process resulted in CQDs with specific optical characteristics [15]. Citric acid has been used together with various amine precursors through the hydrothermal method to produce CQDs with different optical properties. Citric acid acts as the carbon source, and when heated with other precursors, it can form CQD structures that possess attractive fluorescence properties [16].

CBBA (4-carboxy-3-chlorobenzeneboronic acid) is used as an additional precursor to modify the structure and optical properties of Carbon Dots (Cdots). This modification is achieved by conjugating CBBA onto the Cdots surface, which can enhance specific interactions with target molecules such as glycopeptides and glycoproteins. The process involves activating the carboxylate group of CBBA using EDCI/DMAP reagents before reacting with the hydroxyl sites on the Cdots. Furthermore, the presence of the boronic acid sites from CBBA on the nanoparticle surface can be observed through a decrease in the zeta potential value, indicating that CBBA has successfully conjugated to the Cdots [17]..

The influence of precursor combination on particle size and fluorescence properties can vary depending on the type of precursor used and the synthesis conditions [18]. In the context of Carbon Dots (C-dots), the combination of precursors can significantly affect both particle size and fluorescence properties. For example, using amine precursors such as PEG-di- $NH_2$ in C-dot synthesis can result in smaller particle sizes and enhance fluorescence properties. Additionally, doping with metals or other compounds can also modify the fluorescence properties. For instance, doping with metal ions like $Gd^{3+}$ can improve fluorescence characteristics and provide additional capabilities, such as sensitivity to signals in theranostic applications. These combinations can yield C-dots with more controlled particle sizes and customized fluorescence properties for specific applications, such as cell imaging or cancer therapy [19], [20].

The precursor ratio plays a vital role in determining the structure, size, and functional groups of Graphene Quantum Dots (GQDs), which directly influence their optical properties, including fluorescence efficiency [21]. In pyrolysis or oxidation-exfoliation methods, the ratio of citric acid to L-cysteine, as well as the reaction conditions, can alter the degree of oxidation, heteroatom doping, and exciton recombination, which impacts the Quantum Yield (QY). Optimizing this ratio also contributes to the internal quantum efficiency (IQE) and external quantum efficiency (EQE) in devices like OLEDs, by enhancing charge injection efficiency and minimizing non-radiative losses. Thus, the precise precursor ratio can maximize the fluorescence efficiency of GQDs and improve the performance of light-emitting devices [22], [23]. To further enhance QY, it is important to optimize the device structure, material selection, and fabrication process to boost charge injection efficiency, minimize non-radiative losses, and increase light output efficiency [24].

This study aims to investigate the influence of the ratio of citric acid to 4-carboxy-3-chlorobenzeneboronic acid (CBBA) on the quantum yield (QY) of Graphene Quantum Dots (GQDs). Additionally, this research seeks to determine the optimal precursor ratio to enhance the fluorescence efficiency of GQDs. The results of this study are expected to provide insights into synthesis strategies for high-QY GQDs. These findings will contribute to the development of GQDs for various applications in the fields of optoelectronics and biomedicine.

## METHODE

### Materials

The materials used in this study include citric acid, CBBA, and NaOH, all obtained from Sigma-Aldrich. Deionized water was acquired from a chemical supplier in Taipei. The equipment utilized includes an oven, a homogenizer, a UV-VIS spectrophotometer, a photoluminescence (PL) spectroscopy instrument, a 0.22 µm membrane filter, syringes, pipettes, measuring cylinders, and a UV lamp. This research was conducted at the Nanochemistry Laboratory, National Taiwan University of Science and Technology.

### Synthesis Procedure

Graphene quantum dots (GQDs) were synthesized using a bottom-up method by controlling the degree of carbonization of carbon precursors and dispersing the carbonized product into a basic solution. This method allows for better control over the size and optical properties of the resulting GQDs. In the standard procedure for GQD sample preparation, 1 mol of citric acid (192.13 g) and 1 mol of CBBA (200.38 g) were weighed with precision using an analytical balance and then transferred into a 5 mL glass vial. The vial was subsequently heated in an oven at an initial temperature of 200°C for 1 hour to initiate the preliminary carbonization process. Following this stage, the temperature was increased to 240°C and maintained for 4 hours to complete the carbonization and form the optimal graphene quantum dot structure.

After the heating process was complete, the vial was removed from the oven and allowed to cool to room temperature. Subsequently, 2 mL of deionized water was added to the vial to dissolve the carbonized product formed. The solution was then neutralized by adding 20 µL of 1 M NaOH to adjust the pH and ensure the dispersion's stability. After neutralization, the solution was manually shaken to ensure homogeneity, then filtered using a 0.22 µm membrane filter to remove large particles or undissolved residue. The optical properties of the GQDs were measured using a UV-VIS spectrophotometer and photoluminescence (PL) spectroscopy. The UV-Vis absorption spectrum measurement was performed using a JASCO V-670 spectrophotometer to observe the absorption characteristics of the GQDs, while the PL spectrum was measured using a JASCO FP-6500 spectrofluorometer with a 150 W xenon lamp to evaluate the fluorescence properties of the resulting GQDs.

.

After the initial measurements were performed, the quantum yield QY of the GQDs was calculated using the following equation::

$$QY = QY_{R6G} \times \frac{I_{QD}}{I_{R6G}} \times \left(\frac{\eta_{kloroform}}{\eta_{etanol}}\right)^2$$

Where $QY_{R6G}$ is the quantum yield of the reference standard (Rhodamine 6G), $I_{QD}$ and $I_{R6G}$ are the integrated PL intensities of the GQDs and Rhodamine 6G, and η is the refractive index of the solvent used (chloroform and ethanol). In addition to the quantum yield calculation, the fluorescence of the GQD was also visually observed using a UV lamp to confirm the emissive properties of the synthesized samples. These measurement results were used to evaluate the influence of the ratio of citric acid to CBBA on the quantum yield efficiency of the resulting GQDs

.

## RESULT AND DISCUSSION

Carbon Dots (CDs) are carbon materials in dot form that possess luminescent properties and can be synthesized from various carbon sources [25]. This research aims to determine the resulting optical properties, including color, absorbance spectrum, and the energy gap of the CDs. The bottom-up method (chemically) is a process of obtaining nano-sized molecules from precursor compounds. Bottom-up methods include combustion, electrothermal, microwave or ultrasonic, hydrothermal, and acid oxidation.

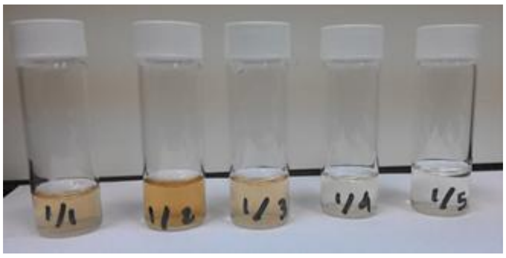
Graphene Quantum Dots (GQDs) are a type of Carbon Dots (CDs) that possess high luminescence properties. In this study, GQDs were synthesized using the hydrothermal method with citric acid (CA) as the carbon source and 4-carboxy-3-chlorobenzene boronic acid (CBBA) as the heteroatom dopant. The addition of CBBA aims to enhance the fluorescence efficiency and quantum yield (QY) of the resulting GQDs [19], [26]. Based on the research results shown in Table 1, increasing the CA/CBBA molar ratio demonstrated a linear increase in QY. The highest molar ratio used in this study, which was 1:5, yielded the highest QY of 5.075%.

**Tabel 1.** The Influence of the CA/CBBA Ratio on Quantum Yield (QY)

| CA/CBBA | UV1 | PL1 | UV2 | PL2 | QY1 (%) | QY2 (%) | Average QY ( %) |
|---|---|---|---|---|---|---|---|
| 1/0 | 0,056 | 64,389 | 0,056 | 64,69 | 1,02 | 1,03 | 1,025 |
| 1/1 | 0.061 | 165.42 | 0.058 | 148.066 | 2.42 | 2.27 | 2,345 |
| 1/2 | 0.063 | 241.99 | 0.054 | 188.001 | 3.44 | 3.09 | 3,265 |
| 1/3 | 0.059 | 250.09 | 0.059 | 309.269 | 3.78 | 4.67 | 4,225 |
| 1/4 | 0.057 | 314.454 | 0.056 | 243.024 | 4.91 | 3.86 | 4,385 |
| 1/5 | 0.057 | 318.89 | 0.052 | 303.889 | 4.98 | 5.17 | 5,075 |

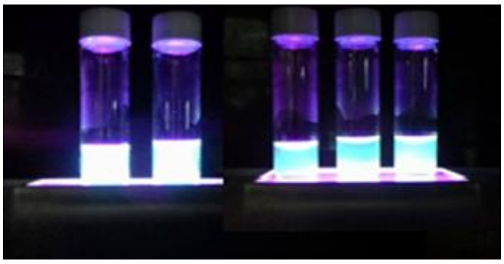
*Note: PL : Photoluminescence.*

Table 1 indicates that without CBBA (1:0), the QY is only 1.025%, suggesting that CA alone is insufficient to enhance fluorescence efficiency. The addition of CBBA increases photoluminescence, likely through surface passivation effects and an increase in the defect level. Further analysis is required to determine the optimal doping limit before a quenching effect occurs. These results demonstrate that CBBA plays an important role in enhancing the luminescence efficiency of GQDs, in addition to its potential as a cancer drug candidate.




**Gambar 1.** GQDs in Water with Varied CA and CBBA Ratios Under Room Light

The Graphene Quantum Dots (GQDs) solutions in water shown in Figure 1 with varied CA/CBBA ratios under room light. It is observed that solutions with ratios 1:1 and 1:2 have a brownish-yellow color, while solutions with ratios 1:3, 1:4, and 1:5 appear clearer. This color change indicates that increasing the CBBA ratio affects the structure and optical characteristics of the GQDs, possibly through changes in the degree of carbonization and intermolecular interactions during the synthesis process. The lighter color at higher ratios may indicate smaller particle size or changes in the composition of the functional groups responsible for their fluorescence properties..



**Gambar 2.** GQDs in Water with Varied CA and CBBA Ratios Under UV Light

The Graphene Quantum Dots (GQDs) solutions in water with varied CA/CBBA ratios under UV light in Figure 2. It is observed that all samples exhibit fluorescence with different intensities, where increasing the CBBA ratio results in a brighter blue luminescence. This indicates that CBBA doping plays a role in enhancing the quantum efficiency and optical properties of the GQDs, possibly through electronic structure modification and surface passivation. The higher fluorescence intensity at the 1:5 ratio suggests that this ratio produced GQDs with the best optical characteristics in this study. Following the hydrothermal synthesis process at 200°C for 1 hour, followed by additional heating at 240°C for 4 hours, the results showed that the GQDs solution changed color to light blue when irradiated with UV light. This color change indicates that GQDs with a size of <100 nm have been formed. However, to confirm the particle size formed, further analysis using High-Resolution Transmission Electron Microscopy (HR-TEM) is required.

In this study, the synthesis of Carbon Quantum Dots CQDs was carried out using the hydrothermal method with citric acid $C_6H_8O_7$ or CA as the carbon C source and 4-carboxy-3-chlorobenzene boronic acid CBBA as the boron atom doping source. Citric acid and 4-carboxy-3-chlorobenzene boronic acid were dissolved in deionized water with varied CA:CBBA molar ratios: (1:0), (1:1), (1:2), (1:3), (1:4), and (1:5). The hydrothermal process was performed in an autoclave at a temperature of 200°C for 1 hour, after which the samples were reheated for 4 hours at 240°C. The synthesis results showed that the GQDs solution changed color to light blue under UV light.

The optical properties of the CDs based on observations using a UV-Vis spectrophotometer and fluorescence can be seen in Table 1. The measurement results of the optical properties of the CDs in colloidal form show that the solution can absorb the UV spectrum. The GQDs solution resulting from hydrothermal synthesis with varied CA/CBBA molar ratios of 1:1, 1:2, 1:3, 1:4, and 1:5, both without and when illuminated by $\text{UV}$ light, is shown in Figure 1. The solution changes from colorless to light blue when irradiated with UV light, indicating that GQDs with a size of <100 nm have been formed. Research conducted by Bachtiar (2022) showed that the color change to blue-green (tosca) when illuminated by a laser with a wavelength of 365 nm indicates that $\text{CQD}$ with a size of <10 nm have been formed [27]. The resulting CQD solutions generally have a low Fluorescence Quantum Yield (FQY), typically <10%, which results in low fluorescence intensity and poor sensitivity in CQD sensing applications [28]. One way to increase the fluorescence efficiency of CQD is through the addition of heteroatoms or heteroatom doping, such as Nitrogen (N), Sulfur (S), Phosphorus (P), or other atoms [29]. The C-dots synthesis was performed with CA/CBBA ratio variations from 1:1, 1:2, 1:3, 1:4, up to 1:5. In the first condition, only citric acid was used without the addition of CBBA. In the second condition, citric acid was added with CBBA. The addition of CBBA was done first (DMS).

The luminescence properties of C-dots can be seen in Figure 2 when illuminated with a UV lamp. CDs synthesized from CA/CBBA are observed to glow. The luminescence occurs due to the generation of electrons that gain energy from the UV light. This energy causes the phenomena of excitation and de-excitation, characterized by the jumping of electrons from the valence band to the conduction band under certain conditions. The electrons then return to fill the vacancies they originally left, which causes the release of energy in the form of electromagnetic wave light emission. Besides applications in the field of fluorescence, carbon dots also have the potential to be used in various other fields, such as biomedicine, optical sensors, and photocatalysis. In biomedical applications, CDs can be used as bioimaging agents due to their luminescent properties and low toxicity. Furthermore, in optical sensors, CDs can be utilized to detect heavy metal ions in solutions, which can contribute to environmental quality monitoring [30]. In photocatalysis, CDs can act as catalysts that enhance the efficiency of photochemical reactions, for example, in the degradation of organic pollutants or the production of hydrogen from water.

## EXPRESSION OF GRATITUDE

The author wishes to thank Prof Jia-Yaw Chang for his guidance and the opportunity to use the Nanochemistry laboratory in the Department of Chemical Engineering at National Taiwan University of Science and Technology.

## CONCLUSION

The ratio of citric acid to CBBA significantly influences the Quantum Yield (QY) of Graphene Quantum Dots (GQDs). A gradual increase in the CBBA ratio enhances the fluorescence efficiency, with the 1:5 ratio yielding the highest QY of 5.075%. This indicates that CBBA plays a role in enhancing surface passivation and reducing non-radiative recombination centers, thereby increasing light emission. Thus, optimizing the precursor ratio can be an effective strategy for improving the optical properties of GQDs for further applications in optoelectronics and biomedicine. Furthermore, the variation in the precursor ratio also affects the particle size and functional groups that contribute to the stability and solubility of the GQDs. Further research is needed to explore the long-term effects of CBBA doping on the stability and fluorescence efficiency of GQDs under various environmental conditions.

## DAFTAR PUSTAKA

[1] P. Gozali Balkanloo, K. Mohammad Sharifi, and A. Poursattar Marjani, “Graphene quantum dots: synthesis, characterization, and application in wastewater treatment: a review,” *Mater Adv*, vol. 4, no. 19, pp. 4272–4293, 2023, doi: 10.1039/D3MA00372H.

[2] Y. Cui *et al.*, “A Review of Advances in Graphene Quantum Dots: From Preparation and Modification Methods to Application,” *C (Basel)*, vol. 10, no. 1, p. 7, Jan. 2024, doi: 10.3390/c10010007.

[3] V. Bressi, A. Ferlazzo, D. Iannazzo, and C. Espro, “Graphene Quantum Dots by Eco-Friendly Green Synthesis for Electrochemical Sensing: Recent Advances and Future Perspectives,” *Nanomaterials*, vol. 11, no. 5, p. 1120, Apr. 2021, doi: 10.3390/nano11051120.

[4] C. Das, M. Sillanpää, S. A. Zaidi, M. A. Khan, and G. Biswas, “Current trends in carbon-based quantum dots development from solid wastes and their applications,” *Environmental Science and Pollution Research*, vol. 30, no. 16, pp. 45528–45554, Feb. 2023, doi: 10.1007/s11356-023-25822-y.

[5] B. D. Mansuriya and Z. Altintas, “Applications of Graphene Quantum Dots in Biomedical Sensors.,” *Sensors (Basel)*, vol. 20, no. 4, Feb. 2020, doi: 10.3390/s20041072.

[6] P. R. Kharangarh, S. Umapathy, and G. Singh, "Effect of defects on quantum yield in blue emitting photoluminescent nitrogen doped graphene quantum dots," *J Appl Phys*, vol. 122, no. 14, Oct. 2017, doi: 10.1063/1.4991693.
[7] E. I. Wafiyah, I. Isnaeni, and D. Beri, "Sintesis Dan Sifat Optik Graphene Quantum DOTS Dengan Metode Elektrokimia," *Jurnal Pendidikan Tambusai*, vol. 8, no. 2, pp. 22800–22807, 2024.
[8] D. Kurniawan, R.-J. Weng, Y.-Y. Chen, M. R. Rahardja, Z. C. Nanaricka, and W.-H. Chiang, "Recent advances in the graphene quantum dot-based biological and environmental sensors," *Sensors and Actuators Reports*, vol. 4, p. 100130, Nov. 2022, doi: 10.1016/j.snr.2022.100130.
[9] C. Zhao *et al.*, "Synthesis of graphene quantum dots and their applications in drug delivery," *J Nanobiotechnology*, vol. 18, no. 1, p. 142, Dec. 2020, doi: 10.1186/s12951-020-00698-z.
[10] K. Umbu Henggu and Y. Nurdiansyah, "Review dari Metabolisme Karbohidrat, Lipid, Protein, dan Asam Nukleat," *QUIMICA: Jurnal Kimia Sains dan Terapan*, vol. 3, no. 2, pp. 9–17, Aug. 2022, doi: 10.33059/jq.v3i2.5688.
[11] J. Belza, A. Opletalová, and K. Poláková, "Carbon dots for virus detection and therapy," *Microchimica Acta*, vol. 188, no. 12, p. 430, Dec. 2021, doi: 10.1007/s00604-021-05076-6.
[12] P. A. Rasheed, M. Ankitha, V. K. Pillai, and S. Alwarappan, "Graphene quantum dots for biosensing and bioimaging," *RSC Adv*, vol. 14, no. 23, pp. 16001–16023, 2024, doi: 10.1039/D4RA01431F.
[13] J. Belza, A. Opletalová, and K. Poláková, "Carbon dots for virus detection and therapy," *Microchimica Acta*, vol. 188, no. 12, p. 430, Dec. 2021, doi: 10.1007/s00604-021-05076-6.
[14] G. G. Njema, J. K. Kibet, and S. M. Ngari, "Performance optimization of a novel perovskite solar cell with power conversion efficiency exceeding 37% based on methylammonium tin iodide," *Next Energy*, vol. 6, p. 100182, Jan. 2025, doi: 10.1016/j.nxener.2024.100182.
[15] E. Yuniarti, "Sintesis Dan Karakteristik Optik Carbon Quantum Dot Yang Berasal Dari Asam Sitrat Dengan Variasi Massa Urea," *Komunikasi Fisika Indonesia*, vol. 18, no. 2, p. 99, Jul. 2021, doi: 10.31258/jkfi.18.2.99-105.
[16] M. C. Biswas, M. T. Islam, P. K. Nandy, and M. M. Hossain, "Graphene Quantum Dots (GQDs) for Bioimaging and Drug Delivery Applications: A Review," *ACS Mater Lett*, vol. 3, no. 6, pp. 889–911, Jun. 2021, doi: 10.1021/acsmaterialslett.0c00550.
[17] M. Z. Fahmi *et al.*, "Design of boronic acid-attributed carbon dots on inhibits HIV-1 entry," *RSC Adv*, vol. 6, no. 95, pp. 92996–93002, 2016, doi: 10.1039/c6ra21062g.
[18] J. Kong *et al.*, "Carbon Quantum Dots: Properties, Preparation, and Applications," *Molecules*, vol. 29, no. 9, p. 2002, Apr. 2024, doi: 10.3390/molecules29092002.
[19] Y.-Y. Aung, A. N. Kristanti, H. V. Lee, and M. Z. Fahmi, "Boronic-Acid-Modified Nanomaterials for Biomedical Applications," *ACS Omega*, vol. 6, no. 28, pp. 17750–17765, Jul. 2021, doi: 10.1021/acsomega.1c01352.
[20] P. K. Jiwanti, B. Y. Wardhana, L. G. Sutanto, D. M. M. Dewi, I. Z. D. Putri, and I. N. I. Savitri, "Recent Development of Nano-Carbon Material in Pharmaceutical Application: A Review," *Molecules*, vol. 27, no. 21, p. 7578, Nov. 2022, doi: 10.3390/molecules27217578.
[21] Y. Huang *et al.*, "Advances in synthesis of the graphene quantum dots from varied raw materials," *Arabian Journal of Chemistry*, vol. 17, no. 2, p. 105533, Feb. 2024, doi: 10.1016/j.arabjc.2023.105533.
[22] X. Yang, G. Mu, K. Weng, and X. Tang, "Advances in High-Efficiency Blue OLED Materials," *Photonics*, vol. 11, no. 9, p. 864, Sep. 2024, doi: 10.3390/photonics11090864.
[23] C. Murawski, K. Leo, and M. C. Gather, "Efficiency Roll-Off in Organic Light-Emitting Diodes," *Advanced Materials*, vol. 25, no. 47, pp. 6801–6827, Dec. 2013, doi: 10.1002/adma.201301603.
[24] L. Zhang *et al.*, "Advances in the Application of Perovskite Materials," *Nanomicro Lett*, vol. 15, no. 1, p. 177, Dec. 2023, doi: 10.1007/s40820-023-01140-3.
[25] Jumardin, A. Maddu, K. Santoso, and Isnaeni, "Karakteristik Sifat Optik Nanopartikel Karbon (Carbon Dots) Dengan Metode Uv-Vis Drs (Ultraviolet-Visible Diffuse Reflectance Spectroscopy)," *JFT: Jurnal Fisika dan Terapannya*, vol. 9, no. 1, pp. 1–15, Jul. 2022, doi: 10.24252/jft.v9i1.28815.

[26] A. Kaur, K. Pandey, R. Kaur, N. Vashishat, and M. Kaur, “Nanocomposites of Carbon Quantum Dots and Graphene Quantum Dots: Environmental Applications as Sensors,” *Chemosensors*, vol. 10, no. 9, p. 367, Sep. 2022, doi: 10.3390/chemosensors10090367.

[27] A. BAHTIAR, “Pengaruh Rasio Molar Asam Sitrat Dan Thiourea Pada Spektra Absorbansi Dan Fluoresensi Larutan Carbon Quantum Dots,” *Jurnal Material dan Energi Indonesia*, vol. 11, no. 2, p. 54, Feb. 2022, doi: 10.24198/jme.v11i2.37296.

[28] J. W. Lim, “Polymer Materials for Optoelectronics and Energy Applications,” *Materials*, vol. 17, no. 15, p. 3698, Jul. 2024, doi: 10.3390/ma17153698.

[29] S. Manzoor *et al.*, “Carbon dots applications for development of sustainable technologies for food safety: A comprehensive review,” *Applied Food Research*, vol. 3, no. 1, p. 100263, Jun. 2023, doi: 10.1016/j.afres.2023.100263.

[30] S. Das, L. Ngashangva, and P. Goswami, “Carbon Dots: An Emerging Smart Material for Analytical Applications,” *Micromachines (Basel)*, vol. 12, no. 1, p. 84, Jan. 2021, doi: 10.3390/mi12010084.