



## Fabrication of Dye-Sensitized Solar Cell Based on $\text{TiO}_2\text{-Fe}_3\text{O}_4$ with Mangosteen Peel Extract

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### Abstract

This study reports on the successful formation of  $\text{TiO}_2\text{-Fe}_3\text{O}_4$  thin films using spin coating fabrication method for solar cell applications with mangosteen peel extract as a dye sensitizer. The thin films were characterized by X-ray diffraction (XRD), scanning electron microscope-energy dispersive x-ray (SEM-EDX), ultraviolet-visible (UV-Vis), and solar cell simulator. The X-ray diffraction pattern showed the presence of  $\text{TiO}_2$  phase with anatase structure and  $\text{Fe}_3\text{O}_4$  with cubic structure, where the crystallite size of each is 52.39 nm and 19.27 nm, respectively. The  $\text{TiO}_2\text{-Fe}_3\text{O}_4$  nanocomposite has a spherical and agglomerated shape. Interestingly, the  $\text{TiO}_2\text{-Fe}_3\text{O}_4$  thin film mangosteen peel extract as a dye sensitizer showed an efficiency of 0.00573%. This result opens a new material candidate for DSSC applications.

**Keywords:**  $\text{TiO}_2\text{-Fe}_3\text{O}_4$ , Mangosteen Peel Extract, DSSC, Thin Film.

### 1. Introduction

Nowadays, renewable energy has become a popular research topic due to the rapidly increasing demand for energy, especially electricity. So far, energy sources come from non-renewable fossil fuels such as petroleum, natural gas, and coal [1]. The use of fossil fuels has also had very significant negative impacts, including climate change, acid rain, air pollution, and temperature changes [2]. Therefore, it encourages researchers to look for other alternative energy sources [3], such as solar thermal energy [4]. Solar heat can be converted into electrical energy using the photovoltaic principle, such as the Dye-Sensitized Solar Cell (DSSC) device [5], [6]. The manufacturing process is simple, with a dye sensitizer component that can capture light and produce electrons [7]. DSSC components, such as photoanode, counter electrode, dye, and electrolyte, result in electron transfer so that it can convert solar thermal energy into electrical energy [8], [9]. Titanium dioxide ( $\text{TiO}_2$ ) is a material often used in DSSC.  $\text{TiO}_2$  was chosen because it has many advantages, including an affordable price [10], and high thermal stability [11]. However, electron transfer in  $\text{TiO}_2$  nanoparticles is a process that only contains electron transfer and recombination, resulting in less dye absorption and impacting the DSSC efficiency value [12], [13]. Furthermore, to increase the photoanode's efficiency, this study employed a special treatment: combining materials, or a composite. In this case,  $\text{TiO}_2$  will be composited with  $\text{Fe}_3\text{O}_4$  nanoparticles.  $\text{Fe}_3\text{O}_4$  nanoparticles have unique characteristics, including being biodegradable [14], dielectric [15], and having a large surface area and good dispersion power [16], which has led to the application of these nanoparticles in the fields of renewable energy [17], photocatalysts [18].

The  $\text{Fe}^{3+}$  ion in  $\text{Fe}_3\text{O}_4$  can increase light absorption from the ultraviolet to visible light range [19]. The hydrothermal preparation of  $\text{Fe}_3\text{O}_4/\text{TiO}_2$  has been successfully carried out by Hatefi et al [20]. Chou et al. (2016) also successfully prepared a  $\text{TiO}_2/\text{Fe}_3\text{O}_4$  composite for the manufacture of DSSC photoanodes, achieving an efficiency of 3.45%. [16]. The pores will make the dye perfectly absorbed [21]. The greater the amount of dye absorbed, the better the performance of the DSSC [22]. In addition to increasing efficiency through electron transfer, selecting appropriate dyes is also necessary. Ruthenium is a dye sensitizer commonly used in the manufacture of DSSCs [23]. However, during its

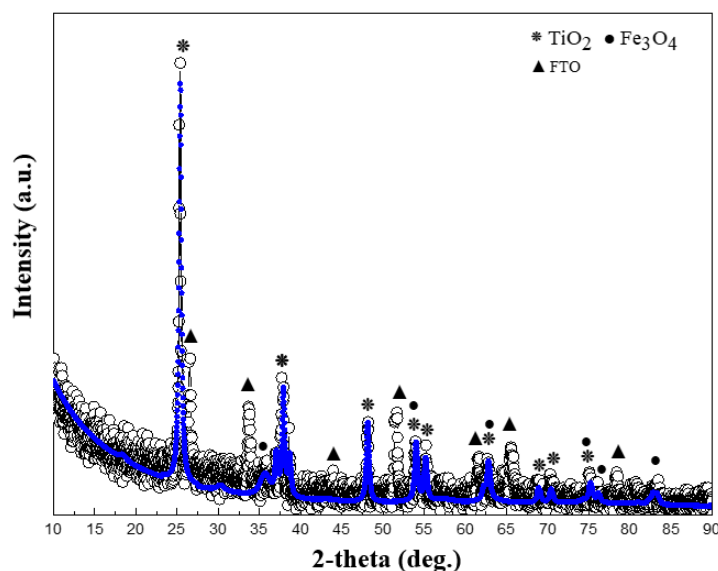
manufacture, ruthenium is quite expensive and difficult to synthesize. Natural dyes contained in fruits are suspected to be an alternative material for making dyes, this is because fruits contain carotene, flavonoids, and anthocyanins [24]. In this study, dye was produced from mangosteen peel extract. Mangosteen peel is believed to be able to be used as a dye because it contains flavonoids, carotenes, and anthocyanins [25], where previous researchers have reported that in 100 grams of mangosteen peel, there are 59.3 mg of anthocyanins [26]. Plants with anthocyanin extracts exhibit a wide range of light absorption due to their conjugated double-bond arrangement. Therefore, the use of mangosteen peel extract can increase the efficiency of DSSC.

## 2. Methods

The initial step for fabricating  $\text{TiO}_2\text{-Fe}_3\text{O}_4$  was to make  $\text{Fe}_3\text{O}_4$  nanoparticles using the method following our previous research [27]. Next, the synthesis of  $\text{TiO}_2\text{-Fe}_3\text{O}_4$  nanocomposites was carried out by mixing  $\text{TiO}_2$  powder with  $\text{Fe}_3\text{O}_4$  (ratio of 1:2) by grinding in a mortar for 10 minutes, followed by the addition of deionized water, Triton X-100, and acetic acid. The next step was the fabrication of  $\text{TiO}_2\text{-Fe}_3\text{O}_4$  paste on FTO, which was carried out with a spin coater for 30 minutes. Then, the resulting FTO was heated to 500 °C. At the same time, mangosteen peel was extracted and used as a dye sensitizer. The mangosteen peel was cleaned, cut into small pieces, and dried using an oven for 120 minutes. Next, the mangosteen peel was ground using a blender and filtered with a mesh. Mangosteen peel powder was dissolved using deionized water at a ratio of 1:10 (w/v) followed by stirring for 60 minutes at a temperature of 100 °C. The resulting solution was then filtered using filter paper to obtain mangosteen peel extract.

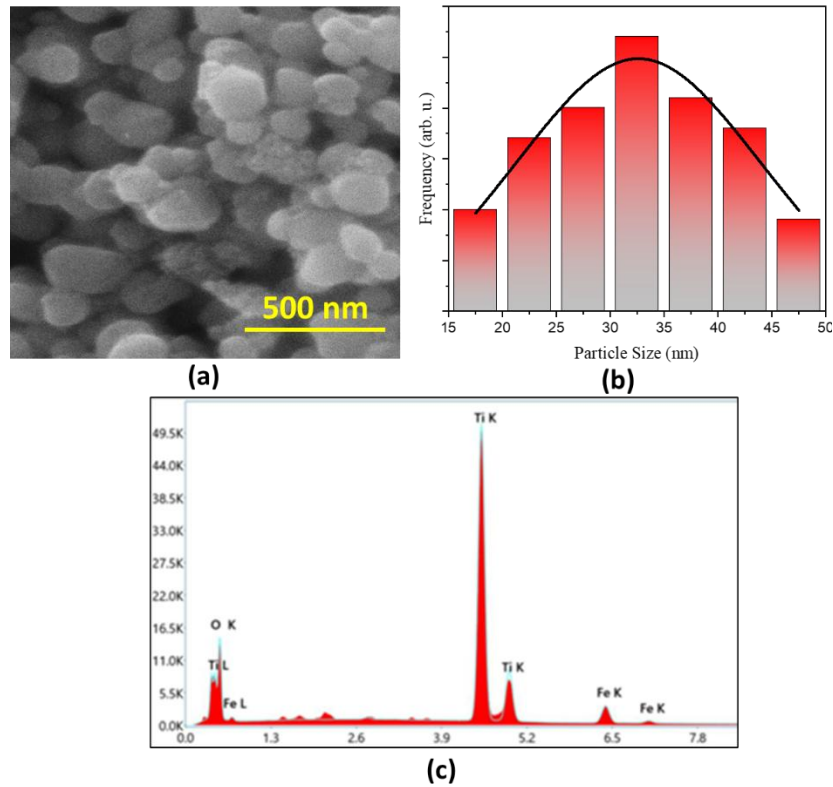
## 3. Results and Discussion

The diffraction peak of the thin film is shown in Figure 1. The figure shows that there are two crystallinity phases, namely  $\text{TiO}_2$  and  $\text{Fe}_3\text{O}_4$ . This is evidenced by  $\text{TiO}_2$  crystals in the anatase phase at  $2\theta = 25.26^\circ, 37.69^\circ, 48.05^\circ, 53.63^\circ, 55.23^\circ, 62.72^\circ, 68.95^\circ, 70.54^\circ, 75.00^\circ$  based on JCPDS card No.: 21-1272 [28]. The  $\text{Fe}_3\text{O}_4$  peaks are at  $2\theta = 35.46^\circ, 53.95^\circ, 62.73^\circ, 75.32^\circ, 76.28^\circ, \text{ and } 82.97^\circ$  [29] [30]. The appearance of FTO peaks was detected at  $2\theta = 26.69^\circ, 33.54^\circ, 43.75^\circ, 51.57^\circ, 61.13^\circ, 65.75^\circ, \text{ and } 78.190^\circ$  [31] [32]. The crystallite sizes for  $\text{TiO}_2$  and  $\text{Fe}_3\text{O}_4$  were 52.39 nm and 19.27 nm, respectively.

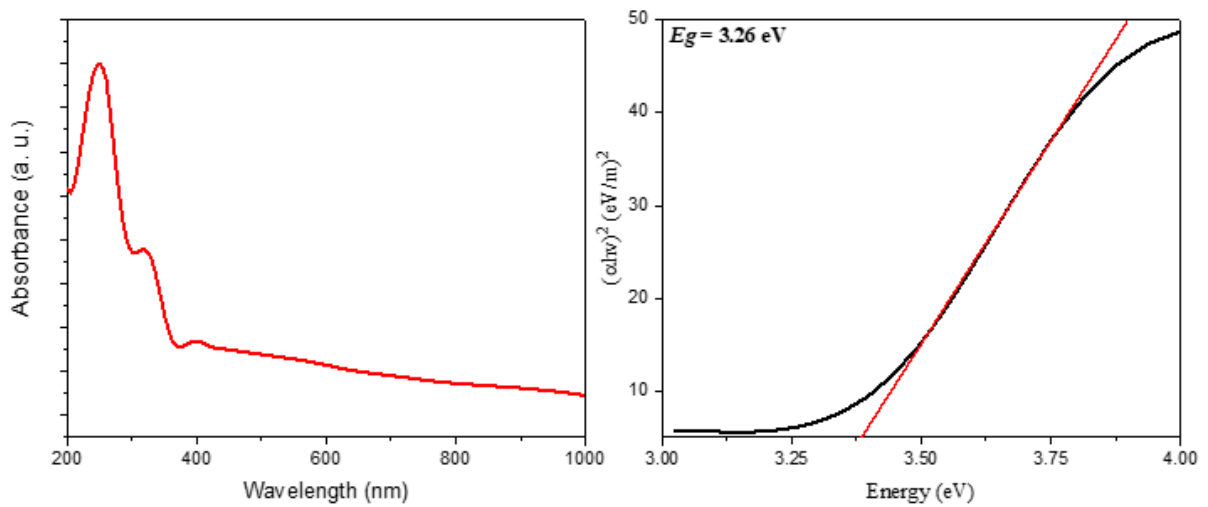


**Figure 1.** XRD Pattern of  $\text{TiO}_2\text{-Fe}_3\text{O}_4$  Thin Film.

The SEM characterization results are shown in Figure 2 (a). The nanocomposite of thin layer has a spherical shape with agglomeration. The particle size distribution of the nanocomposite has an average size of 32.16 nm (Figure 2 (b)). The size obtained is smaller than in previous studies of  $\text{TiO}_2/\text{Fe}_3\text{O}_4$  nanocomposites, approximately 30 nm [33]. The appearance of Ti, O, and Fe peaks confirms the presence of  $\text{TiO}_2$  and  $\text{Fe}_3\text{O}_4$  nanoparticles on EDX (Figure 2 (c)).



**Figure 2.** (a) Morphology (b) Particle Size Distribution and (c) EDX of TiO<sub>2</sub>-Fe<sub>3</sub>O<sub>4</sub> Thin Film.



**Figure 3.** (a) UV-Vis Spectrum and (b) Band Gap Energy of TiO<sub>2</sub>-Fe<sub>3</sub>O<sub>4</sub> Thin Film.

The results of UV-Vis characterization (Figure 3 (a)) show that there are two absorbances, at 276 and 400 nm, which indicate the absorption of Fe<sub>3</sub>O<sub>4</sub> and TiO<sub>2</sub> [34] [35]. The 400 nm absorption peak of TiO<sub>2</sub> is in the blue-purple region, originating from the recombination charge of the defective ground state [36]. Band gap analysis using the Touch Plot method for a thin layer of TiO<sub>2</sub>-Fe<sub>3</sub>O<sub>4</sub> nanocomposite is 3.26 eV (Figure 3 (b)). The value obtained is relatively larger than the value of TiO<sub>2</sub> nanoparticles, which is around 3.2 eV [37]. This difference is caused by the composing of Fe<sub>3</sub>O<sub>4</sub> [38].

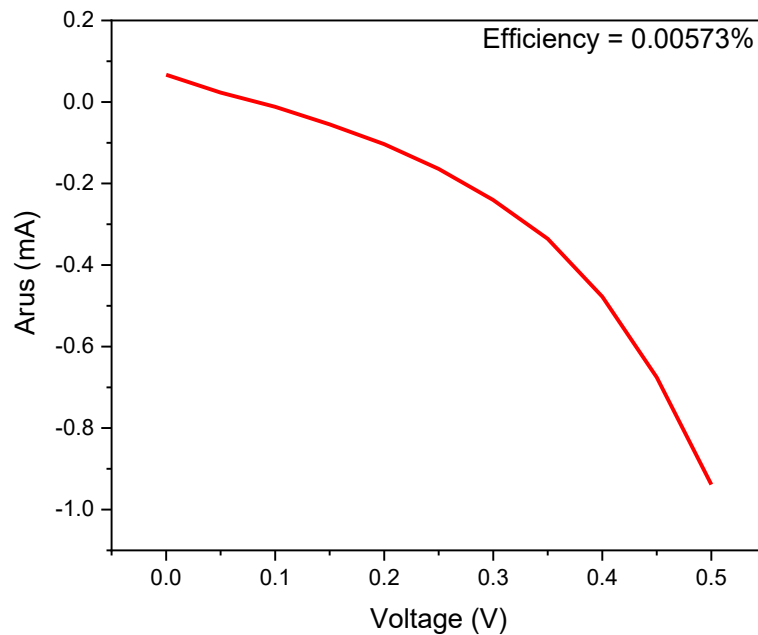
The efficiency of DSSC can be determined using the Equations 1-3 [39]:

$$\eta = \frac{P_{max}}{P_{in}} \tag{1}$$

$$FF = \frac{I_{max} \times V_{max}}{I_{SC} \times V_{OC}} \quad (2)$$

$$\eta = \frac{I_{SC} \times V_{OC} \times FF}{P_{in}} \quad (3)$$

where  $P_{max}$  and  $P_{in}$  are the maximum output power and input power. FF can be interpreted as Fill Factor, Open-Circuit Voltage (VOC),  $I_{max}$  and  $V_{max}$  can be interpreted as photocurrent and photovoltage for maximum power output, Short-Circuit Photocurrent (ISC) [40]. The efficiency of the TiO<sub>2</sub>-Fe<sub>3</sub>O<sub>4</sub> thin film is 0.00573%, as shown in Figure 4.



**Figure 4.** The efficiency of the TiO<sub>2</sub>-Fe<sub>3</sub>O<sub>4</sub> thin film.

### 3 Conclusion

TiO<sub>2</sub>-Fe<sub>3</sub>O<sub>4</sub> thin film has been successfully deposited by the spin coating method. XRD characterization results show that the observed crystal phases are TiO<sub>2</sub>, Fe<sub>3</sub>O<sub>4</sub>, and FTO. The nanocomposite has spherical agglomerates with a particle size of 32.16 nm. The UV-Vis spectrum shows two absorption peaks at 276 and 400 nm, indicating the absorption of Fe<sub>3</sub>O<sub>4</sub> and TiO<sub>2</sub>, with a band gap of 3.26 eV. In addition, the DSSC performance is characterized by an efficiency of 0.00573%. These results indicate that natural materials, such as Mangosteen Peel, also have the potential to serve as DSSC materials.

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### References

- [1] M. Z. A. Khan, H. A. Khan, and M. Aziz, "Harvesting Energy from Ocean: Technologies and Perspectives," *Energies*, vol. 15, no. 9, Art. no. 9, Jan. 2022, doi: 10.3390/en15093456.
- [2] M. Diantoro *et al.*, "Potential of nanooxidic materials and structures of photoanodes for DSSCs," in *Energy Materials*, Elsevier, 2021, pp. 213–247. doi: 10.1016/B978-0-12-823710-6.00013-3.
- [3] J. E. Ikpesu, S. E. Iyuke, M. Daramola, and A. O. Okewale, "Synthesis of improved dye-sensitized solar cell for renewable energy power generation," *Sol. Energy*, vol. 206, pp. 918–934, Aug. 2020, doi: 10.1016/j.solener.2020.05.002.

- [4] W. Arafah, "Marketing strategy for renewable energy development in Indonesia context today," in *Marketing strategy for renewable energy development in Indonesia context today: Arafah, Willy*, 2018.
- [5] M. Hosseinneshad, K. Gharanjig, S. Moradian, and M. R. Saeb, "In quest of power conversion efficiency in nature-inspired dye-sensitized solar cells: Individual, co-sensitized or tandem configuration?," *Energy*, vol. 134, pp. 864–870, Sept. 2017, doi: 10.1016/j.energy.2017.06.045.
- [6] S. Umale, V. Sudhakar, S. M. Sontakke, K. Krishnamoorthy, and A. B. Pandit, "Improved efficiency of DSSC using combustion synthesized TiO<sub>2</sub>," *Mater. Res. Bull.*, vol. 109, pp. 222–226, Jan. 2019, doi: 10.1016/j.materresbull.2018.09.044.
- [7] G. A. Nowsherwan *et al.*, "Numerical optimization and performance evaluation of ZnPC:PC70BM based dye-sensitized solar cell," *Sci. Rep.*, vol. 13, no. 1, p. 10431, June 2023, doi: 10.1038/s41598-023-37486-2.
- [8] D. Schmidt, M. D. Hager, and U. S. Schubert, "Photo-Rechargeable Electric Energy Storage Systems," *Adv. Energy Mater.*, vol. 6, no. 1, p. 1500369, Jan. 2016, doi: 10.1002/aenm.201500369.
- [9] Z. Zhou *et al.*, "Graphene-beaded carbon nanofibers with incorporated Ni nanoparticles as efficient counter-electrode for dye-sensitized solar cells," *Nano Energy*, vol. 22, pp. 558–563, Apr. 2016, doi: 10.1016/j.nanoen.2016.03.003.
- [10] S. Gupta and M. Tripathi, "A review on the synthesis of TiO<sub>2</sub> nanoparticles by solution route," *Open Chem.*, vol. 10, no. 2, pp. 279–294, Apr. 2012, doi: 10.2478/s11532-011-0155-y.
- [11] M. O. Ansari, M. M. Khan, S. A. Ansari, K. Raju, J. Lee, and M. H. Cho, "Enhanced thermal stability under DC electrical conductivity retention and visible light activity of Ag/TiO<sub>2</sub>@ polyaniline nanocomposite film," *ACS Appl. Mater. Interfaces*, vol. 6, no. 11, pp. 8124–8133, 2014.
- [12] J. Maçaira, L. Andrade, and A. Mendes, "Review on nanostructured photoelectrodes for next generation dye-sensitized solar cells," *Renew. Sustain. Energy Rev.*, vol. 27, pp. 334–349, Nov. 2013, doi: 10.1016/j.rser.2013.07.011.
- [13] M. Zhu, X. Li, W. Liu, and Y. Cui, "An investigation on the photoelectrochemical properties of dye-sensitized solar cells based on graphene–TiO<sub>2</sub> composite photoanodes," *J. Power Sources*, vol. 262, pp. 349–355, Sept. 2014, doi: 10.1016/j.jpowsour.2014.04.001.
- [14] H. Zhao, K. Saatchi, and U. O. Häfeli, "Preparation of biodegradable magnetic microspheres with poly(lactic acid)-coated magnetite," *J. Magn. Magn. Mater.*, vol. 321, no. 10, pp. 1356–1363, May 2009, doi: 10.1016/j.jmmm.2009.02.038.
- [15] M. -, H. -, and E. Suharyadi, "Kajian Sifat Dielektrik pada Lempeng Nanopartikel Magnetit (Fe<sub>3</sub>O<sub>4</sub>) yang dienkapsulasi dengan Polyvinyl Alcohol (PVA) (Halaman 34 s.d. 37)," *J. Fis. Indones.*, vol. 19, no. 55, May 2015, doi: 10.22146/jfi.24370.
- [16] J.-C. Chou *et al.*, "An Investigation on the Photovoltaic Properties of Dye-Sensitized Solar Cells Based on Fe<sub>3</sub>O<sub>4</sub>–TiO<sub>2</sub> Compositized Photoelectrode," *IEEE J. Electron Devices Soc.*, vol. 5, no. 1, pp. 32–39, Jan. 2017, doi: 10.1109/JEDS.2016.2618839.
- [17] N. Yulfriska, D. Rianto, F. Murti, Y. Darvina, and R. Ramli, "Optical Properties of Fe<sub>3</sub>O<sub>4</sub> Thin Films Prepared from the Iron Sand by Spin Coating Method," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 335, p. 012010, Apr. 2018, doi: 10.1088/1757-899X/335/1/012010.
- [18] J.-C. Chou *et al.*, "The Incorporation of Graphene and Magnetic Beads Into Dye-Sensitized Solar Cells and Application With Electrochemical Capacitor," *IEEE J. Photovolt.*, vol. 1, no. 6, pp. 223–229, 2016, doi: 10.1109/JPHOTOV.2015.2501730.
- [19] A. Pormehr, Islamic Azad University, M. Niyafar, Islamic Azad University, A. Hassanpour, and Islamic Azad University, "Investigation of structural properties of Yttrium Iron Garnet substituted by Antimony fabricated via sol-gel method," *Iran. J. Crystallogr. Mineral.*, vol. 26, no. 4, pp. 1027–1036, Jan. 2019, doi: 10.29252/ijcm.26.4.1027.
- [20] R. Hatefi, H. Younesi, A. Mashinchian-Moradi, and S. Nojavan, "A facile decoration of anatase Fe<sub>3</sub>O<sub>4</sub>/TiO<sub>2</sub> nanocomposite with graphene quantum dots: Synthesis, characterization, and photocatalytic activity," *Adv. Powder Technol.*, vol. 32, no. 7, pp. 2410–2422, July 2021, doi: 10.1016/j.apt.2021.05.020.
- [21] A. N. B. Zulkifili, T. Kento, M. Daiki, and A. Fujiki, "The Basic Research on the Dye-Sensitized Solar Cells (DSSC)," *J. Clean Energy Technol.*, vol. 3, no. 5, pp. 382–387, 2015, doi: 10.7763/JOCET.2015.V3.228.

- [22] A. K. Yahya and S. B. Sasongko, "Characterization of dye-sensitized solar cell (DSSC) with acid treatment by  $\text{HNO}_3$  in mangosteen peel dye," presented at the International Conference on Science and Applied Science (ICSAS) 2019, Surakarta, Indonesia, 2019, p. 020127. doi: 10.1063/1.5141740.
- [23] A. Maulina, H. Hardeli, and B. Bahrizal, "Preparasi dye sensitized solar cel menggunakan ekstrak antosianin kulit buah manggis (*Garcinia mangostana* L)," *Sainstek J. Sains Dan Teknol.*, vol. 6, no. 2, pp. 158–167, 2016.
- [24] J. A. Castillo-Robles, E. Rocha-Rangel, J. A. Ramírez-de-León, F. C. Caballero-Rico, and E. N. Armendáriz-Mireles, "Advances on Dye-Sensitized Solar Cells (DSSCs) Nanostructures and Natural Colorants: A Review," *J. Compos. Sci.*, vol. 5, no. 11, p. 288, Oct. 2021, doi: 10.3390/jcs5110288.
- [25] H. Rahman and G. Prajitno, "Pengaruh Pemberian Space (Bantalan) untuk Mendapatkan Kestabilan Arus dan Tegangan Prototipe DSSC dengan Ekstraksi Kulit Buah Manggis (*Garcinia Mangostana* L.) sebagai Dye Sensitizer," *Tugas Akhir Intitut Teknol. Sepuluh Nop. Surabaya*, 2013.
- [26] W. Supiyanti, E. D. Wulansari, and L. Kusmita, "Uji aktivitas antioksidan dan penentuan kandungan antosianin total kulit buah manggis (*Garcinia mangostana* L)," *Maj. Obat Tradis.*, vol. 15, no. 2, pp. 64–70, 2010.
- [27] A. Taufiq *et al.*, "Synthesis of  $\text{Fe}_3\text{O}_4/\text{Ag}$  nanohybrid ferrofluids and their applications as antimicrobial and antifibrotic agents," *Heliyon*, vol. 6, no. 12, p. e05813, Dec. 2020, doi: 10.1016/j.heliyon.2020.e05813.
- [28] R. Senthamarai, V. Madurai Ramakrishnan, B. Palanisamy, and S. Kulandhaivel, "Synthesis of  $\text{TiO}_2$  nanostructures by green approach as photoanodes for dye-sensitized solar cells," *Int. J. Energy Res.*, vol. 45, no. 2, pp. 3089–3096, Feb. 2021, doi: 10.1002/er.6002.
- [29] J. Siregar, K. Sebayang, B. Yulianto, and S. Humaidi, "XRD characterization of  $\text{Fe}_3\text{O}_4\text{-ZnO}$  nanocomposite material by the hydrothermal method," presented at the The 1st International Conference on Physics and Applied Physics (THE 1ST ICP&AP) 2019: Fundamental and Innovative Research for Improving Competitive Dignified Nation and Industrial Revolution 4.0, Medan, Indonesia, 2020, p. 110008. doi: 10.1063/5.0003210.
- [30] O. M. Lemine *et al.*, "Maghemite ( $\gamma\text{-Fe}_2\text{O}_3$ ) and  $\gamma\text{-Fe}_2\text{O}_3\text{-TiO}_2$  Nanoparticles for Magnetic Hyperthermia Applications: Synthesis, Characterization and Heating Efficiency," *Materials*, vol. 14, no. 19, p. 5691, Sept. 2021, doi: 10.3390/ma14195691.
- [31] Z. Zhou *et al.*, "CuInS<sub>2</sub> quantum dot-sensitized  $\text{TiO}_2$  nanorod array photoelectrodes: synthesis and performance optimization," *Nanoscale Res. Lett.*, vol. 7, no. 1, p. 652, Dec. 2012, doi: 10.1186/1556-276X-7-652.
- [32] P. Iyengar, C. Das, and K. R. Balasubramaniam, "Photoelectrochemical performance of NiO-coated ZnO–CdS core-shell photoanode," *J. Phys. Appl. Phys.*, vol. 50, no. 10, p. 10LT01, Mar. 2017, doi: 10.1088/1361-6463/aa5875.
- [33] F. Parast, M. Montazeri-Pour, M. Rajabi, and F. Bavarsiha, "Comparison of the structural and photo-catalytic properties of nanostructured  $\text{Fe}_3\text{O}_4/\text{TiO}_2$  core-shell composites synthesized by ultrasonic and Stöber methods," *Sci. Sinter.*, vol. 52, no. 4, pp. 415–432, 2020, doi: 10.2298/SOS2004415P.
- [34] N. Farmanbar, S. Mohseni, and M. Darroudi, "Green synthesis of chitosan-coated magnetic nanoparticles for drug delivery of oxaliplatin and irinotecan against colorectal cancer cells," *Polym. Bull.*, vol. 79, no. 12, pp. 10595–10613, Dec. 2022, doi: 10.1007/s00289-021-04066-1.
- [35] M. Nadimi, A. Ziarati Saravani, M. A. Aroon, and A. Ebrahimian Pirbazari, "Photodegradation of methylene blue by a ternary magnetic  $\text{TiO}_2/\text{Fe}_3\text{O}_4$ /graphene oxide nanocomposite under visible light," *Mater. Chem. Phys.*, vol. 225, pp. 464–474, Mar. 2019, doi: 10.1016/j.matchemphys.2018.11.029.
- [36] M. Stefan *et al.*, "Synthesis and characterization of  $\text{Fe}_3\text{O}_4\text{-TiO}_2$  core-shell nanoparticles," *J. Appl. Phys.*, vol. 116, no. 11, p. 114312, Sept. 2014, doi: 10.1063/1.4896070.
- [37] D. A. H. Hanaor, M. H. N. Assadi, S. Li, A. Yu, and C. C. Sorrell, "Ab initio study of phase stability in doped  $\text{TiO}_2$ ," *Comput. Mech.*, vol. 50, no. 2, pp. 185–194, Aug. 2012, doi: 10.1007/s00466-012-0728-4.

- [38] F. Kassir, M.-A. Azoury, P. Damacet, and A. Et, “Characterization and Performance of TiO<sub>2</sub> Nanoparticles Prepared by Microwave in Different Mixtures of Water and Ethylene Glycol for the Food Dye E131 VF Degradation:,” *Port. Electrochimica Acta*, vol. 41, no. 3, pp. 247–262, 2023, doi: 10.4152/pea.2023410305.
- [39] S. Numa, “[Regulation of lipid synthesis in animal organs],” *Naturwissenschaften*, vol. 62, no. 2, pp. 80–86, Feb. 1975, doi: 10.1007/BF00592180.
- [40] J. Ramirez-Perez, C. Maria, and C. P. Santacruz, “Impact of solvents on the extraction and purification of vegetable dyes onto the efficiency for dye-sensitized solar cells,” *Renew. Wind Water Sol.*, vol. 6, no. 1, p. 1, Dec. 2019, doi: 10.1186/s40807-019-0055-x.