UNIVERSITAS
GADJAH MADA
FOTOKATALIS g-C3N4/Co/ZrTiO4 UNTUK DEGRADASI ZAT WARNA MALACHITE GREEN DI BAWAH IRADIASI CAHAYA TAMPAK: PENGARUH VARIASI KONSENTRASI LOGAM KOBALT DALAM SINTESIS Co/ZrTiO4
Aulia Nur Romadhona, Akhmad Syoufian, S.Si., Ph.D. ; Dr.rer.nat. Rian Kurniawan, S.Si., M.Sc.
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

DAFTAR PUSTAKA

Adawiah, A., Zulys, A., Fitria, I., Khalil, M., Aziz, I., and Khalid, M., 2025, Perylene-based metal-organic frameworks-decorated Zinc Ferrite for enhanced photodegradation of malachite green in aqueous system, *South African J. Chem. Eng.*, 53, 319–330.

Adeel, M., Saeed, M., Khan, I., Muneer, M., and Akram, N., 2021, Synthesis and Characterization of Co–ZnO and Evaluation of Its Photocatalytic Activity for Photodegradation of Methyl Orange, *ACS Omega*, 6, 1426–1435.

Akbar, R., Shahzad, R., Munir, M. A., Saleem, S., Timoumi, A., Khalid, A., Alqahtani, Z., and Almukhlifi, H.A., 2026, Investigating the sintering effects on the photo-degradation efficiency of $CuMnFe_2O_4$@AC heterostructure against malachite green dye for wastewater treatments, *Opt. Mater. (Amst).*, 175, 118077.

Akpan, U.G., and Hameed, B.H., 2010, The advancements in sol-gel method of doped-TiO_2 photocatalysts, *Appl. Catal. A Gen.*, 375, 1–11.

Akram, S., and Javed, T., 2022, Capability of potato peel powder (PPP) for the adsorption of hazardous anionic Congo dye, *J. Dispers. Sci. Technol.*, 41, 1–14.

Akshay, S., Vidya, Y.S., Manjunatha, H.C., Munirathnam, R., Gurushantha, K., Sridhar, K.N., Shivanna, M., and Kumar, S., 2023, Deep yellow emission and high energy device applications of copper doped orthorhombic zirconium titanate nanoparticles, *Mater. Today Sustain.*, 23, 100479.

Al-hadeethy, S., Abdulmajeed, A.Z., Alalusi, A.M., Mahdi, A.M., Hussain, W.N., and Alrazaq, I.A., 2025, RSC Advances Reduced graphene oxide surface modi fi cation with nanoparticles and its e ffi ciency in removing crystal violet and malachite green dyes from wastewater, *RSC Adv.*, 15, 48509–48520.

Ali, S., Humayun, M., Pi, W., Yuan, Y., Wang, M., Khan, A., Yue, P., Shu, L., Zheng, Z., Fu, Q., and Luo, W., 2020, Fabrication of $BiFeO_3$-g-C_3N_4-WO_3 Z-scheme heterojunction as highly efficient visible-light photocatalyst for water reduction and 2,4-dichlorophenol degradation: Insight mechanism, *J. Hazard. Mater.*, 397.

Alijani, M., and Ilkhechi, N.N., 2018, Effect of Ni doping on the structural and optical properties of TiO_2 nanoparticles at various concentration and temperature, *Silicon*, 10, 2569–2575.

Annu, A., Sivasankari, C., and Krupasankar, U., 2020, Synthesis and characerization of Zro_2 nanoparticle by leaf extract bioreduction process for its biological studies, *Mater. Today Proc.*, 33, 5317–5323.

Betseba, A.H.H., and Shaji, Y.C., 2025, Surface area enhanced synthesis of Cu and Ni-based metal-organic frameworks for photocatalytic degradation of malachite green dye and anticancer drug delivery applications, *J. Drug Deliv.*

UNIVERSITAS GADJAH MADA
FOTOKATALIS g-C3N4/Co/ZrTiO4 UNTUK DEGRADASI ZAT WARNA MALACHITE GREEN DI BAWAH IRADIASI CAHAYA
TAMPAK: PENGARUH VARIASI KONSENTRASI LOGAM KOBALT DALAM SINTESIS Co/ZrTiO4
Aulia Nur Romadhona, Akhmad Syoufian, S.Si., Ph.D. ; Dr.rer.nat. Rian Kurniawan, S.Si., M.Sc.
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

Sci. Technol., 111, 1773–2247.

Bopape, D.A., Ntsendwana, B., and Mabasa, F.D., 2024, Photocatalysis as a pre-discharge treatment to improve the effect of textile dyes on human health: A critical review, *Heliyon*, 10, e39316.

Bora, L.V, and Mewada, R.K., 2017, Visible/solar light active photocatalysts for organic effluent treatment : Fundamentals , mechanisms and parametric review, *Renew. Sustain. Energy Rev.*, 76, 1393–1421.

Boualam, O., Gouri, M. El, Kherbeche, A., Addaou, A., and Laajeb, A., 2026, $BiVO_4$@Illite–chitosane nanohybrid under visible light: a green, economical, and high-performance catalyst for fast malachite green degradation, *Chem. Eng. Sci.*, 325, 123500.

Chanda, A., Rout, K., Vasundhara, M., Joshi, S.R., and Singh, J., 2018, Structural and magnetic study of undoped and cobalt doped TiO_2 nanoparticles, *RSC Adv.*, 8, 10939–10947.

Chang, C., Rad, S., Gan, L., Li, Z., Dai, J., and Shahab, A., 2023, Review of the sol–gel method in preparing nano TiO_2 for advanced oxidation process, *Nanotechnol. Rev.*, 12.

Chau, J.H.F., Lai, C.W., Leo, B.F., Juan, J.C., and Johan, M.R., 2022, Advanced photocatalytic degradation of acetaminophen using $Cu_2O/WO_3/TiO_2$ ternary composite under solar irradiation, *Catal. Commun.*, 163, 106396.

Chen, Q., Chang, Y., Shao, C., Zhang, J., Chen, J., Wang, M., and Long, Y., 2014, Effect of grain size on phase transformation and photoluminescence property of the nanocrystalline ZrO_2 powders prepared by sol-gel method, *J. Mater. Sci. Technol.*, 30, 1103–1107.

Chen, T., Foo, C., and Tsang, S.C.E., 2021, Interstitial and substitutional light elements in transition metals for heterogeneous catalysis, *Chem. Sci.*, 12, 517–532.

Chiu, Y.-H., Chang, T.-F., Chen, C.-Y., Sone, M., and Hsu, Y.-J., 2019, Mechanistic insights into photodegradation of organic dyes using heterostructure photocatalysts, *Catalysts*, 9, 430.

de Freitas, L.V.P., Silveira, J.G.F., Damaceno, M.A., Campanharo, S.C., da Silva, A.F.B., Jonas Joaquim Mangabeira, da S., Portela, A.C.V., de Jesus, R.B., Sasanya, J.J., Pilarski, F., Rath, S., and Paschoal, J.A.R., 2024, Evaluating the persistence of malachite green residues in tilapia and pacu fish, *Environ. Toxicol. Pharmacol.*, 106, 104382.

de Lucena, P.R., Roberto Leite, E., Pontes, F.M., Longo, E., Pizani, P.S., and Arana Varela, J., 2006, Photoluminescence: A probe for short, medium and long-range self-organization order in $ZrTiO_4$ oxide, *J. Solid State Chem.*, 179, 3997–4002.

Devi, S.A., Singh, K.J., and Devi, K.N., 2026, High performance and reusable microporous ZnS/PVDF nanocomposite films for photocatalytic degradation

UNIVERSITAS GADJAH MADA
FOTOKATALIS g-C3N4/Co/ZrTiO4 UNTUK DEGRADASI ZAT WARNA MALACHITE GREEN DI BAWAH IRADIASI CAHAYA
TAMPAK: PENGARUH VARIASI KONSENTRASI LOGAM KOBALT DALAM SINTESIS Co/ZrTiO4
Aulia Nur Romadhona, Akhmad Syoufian, S.Si., Ph.D. ; Dr.rer.nat. Rian Kurniawan, S.Si., M.Sc.
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

of malachite green dye, *Mater. Sci. Eng. B*, 330, 119548.

Dutta, H., Nandy, A., and Pradhan, S.K., 2016, Microstructure and optical characterizations of mechanosynthesized nanocrystalline semiconducting $ZrTiO_4$ compound, *J. Phys. Chem. Solids*, 95, 56–64.

Emrie, D.B., 2024, Sol–Gel Synthesis of Nanostructured Mesoporous Silica Powder and Thin Films, *J. Nanomater.*, 2024, 1–16.

Eranezhuth, W.A., Keshari Sahoo, S., and Kumar, R., 2019, Anomalous reduction in the band gap of zirconium titanate based composites, *Mater. Lett.*, 251, 230–233.

Ergun, G., Sahin, Z., and Ataol, A.S., 2018, The effects of adding various ratios of zirconium oxide nanoparticles to poly(methyl methacrylate) on physical and mechanical properties, *J. Oral Sci.*, 60, 304–315.

Ferreira, O., Monteiro, O.C., do Rego, A.M.B., Ferraria, A.M., Batista, M., Santos, R., Monteiro, S., Freire, M., and Silva, E.R., 2021, Visible light-driven photodegradation of triclosan and antimicrobial activity against Legionella pneumophila with cobalt and nitrogen co-doped TiO_2 anatase nanoparticles, *J. Environ. Chem. Eng.*, 9, 106735.

Ganesan, S., Kokulnathan, T., Sumathi, S., and Palaniappan, A., 2024, Efficient photocatalytic degradation of textile dye pollutants using thermally exfoliated graphitic carbon nitride (TE–g–C_3N_4), *Sci. Rep.*, 14, 1–13.

Garanin, Y., Shakirzyanov, R., Borgekov, D., Kozlovskiy, A., Volodina, N., Shlimas, D., and Zdorovets, M., 2024, Study of morphology, phase composition, optical properties, and thermal stability of hydrothermal zirconium dioxide synthesized at low temperatures, *Sci. Rep.*, 14, 1–12.

Ghosh, A., Mohammed, O.F., and Bakr, O.M., 2018, Atomic-level doping of metal clusters, *Acc. Chem. Res.*, 51, 3094–3103.

Ghzal, Q., Javed, T., and Batool, M., 2023, Potential of easily prepared low cost rice husk biochar and burnt clay composite for removal of Methylene Blue dye from contaminated water, *Environ. Sci.: Water Res. Technol*, 9, 2925–2941.

Gonçalves, N.P.F., Paganini, M.C., Armillotta, P., Cerrato, E., and Calza, P., 2019, The effect of cobalt doping on the efficiency of semiconductor oxides in the photocatalytic water remediation, *J. Environ. Chem. Eng.*, 1–9.

Guo, M., Yao, S., Zhang, W., Wang, Q., Lin, R., Liang, D., and Shen, D., 2025, Cobalt-doped rutile/anatase TiO_2 photoanode with oriented energy band offset for photoelectrochemical water splitting, *Appl. Surf. Sci.*, 700, 163159.

Gupta, R., Alam, U., and Verma, N., 2024, Efficient photofixation of nitrogen to ammonia over an S-scheme-based $NiSnO_3$-g-C_3N_4 heterojunction, *Chem. Eng. J.*, 479, 147644.

Hamad, H., Bailón-García, E., Pérez-Cadenas, A. F., Maldonado-Hódar, F.J., and Carrasco-Marín, F., 2020, ZrO_2-TiO_2/Carbon core-shell composites as highly

UNIVERSITAS
GADJAH MADA
FOTOKATALIS g-C3N4/Co/ZrTiO4 UNTUK DEGRADASI ZAT WARNA MALACHITE GREEN DI BAWAH IRADIASI CAHAYA
TAMPAK: PENGARUH VARIASI KONSENTRASI LOGAM KOBALT DALAM SINTESIS Co/ZrTiO4
Aulia Nur Romadhona, Akhmad Syoufian, S.Si., Ph.D. ; Dr.rer.nat. Rian Kurniawan, S.Si., M.Sc.
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

efficient solar-driven photo-catalysts: An approach for removal of hazardous water pollutants, *J. Environ. Chem. Eng.*, 8, 104350.

Hanafi, M. F., and Sapawe, N., 2020, Effect of pH on the photocatalytic degradation of remazol brilliant blue dye using zirconia catalyst, *Mater. Today Proc.*, 31, 260–262.

Hao, R., Wang, G., Tang, H., Sun, L., Xu, C., and Han, D., 2016, Template-free preparation of macro/mesoporous g-C_3N_4/TiO_2 heterojunction photocatalysts with enhanced visible light photocatalytic activity, *Appl. Catal. B Environ.*, 187, 47–58.

Harikumar, B., Okla, M.K., Kokilavani, S., Almunqedhi, B., Alshuwaish, R., Abdel-Maksoud, M.A., El-Tayeb, M.A., and Khan, S.S., 2023, Insights into oxygen defect enriched and non-metal dopant Co modulated Fe_3O_4 nanospheres embedded WO_3 nanorods for ameliorated photodegradation of doxycycline, Cr(VI) reduction and its genotoxicity, *J. Clean. Prod.*, 398, 136549.

Hasan, A.K.M.M., Dey, S.C., Rahman, M.M., Zakaria, A.M., Sarker, M., Ashaduzzaman, M., and Shamsuddin, S.M., 2020, A kaolinite/TiO_2/ZnO-based novel ternary composite for photocatalytic degradation of anionic azo dyes, *Bull. Mater. Sci.*, 43, 1–9.

He, J., Ding, T., and Wu, W., 2022, Surface lattice perturbation of electron transport layer reducing oxygen vacancies for positive photovoltaic effect, *Sol. RRL*, 6.

Hoffmann, M.R., Martin, S.T., Choi, W., and Bahnemann, D.W., 1995, Environmental applications of semiconductor photocatalysis, *Chem. Rev.*, 95, 69–96.

Hong, Y., Li, C., Zhang, G., Meng, Y., Yin, B., Zhao, Y., and Shi, W., 2016, Efficient and stable Nb_2O_5 modified g-C_3N_4 photocatalyst for removal of antibiotic pollutant, *Chem. Eng. J.*, 299, 74–84.

Hossen, M.A., Solayman, H.M., Leong, K.H., Sim, L.C., Yaacof, N., Abd Aziz, A., Wu, L., and Monir, M.U., 2022, Recent progress in TiO_2-Based photocatalysts for conversion of CO_2 to hydrocarbon fuels: A systematic review, *Results Eng.*, 16, 100795.

Hou, J., Cai, W., Ji, H., Ou, L., and He, W., 2024, Recent advances in semi-heterogenous photocatalysis in organic synthesis, *Chinese Chem. Lett.*, 36, 110469.

Hu, B.L., Ge, S.W., Han, J.Y., Hua, X. J., Li, S.L., Xing, H.R., Yuan, L.T., Zhang, X.Y., Wang, K.S., Hu, P., and Volinsky, A.A., 2022, $ZrTiO_4$ secondary phase effects on ductility and toughness of molybdenum alloys, *Mater. Lett.*, 307, 131077.

Humayun, M., Ullah, H., Cao, J., Pi, W., Yuan, Y., Ali, S., Tahir, A.A., Yue, P., Khan, A., Zheng, Z., Fu, Q., and Luo, W., 2020, Experimental and DFT studies of Au deposition over WO_3/g-C_3N_4 Z-scheme heterojunction, *Nano-Micro*

UNIVERSITAS GADJAH MADA
FOTOKATALIS g-C3N4/Co/ZrTiO4 UNTUK DEGRADASI ZAT WARNA MALACHITE GREEN DI BAWAH IRADIASI CAHAYA
TAMPAK: PENGARUH VARIASI KONSENTRASI LOGAM KOBALT DALAM SINTESIS Co/ZrTiO4
Aulia Nur Romadhona, Akhmad Syoufian, S.Si., Ph.D. ; Dr.rer.nat. Rian Kurniawan, S.Si., M.Sc.
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

Lett., 12, 1–18.

Ismael, M., 2023, Environmental remediation and sustainable energy generation via photocatalytic technology using rare earth metals modified g-C_3N_4: A review, *J. Alloys Compd.*, 931, 167469.

Jana, S., and Bhunia, K., 2025, Malachite green degradation by photocatalysis: kinetics and mechanism using sol–gel synthesized nano-titania, *Environ. Eng. Sci.*, 42, 340–353.

Jawhari, A. H., and Ismael, A. M., 2025, Analytical evaluation of an Ag-MOF photocatalyst for efficient malachite green degradation in wastewater: kinetics, mechanism, and stability, *RSC Adv.*, 15, 46164–46177.

Jiang, L., Yuan, X., Pan, Y., Liang, J., Zeng, G., Wu, Z., and Wang, H., 2017, Doping of graphitic carbon nitride for photocatalysis: A reveiw, *Appl. Catal. B Environ.*, 217, 388–406.

Jin, X., Wu, J., Wang, J., Chen, C., Kurioka, T., Sone, M., Hsu, Y., Okamoto, S., and Chang, T.M., 2025, Sintered NiFe2O4 Nanoparticles for the Photocatalytic Degradation of Malachite Green, *ACS Appl. Nano Mater.*, 8, 9066–9076.

Jinendra, U., Bilehal, D., Nagabhushana, B. M., and Praveen, A., 2026, Synthesis and application of Ni-$ZnFe_2O_4$ nanoparticles for effective removal of malachite green dye from aqueous solutions, *Solid State Commun.*, 414, 116456.

Jing, Y.N., Yin, X.L., Li, L.L., Wang, Y.L., Xue, J., Xu, Z.F., Liu, D.Q., Chen, C.W., Liu, X. J., and Liu, E.K., 2024, Fe-TiO_2-x/TiO_2 S-scheme homojunction for efficient photocatalytic CO_2 reduction, *J. Colloid Interface Sci.*, 668, 161–170.

Jubu, P.R., Obaseki, O.S., Ajayi, D.I., Danladi, E., Chahrour, K.M., Muhammad, A., Landi, S., Igbawua, T., Chahul, H.F., and Yam, F.K., 2024, Considerations about the determination of optical bandgap from diffuse reflectance spectroscopy using the tauc plot, *J. Opt.*, 53, 5054–5064.

Karim, A.V, Krishnan, S., and Shriwastav, A., 2022, An overview of heterogeneous photocatalysis for the degradation of organic compounds : A special emphasis on photocorrosion and reusability, *J. Indian Chem. Soc.*, 99, 100480.

Karimi-Shamsabadi, M., Behpour, M., Babaheidari, A.K., and Saberi, Z., 2017, Efficiently enhancing photocatalytic activity of NiO-ZnO doped onto nanozeoliteX by synergistic effects of p-n heterojunction, supporting and zeolite nanoparticles in photo-degradation of Eriochrome Black T and Methyl Orange, *J. Photochem. Photobiol. A Chem.*, 346, 133–143.

Karimi-Shamsabadi, M., Behpour, M., and Khoobi, A., 2025, The promoted photodegradation of mixture of textile dyes under visible-light using CdS-SiO_2-TiO_2/TiO_2 nanotube arrays heterojunction–Studying photocatalyst properties and determinants influencing efficiency, *J. Water Process Eng.*, 70.

UNIVERSITAS GADJAH MADA
FOTOKATALIS g-C3N4/Co/ZrTiO4 UNTUK DEGRADASI ZAT WARNA MALACHITE GREEN DI BAWAH IRADIASI CAHAYA
TAMPAK: PENGARUH VARIASI KONSENTRASI LOGAM KOBALT DALAM SINTESIS Co/ZrTiO4
Aulia Nur Romadhona, Akhmad Syoufian, S.Si., Ph.D. ; Dr.rer.nat. Rian Kurniawan, S.Si., M.Sc.
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

Karimi Shamsabadi, M., and Behpour, M., 2021, Fabricated CuO–ZnO/nanozeolite X heterostructure with enhanced photocatalytic performance: mechanism investigation and degradation pathway, *Mater. Sci. Eng. B*, 269, 115170.

Karthikeyan, C., Arunachalam, P., Ramachandran, K., Al-Mayouf, A.M., and Karuppuchamy, S., 2020, Recent advances in semiconductor metal oxides with enhanced methods for solar photocatalytic applications, *J. Alloys Compd.*, 828, 154281.

Khan, S., Kim, J., Sotto, A., and Van der Bruggen, B., 2015, Humic acid fouling in a submerged photocatalytic membrane reactor with binary TiO_2-ZrO_2 particles, *J. Ind. Eng. Chem.*, 21, 779–786.

Khan, S., Noor, T., Iqbal, N., and Yaqoob, L., 2024, Photocatalytic Dye Degradation from Textile Wastewater : A Review, *ACS Omega*, 9, 21751–21767.

Kim, J.Y., Kim, C.S., Chang, H.K., and Kim, T.O., 2010, Effects of ZrO_2 addition on phase stability and photocatalytic activity of ZrO_2/TiO_2 nanoparticles, *Adv. Powder Technol.*, 21, 141–144.

Kirankumar, V.S., and Sumathi, S., 2020, A review on photodegradation of organic pollutants using spinel oxide, *Mater. Today Chem.*, 18, 100355.

Klein, J., Kampermann, L., Mockenhaupt, B., Behrens, M., Strunk, J., and Bacher, G., 2023, Limitations of the Tauc Plot Method, *Adv. Funct. Mater.*, 33, 1–19.

Kumawat, A., Chattopadhyay, S., Misra, K.P., Halder, N., Jain, S.K., and Choudhary, B.L., 2020, Blue-shift in the optical band gap of sol-gel derived Zn(1-x)SrxO nanoparticles, *Solid State Sci.*, 108, 106379.

Lalge, K.M., Nagtilak, M.C., Labade, S. N., Patil, V.S., Khengare, N.J., Sawant, S.S., and Jadhav, R.K., 2026, Effluent treatment using powdered silk: Spectroscopic and molecular docking insights into malachite green oxalate adsorption, *Mater. Chem. Phys.*, 354, 132193.

Li, X., Garlisi, C., Guan, Q., Anwer, S., Al-Ali, K., Palmisano, G., and Zheng, L., 2021, A review of material aspects in developing direct Z-scheme photocatalysts, *Mater. Today*, 47, 75–107.

Li, X.D., Pang, J.W., and Zhai, Q.Z., 2022, Spectrophotometric determination of bisazo dye malachite green in water sample, *Desalin. Water Treat.*, 266, 197–201.

Li, Y., Wang, Y., Lu, H., and Li, X., 2020, Preparation of $CoFe_2O_4$–P_4VP@Ag NPs as effective and recyclable catalysts for the degradation of organic pollutants with $NaBH_4$ in water, *Int. J. Hydrogen Energy*, 45, 16080–16093.

Lieke, T., Meinelt, T., Hoseinifar, S.H., Pan, B., Straus, D.L., and Steinberg, C.E.W., 2020, Sustainable aquaculture requires environmental-friendly treatment strategies for fish diseases, *Rev. Aquac*, 12, 943–965.

Lin, H., Liu, Y., Deng, J., Xie, S., Zhao, X., Yang, J., Zhang, K., Han, Z., and Dai,

UNIVERSITAS GADJAH MADA
FOTOKATALIS g-C3N4/Co/ZrTiO4 UNTUK DEGRADASI ZAT WARNA MALACHITE GREEN DI BAWAH IRADIASI CAHAYA
TAMPAK: PENGARUH VARIASI KONSENTRASI LOGAM KOBALT DALAM SINTESIS Co/ZrTiO4
Aulia Nur Romadhona, Akhmad Syoufian, S.Si., Ph.D. ; Dr.rer.nat. Rian Kurniawan, S.Si., M.Sc.
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

H., 2017, Graphitic carbon nitride-supported iron oxides: High-performance photocatalysts for the visible-light-driven degradation of 4-nitrophenol, *J. Photochem. Photobiol. A Chem.*, 336, 105–114.

Ling, F., Li, W., and Ye, L., 2018, Applied Surface Science The synergistic effect of non-metal doping or defect engineering and interface coupling on the photocatalytic property of g-C_3N_4 : First-principle investigations, *Appl. Surf. Sci.*, 473, 386–392.

Liu, B., Zhao, X., Terashima, C., Fujishima, A., and Nakata, K., 2014, Thermodynamic and kinetic analysis of heterogeneous photocatalysis for semiconductor systems, *Phys. Chem. Chem. Phys.*, 16, 8751.

Liu, C., Wang, F., Zhu, S., Xu, Y., Liang, Q., and Chen, Z., 2018, Controlled charge-dynamics in cobalt-doped TiO_2 nanowire photoanodes for enhanced photoelectrochemical water splitting, *J. Colloid Interface Sci.*, 530, 403–411.

Liu, H., Wen, X., Zhang, J., Zhang, H., and Wei, J., 2023, High performance membrane filtration coupled with PMS/$CoFe_2O_4$ catalytic degradation for dyes, *Chem. Eng. Res. Des.*, 193, 660–668.

Loviza, A.A., Abirami, S., and Jebarathinam, N.J., 2026, Applied Surface Science Synergistic photocatalysis using La_2O_3-$NiFe_2O_4$/g-C_3N_4 nanocomposites : mechanistic insights and reusability in dye degradation, *Appl. Surf. Sci.*, 740, 166946.

Makuła, P., Pacia, M., and Macyk, W., 2018, How to correctly determine the band gap energy of modified semiconductor photocatalysts based on UV-Vis spectra, *J. Phys. Chem. Lett.*, 9, 6814–6817.

Mehrabada, J.T., Partovib, M., Rad, F. A., and Khalilnezhadc, R., 2019, Nitrogen doped TiO_2 for efficient visible light photocatalytic dye degradation, *Iran. J. Catal.*, 9, 233–239.

Mhalshekar, K., Pawar, V., Gaydhane, M., and Sontakke, S., 2025, Ni-Co doped - TiO_2 catalyst for efficient photocatalytic degradation of malachite green under UV and direct sunlight, *Environ. Sci. Poll. Res*, 32, 28093–28108.

Miad, A. Al, Saikat, S.P., Alam, K., Hassain, S., Bahadur, N.M., and Ahmed, S., 2024, Metal oxide-based photocatalysts for the efficient degradation of organic pollutants for a sustainable environment: a review, *Nanoscale Adv.*, 6, 4781–4803.

Mohtar, S.S., Aziz, F., Ismail, A.F., Sambudi, N.S., Abdullah, H., Rosli, A.N., and Ohtani, B., 2021, Impact of doping and additive applications on photocatalyst textural properties in removing organic pollutants: A review, *Catalysts*, 11, 1–31.

Molaei, M.J., 2023, Graphitic carbon nitride (g-C_3N_4) synthesis and heterostructures, principles, mechanisms, and recent advances: A critical review, *Int. J. Hydrogen Energy*, 48, 32708–32728.

Moumen, A., Belhocine, Y., Sbei, N., Rahali, S., Ali, F.A.M., Mechati, F.,

UNIVERSITAS GADJAH MADA
FOTOKATALIS g-C3N4/Co/ZrTiO4 UNTUK DEGRADASI ZAT WARNA MALACHITE GREEN DI BAWAH IRADIASI CAHAYA
TAMPAK: PENGARUH VARIASI KONSENTRASI LOGAM KOBALT DALAM SINTESIS Co/ZrTiO4
Aulia Nur Romadhona, Akhmad Syoufian, S.Si., Ph.D. ; Dr.rer.nat. Rian Kurniawan, S.Si., M.Sc.
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

Hamdaoui, F., and Seydou, M., 2022, Removal of Malachite Green Dye from Aqueous Solution by Catalytic Wet Oxidation Technique Using Ni/Kaolin as Catalyst, *Molecules*, 27.

Munir, S., Shah, S.M., Hussain, H., and Ali khan, R., 2016, Effect of carrier concentration on the optical band gap of TiO_2 nanoparticles, *Mater. Des.*, 92, 64–72.

Naing, M.T., Hwang, J. B., Lee, J., Kim, Y., Jung, Y., and Lee, S., 2024, Synergistic effect of Co doping and borate impregnation on $BiVO_4$ photoanode for efficient photoelectrochemical water splitting, *Int. J. Hydrogen Energy*, 55, 234–242.

Oanh, L.M., Do, D.B., Hung, N.M., Thang, D.V., Phuong, D.T., Ha, D.T., and Van Minh, N., 2016, Formation of crystal structure of zirconium titanate $ZrTiO_4$ powders prepared by sol–gel method, *J. Electron. Mater.*, 45, 2553–2558.

Paganini, M.C., Giorgini, A., Gonçalves, N.P.F., Gionco, C., Prevot, A.B., and Calza, P., 2018, New insight into zinc oxide doped with iron and its exploitation to pollutants abatement, *Catal. Today*, 328, 230–234.

Parajuli, D., Dangi, S., Sharma, B.R., Shah, N.L., and KC, D., 2023, Sol-gel synthesis, characterization of ZnO thin films on different substrates, and bandgap calculation by the Tauc plot method, *Bibechana*, 20, 113–125.

Polliotto, V., Albanese, E., Livraghi, S., Agnoli, S., Pacchioni, G., and Giamello, E., 2020, Structural, electronic and photochemical properties of cerium-doped zirconium titanate, *Catal. Today*, 340, 49–57.

Polliotto, V., Albanese, E., Livraghi, S., Indyka, P., Sojka, Z., Pacchioni, G., and Giamello, E., 2017, Fifty-Fifty Zr-Ti Solid Solution with a TiO_2-Type Structure: Electronic Structure and Photochemical Properties of Zirconium Titanate $ZrTiO_4$, *J. Phys. Chem. C*, 121, 5487–5497.

Prajapati, J., Maharana, N., Bhoi, B., Badola, A., Chaturvedi, S., and Chandra, V., 2026, Solar-powered degradation of malachite green dye via α-MnO_2 nanorods with CTAB-mediated electron trapping, *Next Mater.*, 10, 101511.

Pramanik, D. Das, Garg, P., Ganesan, D., and Pramanik, A., 2024, Removal of malachite green from an aqueous environment using chitosan-xanthan gum coagulation system: A response surface methodology approach, *J. Water Process Eng.*, 65, 105896.

Raj, S., Bajpai, D., Prasad, L., Kumar, N., and Kumar, A., 2026, Green synthesis and characterization of functionalised Cr_2CTX-OH MXene as an efficient adsorbent for malachite green dye, *Next Mater.*, 12, 102104.

Ramos-Justicia, J.F., Urbieta, A., and Fernández, P., 2026, Refined Langmuir–Hinshelwood Kinetics for Heterogeneous Photocatalytic Systems: Analytical Closed-Form Solution, Enhanced Approximations and Experimental Validation, *Physchem*, 6, 5.

Raval, N.P., Shah, P.U., and Shah, N.K., 2016, Nanoparticles loaded biopolymer as

UNIVERSITAS
GADJAH MADA
FOTOKATALIS g-C3N4/Co/ZrTiO4 UNTUK DEGRADASI ZAT WARNA MALACHITE GREEN DI BAWAH IRADIASI CAHAYA
TAMPAK: PENGARUH VARIASI KONSENTRASI LOGAM KOBALT DALAM SINTESIS Co/ZrTiO4
Aulia Nur Romadhona, Akhmad Syoufian, S.Si., Ph.D. ; Dr.rer.nat. Rian Kurniawan, S.Si., M.Sc.
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

effective adsorbent for adsorptive removal of malachite green from aqueous solution, *Water Conserv. Sci. Eng.*, 1, 69–81.

Raval, N.P., Shah, P.U., and Shah, N.K., 2017, Malachite green "a cationic dye" and its removal from aqueous solution by adsorption, *Appl. Water Sci.*, 7, 3407–3445.

Raveendran, A., Semasko, E., Jagminas, A., Sukoviene, A., and Ramanavicius, S., 2026, Current trends in cobalt and zinc ferrite based magnetic photocatalysts for wastewater treatment, *Inorg. Chem. Commun.*, 183, 115876.

Raza, A., Shoeb, M., Mashkoor, F., Rahaman, S., Mobin, M., Jeong, C., Yusuf Ansari, M., and Ahmad, A., 2022, Phoenix dactylifera mediated green synthesis of Mn doped ZnO nanoparticles and its adsorption performance for methyl orange dye removal: A comparative study, *Mater. Chem. Phys.*, 286, 126173.

Raziq, F., Qu, Y., Humayun, M., Zada, A., Yu, H., and Jing, L., 2017, Synthesis of SnO_2/B-P codoped g-C_3N_4 nanocomposites as efficient cocatalyst-free visible-light photocatalysts for CO_2 conversion and pollutant degradation, *Appl. Catal. B Environ.*, 201, 486–494.

Reza, M., Khaki, D., Saleh, M., Aziz, A., Raman, A., Mohd, W., and Wan, A., 2017, Application of doped photocatalysts for organic pollutant degradation - A review, *J. Environ. Manage.*, 198, 78–94.

Saad, A.M., Abukhadra, M.R., Abdel-Kader Ahmed, S., Elzanaty, A.M., Mady, A. H., Betiha, M.A., Shim, J.J., and Rabie, A.M., 2020, Photocatalytic degradation of malachite green dye using chitosan supported ZnO and Ce–ZnO nano-flowers under visible light, *J. Environ. Manage.*, 258, 110043.

Sadek, O., Touhtouh, S., Rkhis, M., Anoua, R., El Jouad, M., Belhora, F., and Hajjaji, A., 2022, Synthesis by sol-gel method and characterization of nano-TiO2 powders, *Mater. Today Proc.*, 66, 456–458.

Sadia, S.I., Shishir, M.K.H., Ahmed, S., Aidid, A.R., Islam, M.M., Rana, M.M., Al-Reza, S.M., and Alam, M.A., 2024, Crystallographic biography on nanocrystalline phase of polymorphs titanium dioxide (TiO_2): A perspective static review, *South African J. Chem. Eng.*, 50, 51–64.

Samanta, S., Martha, S., and Parida, K., 2014, Facile Synthesis of Au/g-C_3N_4 Nanocomposites: An inorganic/organic hybrid plasmonic photocatalyst with enhanced hydrogen gas evolution under visible-light irradiation, *ChemCatChem*, 6, 1453–1462.

Sapawe, N., Jalil, A.A., Triwahyono, S., Sah, R.N.R.A., Jusoh, N.W.C., Hairom, N.H.H., and Efendi, J., 2013, Electrochemical strategy for grown ZnO nanoparticles deposited onto HY zeolite with enhanced photodecolorization of methylene blue: Effect of the formation of SiOZn bonds, *Appl. Catal. A Gen.*, 456, 144–158.

Saqib, M., Rahman, N., Safeen, K., Mekkey, S.D., Salem, M.A., Safeen, A.,

UNIVERSITAS GADJAH MADA
FOTOKATALIS g-C3N4/Co/ZrTiO4 UNTUK DEGRADASI ZAT WARNA MALACHITE GREEN DI BAWAH IRADIASI CAHAYA
TAMPAK: PENGARUH VARIASI KONSENTRASI LOGAM KOBALT DALAM SINTESIS Co/ZrTiO4
Aulia Nur Romadhona, Akhmad Syoufian, S.Si., Ph.D. ; Dr.rer.nat. Rian Kurniawan, S.Si., M.Sc.
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

Husain, M., Zaman, S., Abdullaev, S., Kalsoom, A., El-Bahy, Z. M., and Khan, R., 2023, Structure phase-induced photodegradation properties of cobalt-sulfur co-doped TiO_2 nanoparticles synthesized by hydrothermal route, *J. Mater. Res. Technol.*, 26, 8048–8060.

Saviola, A.J., Syoufian, A., Oh, W.C., and Wijaya, K., 2025, Atmospheric hydrotreatment of used palm cooking oil over nickel-dispersed phosphated zirconia as highly stable nano-catalyst for bio-jet fuel production, *Inorg. Chem. Commun.*, 173, 113790.

Shabil Sha, M., Anwar, H., Musthafa, F.N., Al-Lohedan, H., Alfarwati, S., Rajabathar, J.R., Khalid Alahmad, J., Cabibihan, J.J., Karnan, M., and Kumar Sadasivuni, K., 2024, Photocatalytic degradation of organic dyes using reduced graphene oxide (rGO), *Sci. Rep.*, 14, 1–14.

Shao, G.N., Imran, S.M., Jeon, S.J., Engole, M., Abbas, N., Salman Haider, M., Kang, S.J., and Kim, H.T., 2014, Sol–gel synthesis of photoactive zirconia–titania from metal salts and investigation of their photocatalytic properties in the photodegradation of methylene blue, *Powder Technol.*, 258, 99–109.

Sharma, S., Mittal, A., Singh Chauhan, N., Makgwane, P.R., Kumari, K., Maken, S., and Kumar, N., 2021, Developments in visible-light active TiO_2/SnX (X = S and Se) and their environmental photocatalytic applications – A mini-review, *Inorg. Chem. Commun.*, 133.

Shearer, A., Montazerian, M., Deng, B., Sly, J.J., and Mauro, J.C., 2024, Zirconia-containing glass-ceramics: From nucleating agent to primary crystalline phase, *Int. J. Ceram. Eng. Sci.*, 6.

Shi, H., Zhao, B., Chen, N., Li, M., Sun, C., Xue, Y., Xing, Y., Wang, J., Ma, B., Wang, S., and Tang, Y., 2025, Synergistic manganese-cobalt co-doped TiO_2 for enhanced photocatalytic degradation of bisphenol A: Mechanism, DFT calculations, and toxicity assessment, *J. Alloys Compd.*, 1036, 182032.

Sivashankar, M., Sabarinathan, S., Khan, H., Alzabut, J., and Gómez-Aguilar, J.F., 2024, Stability and computational results for chemical kinetics reactions in enzyme, *J. Math. Chem.*, 62, 2346–2367.

Song, X., Yang, Q., Jiang, X., Yin, M., and Zhou, L., 2017, Porous graphitic carbon nitride nanosheets prepared under self-producing atmosphere for highly improved photocatalytic activity, *Appl. Catal. B Environ.*, 217, 322–330.

Srivastava, A., Rani, R.M., Patle, D.S., and Kumar, S., 2022, Emerging bioremediation technologies for the treatment of textile wastewater containing synthetic dyes: a comprehensive review, *J. chem. Technol. Biotechnol.*, 97, 26–41.

Sulaikhah, E.F., Kurniawan, R., Pradipta, M.F., Trisunaryanti, W., and Syoufian, A., 2020, Cobalt doping on zirconium titanate as a potential photocatalyst with visible-light-response, *Indones. J. Chem.*, 20, 911–918.

Syoufian, A., Afifah, R., Astuti, I.N., Saviola, A.J., Fitria, R.A., Kunarti, E.S.,

UNIVERSITAS
GADJAH MADA
FOTOKATALIS g-C3N4/Co/ZrTiO4 UNTUK DEGRADASI ZAT WARNA MALACHITE GREEN DI BAWAH IRADIASI CAHAYA
TAMPAK: PENGARUH VARIASI KONSENTRASI LOGAM KOBALT DALAM SINTESIS Co/ZrTiO4
Aulia Nur Romadhona, Akhmad Syoufian, S.Si., Ph.D. ; Dr.rer.nat. Rian Kurniawan, S.Si., M.Sc.
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

Sudiono, S., Kurniawan, R., Wijaya, K., Amin, A.K., Saputra, D.A., and Oh, W.C., 2026, Leveraging nanocomposites of cobalt-nitrogen co-doped-titania immobilized on zirconia as a visible-light active photocatalyst for malachite green and phenol photodegradation, *Vacuum*, 243, 114823.

Tan, H.L., Abdi, F.F., and Ng, Y.H., 2019, Heterogeneous photocatalysts : an overview of classic and modern approaches for optical , electronic , and charge dynamics evaluation, *Chem. Soc. Rev.*, 48, 1255–1271.

Tang, X., Shen, W., Li, D., Li, B., Wang, Y., Song, X., Zhu, Z., and Huo, P., 2023, Research on cobalt-doping sites in g-C_3N_4 framework and photocatalytic reduction CO_2 mechanism insights, *J. Alloys Compd.*, 954, 170044.

Teymori, M., Khorsandi, H., Aghapour, A.A., Jafari, S.J., and Maleki, R., 2020, Electro-fenton method for the removal of malachite green: effect of operational parameters, *Appl. Water Sci.*, 10, 1–14.

Tkaczyk, A., Mitrowska, K., and Posyniak, A., 2020, Synthetic organic dyes as contaminants of the aquatic environment and their implications for ecosystems: A review, *Sci. Total Environ.*, 717, 137222.

Tran, H.D., Nguyen, D.Q., Do, P.T., and Tran, U.N.P., 2023, Kinetics of photocatalytic degradation of organic compounds: a mini-review and new approach, *RSC Adv.*, 13, 16915–16925.

Ullah, S., Rahman, A. U., Ullah, F., Rashid, A., Arshad, T., Viglašová, E., Galamboš, M., Mahmoodi, N.M., and Ullah, H., 2021, Adsorption of malachite green dye onto mesoporous natural inorganic clays: Their equilibrium isotherm and kinetics studies, *Water (Switzerland)*, 13.

Verma, S., Rani, S., Kumar, S., and Khan, M.A.M., 2018, Rietveld refinement, micro-structural, optical and thermal parameters of zirconium titanate composites, *Ceram. Int.*, 44, 1653–1661.

Wang, J., Yang, C., Wang, C., Han, W., and Zhu, W., 2014, Photolytic and photocatalytic degradation of micro pollutants in a tubular reactor and the reaction kinetic models, *Sep. Purif. Technol.*, 122, 105–111.

Wang, J., Zhao, Y.F., Wang, T., Li, H., and Li, C., 2015, Photonic, and photocatalytic behavior of TiO_2 mediated by Fe, CO, Ni, N doping and co-doping, *Phys. B Condens. Matter*, 478, 6–11.

Wang, K., Su, X., Zhou, Z., Hu, L., Li, H., Long, J., Feng, Y., Zhang, X., Zhang, J., and Feng, J., 2026, Dual-Effect of S-Scheme Heterojunction and CQDs Strengthens the Charge Separation and Transfer in CQDs-g-C_3N_4/TiO_2 Photocatalysts Toward Efficient Tetracycline Degradation, *Nanomaterials*, 16, 1–18.

Wang, W., Huang, G., Yu, J.C., and Wong, P.K., 2015, Advances in photocatalytic disinfection of bacteria: Development of photocatalysts and mechanisms, *J. Environ. Sci. (China)*, 34, 232–247.

Xiong, R., Liu, F., Xiao, X., Xiao, Y., Cheng, B., and Lei, S., 2025, Dual electronic-

UNIVERSITAS GADJAH MADA
FOTOKATALIS g-C3N4/Co/ZrTiO4 UNTUK DEGRADASI ZAT WARNA MALACHITE GREEN DI BAWAH IRADIASI CAHAYA
TAMPAK: PENGARUH VARIASI KONSENTRASI LOGAM KOBALT DALAM SINTESIS Co/ZrTiO4
Aulia Nur Romadhona, Akhmad Syoufian, S.Si., Ph.D. ; Dr.rer.nat. Rian Kurniawan, S.Si., M.Sc.
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

spin engineering in cobalt-doped CdS: Photocatalytic pathway switching from competing H_2 evolution to selective CO_2 reduction, *Chem. Eng. J.*, 520, 166224.

Xu, J., Lind, C., Wilkinson, A.P., and Pattanaik, S., 2000, X-ray diffraction and x-ray absorption spectroscopy studies of sol-gel-processed zirconium titanates, *Chem. Mater.*, 12, 3347–3355.

Xu, M., He, L., Wang, Y., Musazade, E., Qin, L., Shi, M., Xiong, G., Maser, E., Guo, L., and Zhang, C., 2025, Biodegradation and decolorization of Congo red dye by metal-dependent hydrolase (MdeH) in Buttiauxella sp. S19-1, *J. Hazard. Mater.*, 500, 140575.

Yadav, R., Chundawat, T. S., Surolia, P.K., and Vaya, D., 2022, Photocatalytic degradation of textile dyes using β -CD-CuO / ZnO nanocomposite, *J. Phys. Chem. Solids*, 165, 110691.

Yang, J., Chang, X., Wei, F., Lv, Z., Liu, H., Li, Z., Wu, W., and Qian, L., 2023, High performance photocatalyst TiO_2@UiO-66 applied to degradation of methyl orange, *Discov. Nano*, 18.

Yang, Z., Peng, Y., Mao, K., and Wang, W., 2025, Optimization of malachite green degradation with response surface methodology in bio-electro-Fenton system, *Biocatal. Agric. Biotechnol*, 67, 103677.

Yong, L., Zhanqi, G., Yuefei, J., Xiaobin, H., Cheng, S., Shaogui, Y., Lianhong, W., Qingeng, W., and Die, F., 2015, Photodegradation of malachite green under simulated and natural irradiation: Kinetics, products, and pathways, *J. Hazard. Mater.*, 285, 127–136.

Zamani-faradanbeh, N., and Nezamzadeh-ejhieh, A., 2026, Results in Chemistry Synergistic effects of the zeolite support and semiconductor coupling in the enhanced photodegradation kinetics of malachite green and Congo red aqueous mixture, *Results Chem.*, 21, 103053.

Zhang, S., Gu, P., Ma, R., Luo, C., Wen, T., Zhao, G., Cheng, W., and Wang, X., 2019, Recent developments in fabrication and structure regulation of visible-light-driven g-C_3N_4-based photocatalysts towards water purification: A critical review, *Catal. Today*, 335, 65–77.

Zhao, G., Yang, H., Liu, M., and Xu, X., 2018, Metal-free graphitic carbon nitride photocatalyst goes into two-dimensional time, *Front. Chem.*, 6, 1–11.

Zhao, S., Xie, H., Tang, X., Lu, G., and Zhang, Y., 2023, Oxidized dextran-crosslinked ferrocene-chitosan-PEI composite porous material integrating adsorption and degradation to malachite green, *Carbohydr. Polym.*, 312, 120770.

Zhao, W.J., Ma, L., and Zhang, J.M., 2023, Investigation on the photocatalytic property of direct Z-type van der Waals g-C_3N_4/AlN heterojunction and its mechanism, *Chem. Phys.*, 571, 111913.

Zhao, Y., Xu, L., Guo, M., Li, Z., Xu, Z., Ye, J., Li, W., and Wei, S., 2022, Effects

UNIVERSITAS
GADJAH MADA
FOTOKATALIS g-C3N4/Co/ZrTiO4 UNTUK DEGRADASI ZAT WARNA MALACHITE GREEN DI BAWAH IRADIASI CAHAYA
TAMPAK: PENGARUH VARIASI KONSENTRASI LOGAM KOBALT DALAM SINTESIS Co/ZrTiO4
Aulia Nur Romadhona, Akhmad Syoufian, S.Si., Ph.D. ; Dr.rer.nat. Rian Kurniawan, S.Si., M.Sc.
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

of calcination temperature on grain growth and phase transformation of nano-zirconia with different crystal forms prepared by hydrothermal method, *J. Mater. Res. Technol.*, 19, 4003–4017.

Zu, D., Wei, H., Lin, Z., Bai, X., Ivan, M.N.A.S., Tsang, Y.H., and Huang, H., 2024, The role of point defects in heterojunction photocatalysts: perspectives and outlooks, *Adv. Funct. Mater.*, 34.