

## **BAB V**

### **PENUTUP**

#### **5.1 Kesimpulan**

Dari penelitian ini, dapat disimpulkan bahwa:

1. Kinerja *printable mesoscopic all-inorganic perovskite solar cell* (p-MAPSC) berbasis CsPbBr<sub>3</sub> yang terbaik pada divais variasi 18NR-T dengan konsentrasi 2:3 diperoleh efisiensi sebesar 4.21%, FF sebesar 61.00%, V<sub>oc</sub> sebesar 1324.1 mV, dan J<sub>sc</sub> sebesar 5.35 mA/cm<sup>2</sup>, yang memiliki ketebalan sebesar 239.91 nm. Serta divais variasi TiO<sub>2</sub> 90-T dengan konsentrasi 2:3 diperoleh efisiensi sebesar 3.80%, FF sebesar 58.40%, V<sub>oc</sub> sebesar 1370.2 mV, dan J<sub>sc</sub> sebesar 4.75 mA/cm<sup>2</sup>, yang memiliki ketebalan sebesar 178.63 nm.
2. Porositas pada mp-TiO<sub>2</sub> variasi 18NR-T sebesar 67.23% lebih besar dibandingkan dengan mp-TiO<sub>2</sub> variasi 90-T sebesar 66.54%, yang menunjukkan bahwa porositas yang lebih tinggi menghasilkan lebih banyak ruang kosong, sehingga memberikan jalur yang lebih baik untuk difusi ion halida dan pergerakan elektron yang lebih efisien di dalam *perovskite*, serta dapat memberikan penetrasi larutan *perovskite* dan distribusi *perovskite* yang lebih merata dan seragam.

#### **5.2 Saran**

Dari penelitian ini, diperlukan penelitian lebih lanjut pada struktur divais *printable mesoscopic all-inorganic perovskite solar cell* (p-MAPSC) berbasis CsPbBr<sub>3</sub>, antara lain:

1. Optimasi material pengikat (*adhesive*) untuk larutan karbon agar dapat meningkatkan kinerja divais p-MAPSC berbasis CsPbBr<sub>3</sub>.
2. Optimasi lapisan *perovskite* berupa suhu dan lama waktu pelapisan agar dapat meningkatkan kinerja divais p-MAPSC berbasis CsPbBr<sub>3</sub>.
3. Karakterisasi lanjut lainnya untuk membuktikan peningkatan stabilitas pada divais p-MAPSC berbasis CsPbBr<sub>3</sub>.

## DAFTAR PUSTAKA

- Afre, R.A. and Pugliese, D. (2024) ‘*Perovskite* Solar Cells: A Review of the Latest Advances in Materials, Fabrication Techniques, and Stability Enhancement Strategies’, *Micromachines*, 15(2), p. 192.
- Anggraini, P.N. *et al.* (2025) ‘Enhanced performance of two-step deposited CsPbBr<sub>3</sub> *perovskite* solar cells by SnO<sub>2</sub> green solvent engineering’, *Materials Letters*, 383, p. 138042.
- Benkstein, K.D. *et al.* (2003) ‘Influence of the Percolation Network Geometry on Electron Transport in Dye-Sensitized Titanium Dioxide Solar Cells’, *The Journal of Physical Chemistry B*, 107(31), pp. 7759–7767.
- Burschka, J. *et al.* (2013) ‘Sequential deposition as a route to high-performance *perovskite*-sensitized solar cells’, *Nature*, 499(7458), pp. 316–319.
- Cao, K. *et al.* (2015) ‘Efficient screen printed *perovskite* solar cells based on mesoscopic TiO<sub>2</sub>/Al<sub>2</sub>O<sub>3</sub>/NiO/carbon architecture’, *Nano Energy*, 17, pp. 171–179.
- Chen, C. *et al.* (2024) ‘Solution fabrication methods and optimization strategies of CsPbBr<sub>3</sub> *perovskite* solar cells’, *Journal of Materials Chemistry C*, 12(1), pp. 16–28.
- Chen, K. *et al.* (2020) ‘High Efficiency Mesoscopic Solar Cells Using CsPbI<sub>3</sub> *Perovskite* Quantum Dots Enabled by Chemical Interface Engineering’, *Journal of the American Chemical Society*, 142(8), pp. 3775–3783.
- Dunbar, R.B. *et al.* (2017) ‘How reliable are efficiency *measurements* of *perovskite* solar cells? The first inter-comparison, between two accredited and eight non-accredited laboratories’, *Journal of Materials Chemistry A*, 5(43), pp. 22542–22558.
- Fatima, Q. *et al.* (2024) ‘A critical review on advancement and challenges in using TiO<sub>2</sub> as electron transport layer for *perovskite* solar cell’, *Materials Today Sustainability*, 27, p. 100857.
- Guan, B., Qin, Y. and Guo, M. (2022) ‘Angle error control model of laser profilometer contact measurement’, *Open Physics*, 20(1), pp. 680–692.
- Gunawan, B. (2016) ‘Karakterisasi Arus dan Tegangan (I-V) pada Dye Sensitized Solar Cell (DSSC) dengan TiO<sub>2</sub> Terdoping Nitrogen Menggunakan Dye Sensitizer N749’. Institut Teknologi Surabaya.
- Haryński, Ł. *et al.* (2022) ‘A facile method for Tauc exponent and corresponding electronic transitions determination in semiconductors directly from UV–Vis spectroscopy data’, *Optical Materials*, 127, p. 112205.

- Hatta, M. *et al.* (2024) 'Influence of photoanode pre-heating treatment temperatures prior to dye immersion process on dye-sensitized solar cells photovoltaic performances', *IOP Conference Series: Earth and Environmental Science*, 1344(1), p. 012013.
- Hosseini, A., Ieli, K.C. and Güllü, H.H. (2013) 'Preparation and characterization of porous TiO<sub>2</sub> thin films by sol-gel method for Extremely Thin Absorber-ETA solar cell applications'. Middle East Technical University.
- Iqbal, S. *et al.* (2023) 'Fully Printed HTL-Free MAPbI<sub>3</sub> Perovskite Solar Cells with Carbon Electrodes', *Coatings*, 13(8), p. 1338.
- Irwansyah, F.S. *et al.* (2022) 'How to Read and Determine the Specific Surface Area of Inorganic Materials using the Brunauer-Emmett-Teller (BET) Method', *ASEAN Journal of Science and Engineering*, 4(1), pp. 61–70.
- Islam, M. (2011) 'Liquid-phase analytical applications of UV-visible broadband cavity-enhanced absorption spectroscopy (BBCEAS)', 23(2). Teesside University.
- Kajal, P. *et al.* (2021) 'Unveiling the role of carbon black in printable mesoscopic perovskite solar cells', *Journal of Power Sources*, 501, p. 230019.
- Katrib, M.A. (2022) 'Development of Perovskite Solar Cells Using Electrodeposition'. Université Grenoble Alpes.
- Kim, H.-S. *et al.* (2012) 'Lead Iodide Perovskite Sensitized All-Solid-State Submicron Thin Film Mesoscopic Solar Cell with Efficiency Exceeding 9%', *Scientific Reports*, 2(1), p. 591.
- Kim, Y.S. *et al.* (2021) 'Reduced extrinsic recombination process in anatase and rutile TiO<sub>2</sub> epitaxial thin films for efficient electron transport layers', *Scientific Reports*, 11(1), p. 6810.
- Kojima, A. *et al.* (2009) 'Organometal Halide Perovskites as Visible-Light Sensitizers for Photovoltaic Cells', *Journal of the American Chemical Society*, 131(17), pp. 6050–6051.
- Ku, Z. *et al.* (2013) 'Full Printable Processed Mesoscopic CH<sub>3</sub>NH<sub>3</sub>PbI<sub>3</sub>/TiO<sub>2</sub> Heterojunction Solar Cells with Carbon Counter Electrode', *Scientific Reports*, 3(1), p. 3132.
- Kulbak, M., Cahen, D. and Hodes, G. (2015) 'How Important Is the Organic Part of Lead Halide Perovskite Photovoltaic Cells? Efficient CsPbBr<sub>3</sub> Cells', *The Journal of Physical Chemistry Letters*, 6(13), pp. 2452–2456.

- Kurniawan, C., Waluyo, T.B. and Sebayang, P. (2011) 'Analisis Ukuran Partikel Menggunakan Free Software Image-J'. Pusat Penelitian Fisika, Lembaga Ilmu Pengetahuan Indonesia.
- Lee, D.G. *et al.* (2019) 'Effect of TiO<sub>2</sub> particle size and layer thickness on mesoscopic *perovskite* solar cells', *Applied Surface Science*, 477, pp. 131–136.
- Lee, J. *et al.* (2014) 'High-Efficiency *Perovskite* Solar Cells Based on the Black Polymorph of HC(NH<sub>2</sub>)<sub>2</sub>PbI<sub>3</sub>', *Advanced Materials*, 26(29), pp. 4991–4998.
- Lian, Q. *et al.* (2020) 'Using Soft Polymer Template Engineering of Mesoporous TiO<sub>2</sub> Scaffolds to Increase *Perovskite* Grain Size and Solar Cell Efficiency', *ACS Applied Materials & Interfaces*, 12(16), pp. 18578–18589.
- Liang, J. *et al.* (2016) 'All-Inorganic *Perovskite* Solar Cells', *Journal of the American Chemical Society*, 138(49), pp. 15829–15832.
- Liu, C. *et al.* (2021) 'Crystallization Kinetics Engineering toward High-Performance and Stable CsPbBr<sub>3</sub>-Based *Perovskite* Solar Cells', *ACS Applied Energy Materials*, 4(10), pp. 10610–10617.
- Liu, T. *et al.* (2015) 'Critical parameters in TiO<sub>2</sub>/ZrO<sub>2</sub>/Carbon-based mesoscopic *perovskite* solar cell', *Journal of Power Sources*, 293, pp. 533–538.
- Liu, Z. *et al.* (2019) 'Dual-sized TiO<sub>2</sub> nanoparticles as scaffold layers in carbon-based mesoscopic *perovskite* solar cells with enhanced performance', *Journal of Power Sources*, 430, pp. 12–19.
- Mahmood, K., Sarwar, S. and Mehran, M.T. (2017) 'Current status of electron transport layers in *perovskite* solar cells: materials and properties', *RSC Advances*, 7(28), pp. 17044–17062.
- Malliga, P. (2013) 'Effect of Film Thickness on Structural and Optical Properties of TiO<sub>2</sub> Thin Films'. Department of physics. V.V.Vanniaperumal College for Women.
- Meroni, S.M.P. *et al.* (2021) 'Triple-Mesosopic Carbon *Perovskite* Solar Cells: Materials, Processing and Applications', *Energies*, 14(2), p. 386.
- Mo, H. *et al.* (2024) 'Laser processing of Li-doped mesoporous TiO<sub>2</sub> for ambient-processed mesoscopic *perovskite* solar cells', *Journal of Materials Chemistry C*, 12(6), pp. 2025–2036.
- Mohammed, A. and Abdullah, A. (2018) 'Scanning Electron Microscopy (SEM): A Review'. University of Sulaimani.

- Moses Kayanda Kiteto and Cleophas Achisa Mecha (2024) 'Insight into the Bouguer-Beer-Lambert Law: A review', *Sustainable Chemical Engineering*, pp. 567–587.
- Noman, M., Khan, Z. and Jan, S.T. (2024) 'A comprehensive review on the advancements and challenges in *perovskite* solar cell technology', *RSC Advances*, 14(8), pp. 5085–5131.
- Park, J.H., Yoon, Y.S. and Kim, J.Y. (2023) 'Fabrication processes for all-inorganic CsPbBr<sub>3</sub> *perovskite* solar cells', *EcoMat*, 5(11), p. e12407.
- Park, N.-G. (2015) '*Perovskite* solar cells: an emerging photovoltaic technology', *Materials Today*, 18(2), pp. 65–72.
- Pascoe, A.R. *et al.* (2016) 'Planar versus mesoscopic *perovskite* microstructures: The influence of CH<sub>3</sub>NH<sub>3</sub>PbI<sub>3</sub> morphology on charge transport and recombination dynamics', *Nano Energy*, 22, pp. 439–452.
- Que, M. *et al.* (2021) 'Carbon-based electrodes for *perovskite* solar cells', *Materials Advances*, 2(17), pp. 5560–5579.
- Rabelsa, G. *et al.* (2025) 'The stability improvements of dye-sensitized solar cell with natural template for photoanode using lignin extracted from rice husk', *Heliyon*, 11(1), p. e39913.
- Rastiadi, H.A., Suhendi, E. and Prima, E.C. (2023) 'Pengaruh Ketebalan Lapisan Film Tipis TiO<sub>2</sub> Nanopartikel terhadap Sifat Optik dan Listrik Sel Surya *Perovskite* CH<sub>3</sub>NH<sub>3</sub>PbI<sub>3</sub>', *Jurnal Fisika*, 13(1), pp. 29–39.
- Rocha, F.S. *et al.* (2018) 'Experimental methods in chemical engineering: Ultraviolet visible spectroscopy—UV-Vis', *The Canadian Journal of Chemical Engineering*, 96(12), pp. 2512–2517.
- Roy, P. *et al.* (2020) 'A review on *perovskite* solar cells: Evolution of architecture, fabrication techniques, commercialization issues and status', *Solar Energy*, 198, pp. 665–688.
- Salim, T. *et al.* (2015) '*Perovskite*-based solar cells: impact of morphology and device architecture on device performance', *Journal of Materials Chemistry A*, 3(17), pp. 8943–8969.
- Sengupta, J. (2020) 'Application of carbon nanomaterials in the electronic industry', in *Handbook of Nanomaterials for Manufacturing Applications*. Elsevier, pp. 421–450.
- Setyawan, L.B. (2018) 'Perkembangan dan Prospek Sel Fotovoltaik Organik: Sebuah Telaah Ilmiah', *Techné: Jurnal Ilmiah Elektroteknika*, 17(02), pp. 93–100.

- Shao, J. *et al.* (2016) 'Pore Size Dependent Hysteresis Elimination in *Perovskite* Solar Cells Based on Highly Porous TiO<sub>2</sub> Films with Widely Tunable Pores of 15–34 nm', *Chemistry of Materials*, 28(19), pp. 7134–7144.
- Sharif, R. *et al.* (2023) 'A comprehensive review of the current progresses and material advances in *perovskite* solar cells', *Nanoscale Advances*, 5(15), pp. 3803–3833.
- Shindume L, H. *et al.* (2019) 'Enhanced Photocatalytic Activity of B, N-Codoped TiO<sub>2</sub> by a New Molten Nitrate Process', *Journal of Nanoscience and Nanotechnology*, 19(2), pp. 839–849.
- Shioki, T. *et al.* (2024) 'Designed Mesoporous Architecture by 10–100 nm TiO<sub>2</sub> as Electron Transport Materials in Carbon-Based Multiporous-Layered-Electrode *Perovskite* Solar Cells', *Photonics*, 11(3), p. 236.
- Singh, R. and Parashar, M. (2020) 'Origin of Hysteresis in *Perovskite* Solar Cells', in J. Ren and Z. Kan (eds) *Soft-Matter Thin Film Solar Cells*. AIP Publishing LLC Melville, New York, pp. 1-1-1–42.
- Sławek, A., Starowicz, Z. and Lipiński, M. (2021) 'The Influence of the Thickness of Compact TiO<sub>2</sub> Electron Transport Layer on the Performance of Planar CH<sub>3</sub>NH<sub>3</sub>PbI<sub>3</sub> *Perovskite* Solar Cells', *Materials*, 14(12), p. 3295.
- Sun, X. *et al.* (2017) 'Influence of the Porosity of the TiO<sub>2</sub> Film on the Performance of the *Perovskite* Solar Cell', *International Journal of Photoenergy*, 2017, pp. 1–10.
- Tomulescu, A.G. *et al.* (2020) 'Reticulated Mesoporous TiO<sub>2</sub> Scaffold, Fabricated by Spray Coating, for Large-Area *Perovskite* Solar Cells', *Energy Technology*, 8(1), p. 1900922.
- Ullah, S. *et al.* (2021) 'All-inorganic CsPbBr<sub>3</sub> *perovskite*: a promising choice for photovoltaics', *Materials Advances*, 2(2), pp. 646–683.
- Valsalakumar, S. *et al.* (2022) 'An Overview of Current Printing Technologies for Large-Scale *Perovskite* Solar Cell Development', *Energies*, 16(1), p. 190.
- Vasilopoulou, M. *et al.* (2022) 'Charge transport materials for mesoscopic *perovskite* solar cells', *Journal of Materials Chemistry C*, 10(31), pp. 11063–11104.
- Verma, A. *et al.* (2020) 'Inkjet printed mesoscopic *perovskite* solar cells with custom design capability', *Materials Advances*, 1(2), pp. 153–160.
- Vivo, P. *et al.* (2017) 'Influence of TiO<sub>2</sub> compact layer precursor on the performance of *perovskite* solar cells', *Organic Electronics*, 41, pp. 287–293.

- Wang, S. *et al.* (2020) ‘Mesoporous-Carbon-Based Fully-Printable All-Inorganic Monoclinic CsPbBr<sub>3</sub> Perovskite Solar Cells with Ultrastability under High Temperature and High Humidity’, *The Journal of Physical Chemistry Letters*, 11(22), pp. 9689–9695.
- Widjonarko, N. (2016) ‘Introduction to Advanced X-ray Diffraction Techniques for Polymeric Thin Films’, *Coatings*, 6(4), p. 54.
- Yang, H.-Y. *et al.* (2021) ‘Optimizing the Aspect Ratio of Nanopatterned Mesoporous TiO<sub>2</sub> Thin-Film Layer to Improve Energy Conversion Efficiency of Perovskite Solar Cells’, *International Journal of Molecular Sciences*, 22(22), p. 12235.
- Yang, Y. *et al.* (2015) ‘The size effect of TiO<sub>2</sub> nanoparticles on a printable mesoscopic perovskite solar cell’, *Journal of Materials Chemistry A*, 3(17), pp. 9103–9107.
- Yu, J. *et al.* (2020) ‘Perovskite CsPbBr<sub>3</sub> crystals: growth and applications’, *Journal of Materials Chemistry C*, 8(19), pp. 6326–6341.
- Zhao, Y. *et al.* (2023) ‘Two-in-one additive engineering strategy induced high-quality CsPbBr<sub>3</sub> film in printable mesoscopic perovskite solar cells’, *Journal of Alloys and Compounds*, 965, p. 171317.
- Zheng, Z. *et al.* (2022) ‘Development of formamidinium lead iodide-based perovskite solar cells: efficiency and stability’, *Chemical Science*, 13(8), pp. 2167–2183.
- Zhou, D. *et al.* (2018) ‘Perovskite-Based Solar Cells: Materials, Methods, and Future Perspectives’, *Journal of Nanomaterials*, 2018, pp. 1–15.
- Zhu, X. *et al.* (2024) ‘Sublimation and Recrystallization of CsPbBr<sub>3</sub> Constructing a Perovskite–Carbon Interface to Facilitate Hole Transfer in Printable All-Inorganic Perovskite Solar Cells’, *ACS Applied Materials & Interfaces*, 16(44), pp. 60321–60330.
- Zimmermann, E. *et al.* (2016) ‘Characterization of perovskite solar cells: Towards a reliable measurement protocol’, *APL Materials*, 4(9), p. 091901.