

REFERENCES

- [1] “Energy Explained - U.S. Energy Information Administration (EIA).” Accessed: Jul. 28, 2024. [Online]. Available: <https://www.eia.gov/energyexplained/>
- [2] “Energy Sources | Department of Energy.” Accessed: Jul. 28, 2024. [Online]. Available: <https://www.energy.gov/energy-sources>
- [3] “Energy demand: Three drivers | ExxonMobil.” Accessed: Sep. 07, 2023. [Online]. Available: <https://corporate.exxonmobil.com/what-we-do/energy-supply/global-outlook/energy-demand>
- [4] “Executive summary – World Energy Outlook 2022 – Analysis - IEA.” Accessed: Sep. 08, 2023. [Online]. Available: <https://www.iea.org/reports/world-energy-outlook-2022/executive-summary>
- [5] C. H. Moris, M. T. C. Guevara, A. Salmon, and A. Lorca, “Comparison between concentrated solar power and gas-based generation in terms of economic and flexibility-related aspects in chile,” *Energies*, vol. 14, no. 4, Feb. 2021, doi: 10.3390/EN14041063.
- [6] A. Coomaraswamy Mawatha and S. Lanka, “Sri Lanka Sustainable Energy Authority,” 2019.
- [7] “Sri Lanka | Climate Promise.” Accessed: Sep. 08, 2023. [Online]. Available: <https://climatepromise.undp.org/what-we-do/where-we-work/sri-lanka>
- [8] “Sooriyabala Sangaramaya | Sri Lanka Sustainable Energy Authority.” Accessed: Sep. 08, 2023. [Online]. Available: <https://www.energy.gov.lk/en/soorya-bala-sangramaya>
- [9] “Recycling | First Solar.” Accessed: Jul. 28, 2024. [Online]. Available: <https://www.firstsolar.com/en/Solutions/Recycling>
- [10] “Inzicht in Spectra van de Aarde.” Accessed: Sep. 08, 2023. [Online]. Available: <https://seos-project.eu/earthspectra/earthspectra-c02-p12.nl.html>
- [11] V. Malgras, A. Nattestad, J. H. Kim, S. X. Dou, and Y. Yamauchi, “Understanding chemically processed solar cells based on quantum dots,” *Sci. Technol. Adv. Mater.*, vol. 18, no. 1, pp. 334–350, 2017, doi: 10.1080/14686996.2017.1317219.
- [12] “Solar cell evolution: Past, present, future | Electronics360.” Accessed: Sep. 09, 2023. [Online]. Available: <https://electronics360.globalspec.com/article/15210/solar-cell-evolution-past-present-future>
- [13] “Best Research-Cell Efficiency Chart | Photovoltaic Research | NREL.” Accessed: Sep. 10, 2023. [Online]. Available: <https://www.nrel.gov/pv/cell-efficiency.html>

- [14] T. Saga, "Advances in crystalline silicon solar cell technology for industrial mass production," *NPG Asia Mater.*, vol. 2, no. 3, pp. 96–102, Jul. 2010, doi: 10.1038/asiamat.2010.82.
- [15] J. Pastuszak and P. Węgierek, "Photovoltaic Cell Generations and Current Research Directions for Their Development," *Materials (Basel)*, vol. 15, no. 16, p. 5542, Aug. 2022, doi: 10.3390/ma15165542.
- [16] K. L. Chopra, P. D. Paulson, and V. Dutta, "Thin-film solar cells: An overview," *Prog. Photovoltaics Res. Appl.*, vol. 12, no. 2–3, pp. 69–92, 2004, doi: 10.1002/pip.541.
- [17] M. A. Scarpulla *et al.*, "CdTe-based thin film photovoltaics: Recent advances, current challenges and future prospects," *Sol. Energy Mater. Sol. Cells*, vol. 255, p. 112289, Jun. 2023, doi: 10.1016/j.solmat.2023.112289.
- [18] S. Karthikeyan and P. Thirunavukkarasu, "Evolution of Amorphous-Si , CIGS and CdTe Solar Thin Films With a Comparative Market Analysis and Reliability Measures," vol. 8, no. 2, pp. 1633–1646, 2019.
- [19] N. Shah *et al.*, "A Review of Third Generation Solar Cells," *Processes*, vol. 11, no. 6, p. 1852, 2023, doi: 10.3390/pr11061852.
- [20] Y. Da and Y. Xuan, "Role of surface recombination in affecting the efficiency of nanostructured thin-film solar cells," *Opt. Express*, vol. 21, no. S6, p. A1065, Nov. 2013, doi: 10.1364/OE.21.0A1065.
- [21] A. ur Rehman *et al.*, "Development and prospects of surface passivation schemes for high-efficiency c-Si solar cells," *Sol. Energy*, vol. 166, pp. 90–97, May 2018, doi: 10.1016/j.solener.2018.03.025.
- [22] B. Barman and P. K. Kalita, "Influence of back surface field layer on enhancing the efficiency of CIGS solar cell," *Sol. Energy*, vol. 216, no. October 2020, pp. 329–337, 2021, doi: 10.1016/j.solener.2021.01.032.
- [23] "Anti Reflective Coating | A Brief History of AR Coatings." Accessed: Sep. 24, 2023. [Online]. Available: <https://diamondcoatings.co.uk/brief-history-anti-reflective-coatings/>
- [24] D. Kc, D. K. Shah, A. M. Alanazi, and M. S. Akhtar, "Impact of Different Antireflection Layers on Cadmium Telluride (CdTe) Solar Cells: a PC1D Simulation Study," *J. Electron. Mater.*, vol. 50, no. 4, pp. 2199–2205, 2021, doi: 10.1007/s11664-020-08696-5.
- [25] R. Sharma, A. Gupta, and A. Viridi, "Effect of single and double layer antireflection coating to enhance photovoltaic efficiency of silicon solar," *J. Nano- Electron. Phys.*, vol. 9, no. 2, pp. 4–7, 2017, doi: 10.21272/jnep.9(2).02001.
- [26] U. Gangopadhyay, K. Kim, D. Mangalaraj, and J. Yi, "Low cost CBD ZnS antireflection coating on large area commercial mono-crystalline silicon solar cells," *Appl. Surf. Sci.*, vol. 230, no. 1–4, pp. 364–370, 2004, doi:

10.1016/j.apsusc.2004.02.059.

- [27] A. T. Salih, A. A. Najim, M. A. H. Muhi, and K. R. Gbashi, "Single-material multilayer ZnS as anti-reflective coating for solar cell applications," *Opt. Commun.*, vol. 388, no. December, pp. 84–89, 2017, doi: 10.1016/j.optcom.2016.12.035.
- [28] M. Li, H. Shen, L. Zhuang, D. Chen, and X. Liang, "SiO₂ antireflection coatings fabricated by electron-beam evaporation for black monocrystalline silicon solar cells," *Int. J. Photoenergy*, vol. 2014, 2014, doi: 10.1155/2014/670438.
- [29] W. Zhang, J. Tu, W. Long, W. Lai, Y. Sheng, and T. Guo, "Preparation of SiO₂ anti-reflection coatings by sol-gel method," *Energy Procedia*, vol. 130, pp. 72–76, 2017, doi: 10.1016/j.egypro.2017.09.398.
- [30] J.-Y. Wang, C.-S. Huang, S.-L. Ou, Y.-S. Cho, and J.-J. Huang, "One-step preparation of TiO₂ anti-reflection coating and cover layer by liquid phase deposition for monocrystalline Si PERC solar cell," *Sol. Energy Mater. Sol. Cells*, vol. 234, p. 111433, Jan. 2022, doi: 10.1016/j.solmat.2021.111433.
- [31] R. Sagar and A. Rao, "Increasing the silicon solar cell efficiency with transition metal oxide nano-thin films as anti-reflection coatings," *Mater. Res. Express*, vol. 7, no. 1, 2020, doi: 10.1088/2053-1591/ab6ad5.
- [32] K. A. Salman, K. Omar, and Z. Hassan, "Improved performance of a crystalline silicon solar cell based on ZnO/PS anti-reflection coating layers," *Superlattices Microstruct.*, vol. 50, no. 5, pp. 517–528, 2011, doi: 10.1016/j.spmi.2011.08.014.
- [33] S.-H. Yi, S.-K. Choi, J.-M. Jang, J.-A. Kim, and W.-G. Jung, "Low-temperature growth of ZnO nanorods by chemical bath deposition," *J. Colloid Interface Sci.*, vol. 313, no. 2, pp. 705–710, Sep. 2007, doi: 10.1016/j.jcis.2007.05.006.
- [34] N. B. Patil, A. R. Nimbalkar, and M. G. Patil, "ZnO thin film prepared by a sol-gel spin coating technique for NO₂ detection," *Mater. Sci. Eng. B*, vol. 227, pp. 53–60, Jan. 2018, doi: 10.1016/j.mseb.2017.10.011.
- [35] D. Time *et al.*, "Controlling the Layer Thickness of Zinc Oxide Photoanode and," pp. 1–16, 2023.
- [36] O. A. Azeez, R. S. Sabry, M. A. M. Hassan, and S. F. Madlul, "Synthesis and characteristics of screen printed ZnO thick films nanostructures grown using different methods," *J. Mater. Sci. Mater. Electron.*, vol. 26, no. 6, pp. 4051–4061, Jun. 2015, doi: 10.1007/s10854-015-2944-0.
- [37] A. M. Alsaad, Q. M. Al-Bataineh, A. A. Ahmad, Z. Albataineh, and A. Telfah, "Optical band gap and refractive index dispersion parameters of boron-doped ZnO thin films: A novel derived mathematical model from the experimental transmission spectra," *Optik (Stuttg.)*, vol. 211, p. 164641, Jun. 2020, doi: 10.1016/J.IJLEO.2020.164641.
- [38] K. Ellmer, A. Klein, and B. Rech, Eds., *Transparent Conductive Zinc Oxide*,

vol. 104. in Springer Series in Materials Science, vol. 104. Berlin, Heidelberg: Springer Berlin Heidelberg, 2008. doi: 10.1007/978-3-540-73612-7.

- [39] N. B. Patil, A. R. Nimbalkar, and M. G. Patil, “ZnO thin film prepared by a sol-gel spin coating technique for NO₂ detection,” *Mater. Sci. Eng. B*, vol. 227, no. 2, pp. 53–60, 2018, doi: 10.1016/j.mseb.2017.10.011.
- [40] S. A. Kamaruddin, K. Y. Chan, H. K. Yow, M. Zainizan Sahdan, H. Saim, and D. Knipp, “Zinc oxide films prepared by sol-gel spin coating technique,” *Appl. Phys. A Mater. Sci. Process.*, vol. 104, no. 1, pp. 263–268, 2011, doi: 10.1007/s00339-010-6121-2.
- [41] Mursal, Irhamni, Bukhari, and Z. Jalil, “Structural and Optical Properties of Zinc Oxide (ZnO) based Thin Films Deposited by Sol-Gel Spin Coating Method,” *J. Phys. Conf. Ser.*, vol. 1116, no. 3, 2018, doi: 10.1088/1742-6596/1116/3/032020.
- [42] M. Smirnov, C. Baban, and G. I. Rusu, “Structural and optical characteristics of spin-coated ZnO thin films,” *Appl. Surf. Sci.*, vol. 256, no. 8, pp. 2405–2408, 2010, doi: 10.1016/j.apsusc.2009.10.075.
- [43] T. Amakali, L. S. Daniel, V. Uahengo, N. Y. Dzade, and N. H. De Leeuw, “Structural and Optical Properties of ZnO Thin Films Sol – Gel Methods,” *Crystals*, vol. 10(2), p. 132, 2020.
- [44] G. Womack, K. Isbilir, F. Lisco, G. Durand, A. Taylor, and J. M. Walls, “The performance and durability of single-layer sol-gel anti-reflection coatings applied to solar module cover glass,” *Surf. Coatings Technol.*, vol. 358, no. October 2018, pp. 76–83, 2019, doi: 10.1016/j.surfcoat.2018.11.030.
- [45] A. Kowsar, “Comparative Study on Solar Cell Simulators,” pp. 23–24, 2019.
- [46] K. C. Devendra *et al.*, “Numerical investigation of graphene as a back surface field layer on the performance of cadmium telluride solar cell,” *Molecules*, vol. 26, no. 11, pp. 1–10, 2021, doi: 10.3390/molecules26113275.
- [47] V. Shukla and G. Panda, “Effect of BSF layer on the performance of CdTe solar cell,” *Mater. Today Proc.*, vol. 44, pp. 2300–2303, 2021, doi: 10.1016/j.matpr.2020.12.394.
- [48] A. Haddout, A. Raidou, and M. Fahoume, “Influence of the layer parameters on the performance of the CdTe solar cells,” *Optoelectron. Lett.*, vol. 14, no. 2, pp. 98–103, Mar. 2018, doi: 10.1007/s11801-018-7229-4.
- [49] S. R. I. Biplab, M. H. Ali, M. M. A. Moon, M. F. Pervez, M. F. Rahman, and J. Hossain, “Performance enhancement of CIGS-based solar cells by incorporating an ultrathin BaSi₂ BSF layer,” *J. Comput. Electron.*, vol. 19, no. 1, pp. 342–352, 2020, doi: 10.1007/s10825-019-01433-0.
- [50] N. Amin, K. Sopian, and M. Konagai, “Numerical modeling of CdS/CdTe and CdS/CdTe/ZnTe solar cells as a function of CdTe thickness,” *Sol. Energy Mater. Sol. Cells*, vol. 91, no. 13, pp. 1202–1208, 2007, doi:

10.1016/j.solmat.2007.04.006.

- [51] N. Amin, T. Isaka, A. Yamada, and M. Konagai, “Highly efficient 1µm thick CdTe solar cells with textured TCOs,” *Sol. Energy Mater. Sol. Cells*, vol. 67, no. 1–4, pp. 195–201, Mar. 2001, doi: 10.1016/S0927-0248(00)00281-6.
- [52] S. Benabbas, Z. Rouabah, N. Bouarissa, and N. Chelali, “The role of back surface field SnS layer in improvement of efficiency of CdTe thin film solar cells,” *Optik (Stuttg.)*, vol. 127, no. 15, pp. 6210–6217, Aug. 2016, doi: 10.1016/j.ijleo.2016.04.050.
- [53] X. Yang, B. Chen, J. Chen, Y. Zhang, W. Liu, and Y. Sun, “ZnS thin film functionalized as back surface field in Si solar cells,” *Mater. Sci. Semicond. Process.*, vol. 74, no. April 2017, pp. 309–312, 2018, doi: 10.1016/j.mssp.2017.08.011.
- [54] Y. Liu, Y. Sun, W. Liu, and J. Yao, “Novel high-efficiency crystalline-silicon-based compound heterojunction solar cells: HCT (heterojunction with compound thin-layer),” *Phys. Chem. Chem. Phys.*, vol. 16, no. 29, pp. 15400–15410, 2014, doi: 10.1039/C4CP00668B.
- [55] A. Kaminski *et al.*, “Aluminium BSF in silicon solar cells,” *Sol. Energy Mater. Sol. Cells*, vol. 72, no. 1–4, pp. 373–379, Apr. 2002, doi: 10.1016/S0927-0248(01)00185-4.
- [56] L. D. S. Yadav, “Ultraviolet (UV) and Visible Spectroscopy,” in *Organic Spectroscopy*, Dordrecht: Springer Netherlands, 2005, pp. 7–51. doi: 10.1007/978-1-4020-2575-4_2.
- [57] “PVE300 Photovoltaic EQE (IPCE) and IQE solution - Bentham Instruments.” Accessed: Oct. 12, 2023. [Online]. Available: <https://www.bentham.co.uk/products/systems/pve300-photovoltaic-eqe-ipce-and-iqe-solution-16/>
- [58] “DTR6 Integrating Sphere (300-2000nm) - Bentham Instruments.” Accessed: Oct. 12, 2023. [Online]. Available: <https://www.bentham.co.uk/products/components/dtr6-integrating-sphere-300-2000nm-100/>
- [59] “Scanning Electron Microscopy | Nanoscience Instruments.” Accessed: Dec. 07, 2023. [Online]. Available: <https://www.nanoscience.com/techniques/scanning-electron-microscopy/>
- [60] “Principles of Operation: Stylus Profiler — Australia Surface Metrology Lab.” Accessed: Oct. 13, 2023. [Online]. Available: <https://australiasurfacemetrologylab.org/new-page>
- [61] “MST | [SEM-EDX] Energy Dispersive X-ray Spectroscopy (SEM).” Accessed: Oct. 13, 2023. [Online]. Available: https://www.mst.or.jp/Portals/0/en/en_sem-edx.htm
- [62] T. A. Gessert, R. G. Dhere, J. N. Duenow, J. V. Li, S. E. Asher, and M. R.

- Young, "Comparison of CdS/CdTe superstrate and substrate devices fabricated with a ZnTe:Cu contact interface," in *2010 35th IEEE Photovoltaic Specialists Conference*, IEEE, Jun. 2010, pp. 000335–000339. doi: 10.1109/PVSC.2010.5616922.
- [63] G. K. U. P. Gajanayake, A. A. I. Lakmal, D. S. M. De Silva, and B. S. Dassanayake, "Chemical Bath Deposited CdS Along with Electrodeposited and Closed Space Sublimated CdTe for Solar Cell Fabrication," 2022, pp. 7–12. doi: 10.1007/978-981-16-9280-2_2.
- [64] G. K. U. P. Gajanayake, D. S. M. De Silva, and H. Y. R. Atapattu, "Altering NH₄OH concentration in producing chemical bath deposited CdS to steadily support electrodeposited CdTe," *Mater. Sci. Eng. B*, vol. 265, no. April 2020, p. 114952, 2021, doi: 10.1016/j.mseb.2020.114952.
- [65] G. K. U. P. Gajanayake, A. A. I. Lakmal, D. S. M. De Silva, and B. S. Dassanayake, "Effect of CdTe nucleation layer on the performance of CdS/CdTe thin film solar cells," *J. Mater. Sci. Mater. Electron.*, vol. 34, no. 6, p. 508, Feb. 2023, doi: 10.1007/s10854-023-09895-6.
- [66] "PC1D | PVEducation." Accessed: Nov. 01, 2023. [Online]. Available: <https://www.pveducation.org/pvcdrom/welcome-to-pvcdrom/pc1d>
- [67] B. Ganesh, K. Y. Rani, B. Satyavathi, and K. S. K. R. Patnaik, "Experimental analysis in different batch operating units for process intensification: methyl acetate production case study," *Int. J. Ind. Chem.*, vol. 5, no. 3–4, pp. 85–93, Dec. 2014, doi: 10.1007/s40090-014-0023-7.
- [68] V. N. Jafarova and G. S. Orudzhev, "Structural and electronic properties of ZnO: A first-principles density-functional theory study within LDA(GGA) and LDA(GGA)+U methods," *Solid State Commun.*, vol. 325, p. 114166, Feb. 2021, doi: 10.1016/j.ssc.2020.114166.
- [69] T. A. Saleh, "Overview of surface and interface science," *Interface Sci. Technol.*, vol. 34, pp. 1–38, Jan. 2022, doi: 10.1016/B978-0-12-849876-7.00001-4.
- [70] K. Decock, A. Niemegeers, and J. Verschraegen, "SCAPS manual." Accessed: Nov. 01, 2023. [Online]. Available: <https://scaps.elis.ugent.be/SCAPS%20manual%20most%20recent.pdf>.
- [71] A. M. M. Ul Akhir and M. T. Imam, "Numerical Simulation of an Improved CZTS/WS₂ PV Cell by SCAPS 1-D," *GUB J. Sci. Eng.*, vol. 8, no. 1, pp. 41–48, Nov. 2022, doi: 10.3329/gubjse.v8i1.62331.
- [72] H. Dang, E. Ososanya, N. Zhang, and V. Singh, "Numerical modeling and simulation of stable nanowire CdS-CdTe solar cells," in *2017 IEEE 17th International Conference on Nanotechnology (IEEE-NANO)*, IEEE, Jul. 2017, pp. 171–176. doi: 10.1109/NANO.2017.8117357.
- [73] S. Ahmmed, A. Aktar, M. F. Rahman, J. Hossain, and A. B. M. Ismail, "A numerical simulation of high efficiency CdS/CdTe based solar cell using NiO

- HTL and ZnO TCO,” *Optik (Stuttg.)*, vol. 223, p. 165625, Dec. 2020, doi: 10.1016/j.ijleo.2020.165625.
- [74] B. Z. Bhari, K. S. Rahman, P. Chelvanathan, and M. A. Ibrahim, “Numerical Simulation of Ultrathin CdTe Solar Cell by SCAPS-1D,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1278, no. 1, p. 012002, Feb. 2023, doi: 10.1088/1757-899X/1278/1/012002.
 - [75] D. Parashar, V. S. G. Krishna, S. N. Moger, R. Keshav, and M. G. Mahesha, “Thickness Optimization of ZnO/CdS/CdTe Solar Cell by Numerical Simulation,” *Trans. Electr. Electron. Mater.*, vol. 21, no. 6, pp. 587–593, Dec. 2020, doi: 10.1007/s42341-020-00209-9.
 - [76] H. Dang, E. Ososanya, N. Zhang, and V. Singh, “Numerical modeling and simulation of stable nanowire CdS-CdTe solar cells,” in *2017 IEEE 17th International Conference on Nanotechnology (IEEE-NANO)*, IEEE, Jul. 2017, pp. 171–176. doi: 10.1109/NANO.2017.8117357.
 - [77] V. K. Arepalli, Y. Shin, and J. Kim, “Influence of working pressure on the structural, optical, and electrical properties of RF-sputtered SnS thin films,” *Superlattices Microstruct.*, vol. 122, pp. 253–261, Oct. 2018, doi: 10.1016/j.spmi.2018.08.001.
 - [78] T. D. Nguyen *et al.*, “Synthesis of Ag-embedded SnS films by the RF method for photovoltaic applications,” *Surfaces and Interfaces*, vol. 25, p. 101151, Aug. 2021, doi: 10.1016/j.surfin.2021.101151.
 - [79] J. Y. Cho, S. Sinha, M. G. Gang, and J. Heo, “Controlled thickness of a chemical-bath-deposited CdS buffer layer for a SnS thin film solar cell with more than 3% efficiency,” *J. Alloys Compd.*, vol. 796, pp. 160–166, Aug. 2019, doi: 10.1016/j.jallcom.2019.05.035.
 - [80] J. Vidal *et al.*, “Band-structure, optical properties, and defect physics of the photovoltaic semiconductor SnS,” *Appl. Phys. Lett.*, vol. 100, no. 3, Jan. 2012, doi: 10.1063/1.3675880.
 - [81] I. Ammar, A. Gassoumi, A. Akkari, F. Delpech, S. Ammar, and N. Turki-Kamoun, “Deposition of SnS thin films by chemical bath deposition method: Effect of surfactants,” *Eur. Phys. J. Plus*, vol. 134, no. 10, p. 505, Oct. 2019, doi: 10.1140/epjp/i2019-12976-3.
 - [82] H. Kafashan, M. Azizieh, and H. Nasiri Vatan, “Ultrasound-assisted electrodeposition of SnS: Effect of ultrasound waves on the physical properties of nanostructured SnS thin films,” *J. Alloys Compd.*, vol. 686, pp. 962–968, Nov. 2016, doi: 10.1016/j.jallcom.2016.06.201.
 - [83] T. Garmim *et al.*, “Optical, electrical and electronic properties of SnS thin films deposited by sol gel spin coating technique for photovoltaic applications,” *J. Mater. Sci. Mater. Electron.*, vol. 31, no. 23, pp. 20730–20741, Dec. 2020, doi: 10.1007/s10854-020-04586-y.
 - [84] F. Aslan, F. Arslan, A. Tumbul, and A. Goktas, “Synthesis and characterization

of solution processed p-SnS and n-SnS₂ thin films: Effect of starting chemicals,” *Opt. Mater. (Amst)*., vol. 127, p. 112270, May 2022, doi: 10.1016/j.optmat.2022.112270.

- [85] R. M. Geisthardt, M. Topic, and J. R. Sites, “Status and Potential of CdTe Solar-Cell Efficiency,” *IEEE J. Photovoltaics*, vol. 5, no. 4, pp. 1217–1221, Jul. 2015, doi: 10.1109/JPHOTOV.2015.2434594.
- [86] M. Isah *et al.*, “Exploring the impact of defect energy levels in CdTe/Si dual-junction solar cells using wxAMPS,” *Sci. Rep.*, vol. 14, no. 1, p. 4804, Feb. 2024, doi: 10.1038/s41598-024-55616-2.