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### References:

- [1] R. K. VK and M. Vimala, “ENERGY CONSUMPTION IN INDIA-RECENT TRENDS,” *Asia Pacific Journal of Research Vol: I. Issue XXXVI*, 2016.
- [2] R. Gupta and G. Dyanamina, “Matlab Simulation of DTC-SVM of Doubly Fed Induction Generator for Wind Energy System,” in *2019 Innovations in Power and Advanced Computing Technologies (i-PACT)*, 2019, vol. 1, pp. 1–6.
- [3] N. Barkatullah and A. Ahmad, “Current status and emerging trends in financing nuclear power projects,” *Energy Strategy Reviews*, vol. 18, pp. 127–140, 2017.
- [4] A. B. Stambouli and E. Traversa, “Solid oxide fuel cells (SOFCs): a review of an environmentally clean and efficient source of energy,” *Renewable and sustainable energy reviews*, vol. 6, no. 5, pp. 433–455, 2002.
- [5] S. Park, J. M. Vohs, and R. J. Gorte, “Direct oxidation of hydrocarbons in a solid-oxide fuel cell,” *Nature*, vol. 404, no. 6775, pp. 265–267, Mar. 2000, doi: 10.1038/35005040.
- [6] V. Kharton, F. Marques, and A. Atkinson, “Transport properties of solid oxide electrolyte ceramics: a brief review,” *Solid State Ion*, vol. 174, no. 1–4, pp. 135–149, Oct. 2004, doi: 10.1016/j.ssi.2004.06.015.

- [7] S. Baskaran, C. A. Lewinsohn, Y.-S. Chou, M. Qian, J. W. Stevenson, and T. R. Armstrong, "Mechanical properties of alkaline earth-doped lanthanum gallate."
- [8] N. MINH, "Solid oxide fuel cell technology?features and applications," *Solid State Ion*, vol. 174, no. 1–4, pp. 271–277, Oct. 2004, doi: 10.1016/j.ssi.2004.07.042.
- [9] A. Esquirol, "Electrochemical Characterisation of a  $\text{La}_{0.6}\text{Sr}_{0.4}\text{Co}_{0.2}\text{Fe}_{0.8}\text{O}_{3-\delta}$  Cathode for IT-SOFCs," *ECS Proceedings Volumes*, vol. 2003–07, no. 1, pp. 580–590, Jan. 2003, doi: 10.1149/200307.0580PV.
- [10] N. Q. Minh, "Ceramic Fuel Cells," *Journal of the American Ceramic Society*, vol. 76, no. 3, pp. 563–588, Mar. 1993, doi: 10.1111/j.1151-2916.1993.tb03645.x.
- [11] S. (Rob) Hui *et al.*, "A brief review of the ionic conductivity enhancement for selected oxide electrolytes," *J Power Sources*, vol. 172, no. 2, pp. 493–502, Oct. 2007, doi: 10.1016/j.jpowsour.2007.07.071.
- [12] K. Eguchi, T. Setoguchi, T. Inoue, and H. Arai, "Electrical properties of ceria-based oxides and their application to solid oxide fuel cells," *Solid State Ion*, vol. 52, no. 1–3, pp. 165–172, May 1992, doi: 10.1016/0167-2738(92)90102-U.
- [13] D. Y. Chung and E. H. Lee, "Microwave-induced combustion synthesis of  $\text{Ce}_{1-x}\text{Sm}_x\text{O}_{2-x/2}$  powder and its characterization," *J Alloys Compd*, vol. 374, no. 1–2, pp. 69–73, Jul. 2004, doi: 10.1016/j.jallcom.2003.11.094.

- [14] X. Chu, W. Chung, and L. D. Schmidt, "Sintering of Sol-Gel-Prepared Submicrometer Particles Studied by Transmission Electron Microscopy," *Journal of the American Ceramic Society*, vol. 76, no. 8, pp. 2115–2118, Aug. 1993, doi: 10.1111/j.1151-2916.1993.tb08344.x.
- [15] S. V. Chavan and A. K. Tyagi, "Combustion synthesis of nanocrystalline yttria-doped ceria," *J Mater Res*, vol. 19, no. 2, pp. 474–480, Feb. 2004, doi: 10.1557/jmr.2004.19.2.474.
- [16] V. Butler, C. Catlow, B. Fender, and J. Harding, "Dopant ion radius and ionic conductivity in cerium dioxide," *Solid State Ion*, vol. 8, no. 2, pp. 109–113, Apr. 1983, doi: 10.1016/0167-2738(83)90070-X.
- [17] *High-Temperature Solid Oxide Fuel Cells for the 21st Century*. Elsevier, 2016. doi: 10.1016/C2011-0-09278-5.
- [18] S. Nakayama, H. Aono, and Y. Sadaoka, "Ionic Conductivity of  $\text{Ln}_{10}(\text{SiO}_4)_6\text{O}_3$  (Ln = La, Nd, Sm, Gd and Dy)," *Chem Lett*, vol. 24, no. 6, pp. 431–432, Jun. 1995, doi: 10.1246/cl.1995.431.
- [19] H. Arikawa, H. Nishiguchi, T. Ishihara, and Y. Takita, "Oxide ion conductivity in Sr-doped  $\text{La}_{10}\text{Ge}_6\text{O}_{27}$  apatite oxide," *Solid State Ion*, vol. 136–137, pp. 31–37, Nov. 2000, doi: 10.1016/S0167-2738(00)00386-6.

- [20] S. S. Pramana, W. T. Klooster, and T. J. White, "Framework 'interstitial' oxygen in  $\text{La}_{10}(\text{GeO}_4)_5(\text{GeO}_5)\text{O}_2$  apatite electrolyte," *Acta Crystallogr B*, vol. 63, no. 4, pp. 597–602, Aug. 2007, doi: 10.1107/S0108768107024317.
- [21] S. Tao and J. T. S. Irvine, "Preparation and characterisation of apatite-type lanthanum silicates by a sol-gel process," *Mater Res Bull*, vol. 36, no. 7–8, pp. 1245–1258, May 2001, doi: 10.1016/S0025-5408(01)00625-0.
- [22] S. Nakayama, Y. Higuchi, Y. Kondo, and M. Sakamoto, "Effects of cation- or oxide ion-defect on conductivities of apatite-type La–Ge–O system ceramics," *Solid State Ion*, vol. 170, no. 3–4, pp. 219–223, May 2004, doi: 10.1016/j.ssi.2004.02.023.
- [23] S. Nakayama, T. Kageyama, H. Aono, and Y. Sadaoka, "Ionic conductivity of lanthanoid silicates,  $\text{Ln}_{10}(\text{SiO}_4)_6\text{O}_3$  (Ln = La, Nd, Sm, Gd, Dy, Y, Ho, Er and Yb)," *J Mater Chem*, vol. 5, no. 11, p. 1801, 1995, doi: 10.1039/jm9950501801.
- [24] A. L. Shaula, V. V. Kharton, and F. M. B. Marques, "Oxygen ionic and electronic transport in apatite-type  $\text{La}_{10-x}(\text{Si,Al})_6\text{O}_{26\pm\delta}$ ," *J Solid State Chem*, vol. 178, no. 6, pp. 2050–2061, Jun. 2005, doi: 10.1016/j.jssc.2005.04.018.
- [25] V. v. Kharton *et al.*, "Oxygen Ionic and Electronic Transport in Apatite-Type Solid Electrolytes," *J Electrochem Soc*, vol. 151, no. 8, p. A1236, 2004, doi: 10.1149/1.1768948.

- [26] S. Tao and J. T. S. Irvine, "Preparation and characterisation of apatite-type lanthanum silicates by a sol-gel process," *Mater Res Bull*, vol. 36, no. 7–8, pp. 1245–1258, May 2001, doi: 10.1016/S0025-5408(01)00625-0.
- [27] S. Nakayama, Y. Higuchi, Y. Kondo, and M. Sakamoto, "Effects of cation- or oxide ion-defect on conductivities of apatite-type La–Ge–O system ceramics," *Solid State Ion*, vol. 170, no. 3–4, pp. 219–223, May 2004, doi: 10.1016/j.ssi.2004.02.023.
- [28] P. R. Slater, J. E. H. Sansom, and J. R. Tolchard, "Development of apatite-type oxide ion conductors," *The Chemical Record*, vol. 4, no. 6, pp. 373–384, 2004, doi: 10.1002/tcr.20028.
- [29] S. Nakayama, M. Sakamoto, M. Highchi, and K. Kodaira, "1," *J Mater Sci Lett*, vol. 19, no. 2, pp. 91–93, 2000, doi: 10.1023/A:1006674708833.
- [30] S. Nakayama and M. Highchi, "Electrical properties of apatite-type oxide ionic conductors RE<sub>9.33</sub>(SiO<sub>4</sub>)<sub>6</sub>O<sub>2</sub> (RE = Pr, Nd and Sm) single crystals."
- [31] J. E. H. Sansom, E. Kendrick, J. R. Tolchard, M. S. Islam, and P. R. Slater, "A comparison of the effect of rare earth vs Si site doping on the conductivities of apatite-type rare earth silicates," *Journal of Solid State Electrochemistry*, vol. 10, no. 8, pp. 562–568, Aug. 2006, doi: 10.1007/s10008-006-0129-8.
- [32] X. G. Cao and S. P. Jiang, "Synthesis and characterization of lanthanum silicate oxyapatites co-doped with A (A = Ba, Sr, and Ca) and Fe for solid oxide fuel cells," *J. Mater. Chem. A*, vol. 2, no. 48, pp. 20739–20747, 2014, doi: 10.1039/C4TA04616A.

- [33] P. R. Slater, J. E. H. Sansom, and J. R. Tolchard, "Development of apatite-type oxide ion conductors," *The Chemical Record*, vol. 4, no. 6, pp. 373–384, 2004, doi: 10.1002/tcr.20028.
- [34] P. R. Slater, J. E. H. Sansom, and J. R. Tolchard, "Development of apatite-type oxide ion conductors," *The Chemical Record*, vol. 4, no. 6, pp. 373–384, 2004, doi: 10.1002/tcr.20028.
- [35] J. E. H. Sansom, E. Kendrick, J. R. Tolchard, M. S. Islam, and P. R. Slater, "A comparison of the effect of rare earth vs Si site doping on the conductivities of apatite-type rare earth silicates," *Journal of Solid State Electrochemistry*, vol. 10, no. 8, pp. 562–568, Aug. 2006, doi: 10.1007/s10008-006-0129-8.
- [36] A. Najib, J. E. H. Sansom, J. R. Tolchard, P. R. Slater, and M. S. Islam, "Doping strategies to optimise the oxide ion conductivity in apatite-type ionic conductors," *Dalton Transactions*, no. 19, p. 3106, 2004, doi: 10.1039/b401273a.
- [37] E. Kendrick, A. Orera, and P. R. Slater, "Neutron diffraction structural study of the apatite-type oxide ion conductor,  $\text{La}_8\text{Y}_2\text{Ge}_6\text{O}_{27}$ : location of the interstitial oxide ion site," *J Mater Chem*, vol. 19, no. 42, p. 7955, 2009, doi: 10.1039/b911404a.
- [38] A. Jones, P. R. Slater, and M. S. Islam, "Local Defect Structures and Ion Transport Mechanisms in the Oxygen-Excess Apatite  $\text{La}_{9.67}(\text{SiO}_4)_6\text{O}_{2.5}$ ," *Chemistry of Materials*, vol. 20, no. 15, pp. 5055–5060, Aug. 2008, doi: 10.1021/cm801101j.

- [39] E. Kendrick, A. Orera, and P. R. Slater, "Neutron diffraction structural study of the apatite-type oxide ion conductor, La<sub>8</sub>Y<sub>2</sub>Ge<sub>6</sub>O<sub>27</sub>: location of the interstitial oxide ion site," *J Mater Chem*, vol. 19, no. 42, p. 7955, 2009, doi: 10.1039/b911404a.
- [40] S. S. Pramana, W. T. Klooster, and T. J. White, "Framework 'interstitial' oxygen in La<sub>10</sub>(GeO<sub>4</sub>)<sub>5</sub>(GeO<sub>5</sub>)O<sub>2</sub> apatite electrolyte," *Acta Crystallogr B*, vol. 63, no. 4, pp. 597–602, Aug. 2007, doi: 10.1107/S0108768107024317.
- [41] E. Kendrick, A. Orera, and P. R. Slater, "Neutron diffraction structural study of the apatite-type oxide ion conductor, La<sub>8</sub>Y<sub>2</sub>Ge<sub>6</sub>O<sub>27</sub>: location of the interstitial oxide ion site," *J Mater Chem*, vol. 19, no. 42, p. 7955, 2009, doi: 10.1039/b911404a.
- [42] A. Jones, P. R. Slater, and M. S. Islam, "Local Defect Structures and Ion Transport Mechanisms in the Oxygen-Excess Apatite La<sub>9.67</sub>(SiO<sub>4</sub>)<sub>6</sub>O<sub>2.5</sub>," *Chemistry of Materials*, vol. 20, no. 15, pp. 5055–5060, Aug. 2008, doi: 10.1021/cm801101j.
- [43] E. Kendrick, M. S. Islam, and P. R. Slater, "Developing apatites for solid oxide fuel cells: insight into structural, transport and doping properties," *J Mater Chem*, vol. 17, no. 30, p. 3104, 2007, doi: 10.1039/b704426g.
- [44] Y. Masubuchi, M. Higuchi, T. Takeda, and S. Kikkawa, "Oxide ion conduction mechanism in RE<sub>9.33</sub>(SiO<sub>4</sub>)<sub>6</sub>O<sub>2</sub> and Sr<sub>2</sub>RE<sub>8</sub>(SiO<sub>4</sub>)<sub>6</sub>O<sub>2</sub> (RE=La, Nd) from neutron powder diffraction," *Solid State Ion*, vol. 177, no. 3–4, pp. 263–268, Jan. 2006, doi: 10.1016/j.ssi.2005.09.015.

- [45] E. Béchade *et al.*, “Diffusion Path and Conduction Mechanism of Oxide Ions in Apatite-Type Lanthanum Silicates,” *Chemistry of Materials*, vol. 21, no. 12, pp. 2508–2517, Jun. 2009, doi: 10.1021/cm900783j.
- [46] T. J. White and D. ZhiLi, “Structural derivation and crystal chemistry of apatites,” *Acta Crystallogr B*, vol. 59, no. 1, pp. 1–16, Feb. 2003, doi: 10.1107/S0108768102019894.
- [47] T. J. White and D. ZhiLi, “Structural derivation and crystal chemistry of apatites,” *Acta Crystallogr B*, vol. 59, no. 1, pp. 1–16, Feb. 2003, doi: 10.1107/S0108768102019894.
- [48] L. León-Reina, E. R. Losilla, M. Martínez-Lara, S. Bruque, and M. A. G. Aranda, “Interstitial oxygen conduction in lanthanum oxy-apatite electrolytes,” *J Mater Chem*, vol. 14, no. 7, pp. 1142–1149, 2004.
- [49] O. N. Verma, P. K. Jha, and P. Singh, “A structural–electrical property correlation in A-site double substituted lanthanum aluminate,” *J Appl Phys*, vol. 122, no. 22, p. 225106, Dec. 2017, doi: 10.1063/1.4999002.
- [50] O. N. Verma, P. A. Jha, P. Singh, P. K. Jha, and P. Singh, “Influence of iso-valent ‘Sm’ double substitution on the ionic conductivity of  $\text{La}_{0.9}\text{Sr}_{0.1}\text{Al}_{10.9}\text{Mg}_{0.1}\text{O}_{3-\delta}$  ceramic system,” *Mater Chem Phys*, vol. 241, p. 122345, Feb. 2020, doi: 10.1016/j.matchemphys.2019.122345.

- [51] P. Singh, P. K. Jha, A. S. K. Sinha, P. A. Jha, and P. Singh, "Ion dynamics of non-stoichiometric  $\text{Na}_{0.5+x}\text{Bi}_{0.5-x}\text{TiO}_{3-\delta}$ : A degradation study," *Solid State Ion*, vol. 345, p. 115158, Feb. 2020, doi: 10.1016/j.ssi.2019.115158.
- [52] H. Yoshioka, "Enhancement of Ionic Conductivity of Apatite-Type Lanthanum Silicates Doped With Cations," *Journal of the American Ceramic Society*, vol. 90, no. 10, pp. 3099–3105, Oct. 2007, doi: 10.1111/j.1551-2916.2007.01862.x.
- [53] E. Béchade *et al.*, "Synthesis of lanthanum silicate oxyapatite materials as a solid oxide fuel cell electrolyte," *J Eur Ceram Soc*, vol. 28, no. 14, pp. 2717–2724, Oct. 2008, doi: 10.1016/j.jeurceramsoc.2008.03.045.
- [54] H. Yoshioka, Y. Nojiri, and S. Tanase, "Ionic conductivity and fuel cell properties of apatite-type lanthanum silicates doped with Mg and containing excess oxide ions," *Solid State Ion*, vol. 179, no. 38, pp. 2165–2169, Nov. 2008, doi: 10.1016/j.ssi.2008.07.022.
- [55] Y. Nojiri, S. Tanase, M. Iwasa, H. Yoshioka, Y. Matsumura, and T. Sakai, "Ionic conductivity of apatite-type solid electrolyte material,  $\text{La}_{10-x}\text{Ba}_x\text{Si}_6\text{O}_{27-2x}$  ( $x=0-1$ ), and its fuel cell performance," *J Power Sources*, vol. 195, no. 13, pp. 4059–4064, Jul. 2010, doi: 10.1016/j.jpowsour.2010.01.050.
- [56] K. Kobayashi and Y. Sakka, "Research progress in nondoped lanthanoid silicate oxyapatites as new oxygen-ion conductors," *Journal of the Ceramic Society of Japan*, vol. 122, no. 1431, pp. 921–939, 2014, doi: 10.2109/jcersj2.122.921.

- [57] H. K. Cammenga and M. Epple, “Basic Principles of Thermoanalytical Techniques and Their Applications in Preparative Chemistry,” *Angewandte Chemie International Edition in English*, vol. 34, no. 11, pp. 1171–1187, Jun. 1995, doi: 10.1002/anie.199511711.
- [58] C. Huang *et al.*, “Preparation of BaSnO<sub>3</sub> and Ba<sub>0.96</sub>La<sub>0.04</sub>SnO<sub>3</sub> by reactive core–shell precursor: formation process, CO sensitivity, electronic and optical properties analysis,” *RSC Adv*, vol. 6, no. 30, pp. 25379–25387, 2016, doi: 10.1039/C6RA02207C.
- [59] J. Reid, D. Crane, J. Blanton, C. Crowder, S. Kabekkodu, and T. Fawcett, “Tools for Electron Diffraction Pattern Simulation for the Powder Diffraction File,” *Micros Today*, vol. 19, no. 1, pp. 32–37, Jan. 2011, doi: 10.1017/S1551929510001240.
- [60] A. Leineweber, “Understanding anisotropic microstrain broadening in Rietveld refinement,” *Zeitschrift für Kristallographie*, vol. 226, no. 12, pp. 905–923, Dec. 2011, doi: 10.1524/zkri.2011.1413.
- [61] I. A. Zaliznyak, “Spin Structures and Spin Wave Excitations,” in *Handbook of Magnetism and Advanced Magnetic Materials*, Chichester, UK: John Wiley & Sons, Ltd, 2007. doi: 10.1002/9780470022184.hmm301.
- [62] Gh. H. Khorrami, A. Khorsand Zak, A. Kompany, and R. yousefi, “Optical and structural properties of X-doped (X=Mn, Mg, and Zn) PZT nanoparticles by Kramers–

- Kronig and size strain plot methods,” *Ceram Int*, vol. 38, no. 7, pp. 5683–5690, Sep. 2012, doi: 10.1016/j.ceramint.2012.04.012.
- [63] “Permission Acknowledgments,” in *Encyclopedia of Spectroscopy and Spectrometry*, Elsevier, 2017, p. lix. doi: 10.1016/B978-0-12-803224-4.09962-3.
- [64] J. I. Goldstein, D. E. Newbury, J. R. Michael, N. W. M. Ritchie, J. H. J. Scott, and D. C. Joy, *Scanning Electron Microscopy and X-Ray Microanalysis*. New York, NY: Springer New York, 2018. doi: 10.1007/978-1-4939-6676-9.
- [65] M. von Ardenne, “Das Elektronen-Rastermikroskop,” *Zeitschrift für Physik*, vol. 109, no. 9–10, pp. 553–572, Sep. 1938, doi: 10.1007/BF01341584.
- [66] I. M. Hodge, M. D. Ingram, and A. R. West, “Impedance and modulus spectroscopy of polycrystalline solid electrolytes,” *J Electroanal Chem Interfacial Electrochem*, vol. 74, no. 2, pp. 125–143, Dec. 1976, doi: 10.1016/S0022-0728(76)80229-X.
- [67] O. N. Verma, P. A. Jha, P. Singh, P. K. Jha, and P. Singh, “Influence of iso-valent ‘Sm’ double substitution on the ionic conductivity of  $\text{La}_{0.9}\text{Sr}_{0.1}\text{Al}_{10.9}\text{Mg}_{0.1}\text{O}_{3-\delta}$  ceramic system,” *Mater Chem Phys*, vol. 241, p. 122345, Feb. 2020, doi: 10.1016/j.matchemphys.2019.122345.
- [68] F. Krok, I. Abrahams, W. Wrobel, A. Kozanecka-Szmigiel, and J. R. Dygas, “Oxide-ion conductors for fuel cells,” *MATERIALS SCIENCE-WROCLAW-*, vol. 24, no. 1, p. 13, 2006.

- [69] G. Cacciola, V. Antonucci, and S. Freni, "Technology up date and new strategies on fuel cells," *J Power Sources*, vol. 100, no. 1–2, pp. 67–79, 2001.
- [70] L. Malavasi, C. A. J. Fisher, and M. S. Islam, "Oxide-ion and proton conducting electrolyte materials for clean energy applications: structural and mechanistic features," *Chem Soc Rev*, vol. 39, no. 11, pp. 4370–4387, 2010.
- [71] W. Zhao, S. An, and L. Ma, "Processing and characterization of Bi<sub>2</sub>O<sub>3</sub> and Sm<sub>2</sub>O<sub>3</sub> codoped CeO<sub>2</sub> electrolyte for intermediate-temperature solid oxide fuel cell," *Journal of the American Ceramic Society*, vol. 94, no. 5, pp. 1496–1502, 2011.
- [72] F. Krok, I. Abrahams, W. Wrobel, A. Kozanecka-Szmigiel, and J. R. Dygas, "Oxide-ion conductors for fuel cells," *MATERIALS SCIENCE-WROCLAW-*, vol. 24, no. 1, p. 13, 2006.
- [73] A. M. Azad, S. Larose, and S. A. Akbar, "Bismuth oxide-based solid electrolytes for fuel cells," *J Mater Sci*, vol. 29, no. 16, pp. 4135–4151, 1994.
- [74] T. Yang *et al.*, "Synthesis and densification of lanthanum silicate apatite electrolyte for intermediate temperature solid oxide fuel cell via co-precipitation method," *J Eur Ceram Soc*, vol. 34, no. 6, pp. 1563–1569, 2014.
- [75] G. L. Macedo *et al.*, "Electrical properties of lanthanum silicate apatite electrolytes prepared by an innovative chemical route," *ECS Trans*, vol. 61, no. 36, p. 23, 2014.

- [76] A. Behnam *et al.*, *Highlights in Applied Mineralogy*. Walter de Gruyter GmbH & Co KG, 2017.
- [77] X. G. Cao, “Identification of oxygen reduction processes at (La, Sr) MnO<sub>3</sub> electrode/La<sub>9</sub>. 5Si<sub>6</sub>O<sub>26</sub>. 25 apatite electrolyte interface of solid oxide fuel cells,” *Int J Hydrogen Energy*, vol. 38, no. 5, pp. 2421–2431, 2013.
- [78] E. Jothinathan, K. Vanmeensel, J. Vleugels, and O. van der Biest, “Synthesis of nano-crystalline apatite type electrolyte powders for solid oxide fuel cells,” *J Eur Ceram Soc*, vol. 30, no. 7, pp. 1699–1706, 2010.
- [79] M. R. Cesário and D. A. de Macedo, *Functional Materials for Solid Oxide Fuel Cells: Processing, Microstructure and Performance*, vol. 1. Bentham Science Publishers, 2017.
- [80] Y. Ma, M. Moliere, Z. Yu, N. Fenineche, and O. Elkedim, “Novel chemical reaction co-precipitation method for the synthesis of apatite-type lanthanum silicate as an electrolyte in SOFC,” *J Alloys Compd*, vol. 723, pp. 418–424, 2017.
- [81] A. Destainville, E. Champion, D. Bernache-Assollant, and E. Laborde, “Synthesis, characterization and thermal behavior of apatitic tricalcium phosphate,” *Mater Chem Phys*, vol. 80, no. 1, pp. 269–277, 2003.
- [82] M. S. Chambers, P. A. Chater, I. R. Evans, and J. S. O. Evans, “Average and local structure of apatite-type germanates and implications for oxide ion conductivity,” *Inorg Chem*, vol. 58, no. 21, pp. 14853–14862, 2019.

- [83] A. Mineshige *et al.*, “Preparation of lanthanum silicate electrolyte with high conductivity and high chemical stability,” *Solid State Ion*, vol. 319, pp. 223–227, 2018.
- [84] R. Murugaraj, “Ac conductivity and its scaling behavior in borate and bismuthate glasses,” *J Mater Sci*, vol. 42, no. 24, pp. 10065–10073, 2007.
- [85] D. P. Singh, K. Shahi, and K. K. Kar, “Superlinear frequency dependence of AC conductivity and its scaling behavior in  $x\text{AgI}-(1-x)\text{AgPO}_3$  glass superionic conductors,” *Solid State Ion*, vol. 287, pp. 89–96, 2016.
- [86] P. Singh, D. C. Bharati, H. Kumar, and A. L. Saroj, “Ion transport mechanism and dielectric relaxation behavior of PVA-imidazolium ionic liquid-based polymer electrolytes,” *Phys Scr*, vol. 94, no. 10, p. 105801, 2019.
- [87] D. P. Almond and A. R. West, “The activation entropy for transport in ionic conductors,” *Solid State Ion*, vol. 23, no. 1–2, pp. 27–35, 1987.
- [88] S. R. Elliott, “Frequency-dependent conductivity in ionic glasses: A possible model,” *Solid State Ion*, vol. 27, no. 3, pp. 131–149, 1988.
- [89] D. P. Almond and A. R. West, “Impedance and modulus spectroscopy of ‘real’ dispersive conductors,” *Solid State Ion*, vol. 11, no. 1, pp. 57–64, 1983.
- [90] W. G. Glöckle and T. F. Nonnenmacher, “Fractional relaxation and the time-temperature superposition principle,” *Rheol Acta*, vol. 33, no. 4, pp. 337–343, 1994.

- [91] K. Momma and F. Izumi, “An integrated three-dimensional visualization system VESTA using wxWidgets,” in *atelier de diffraction sur poudre Seventh Canadian Powder Diffraction Workshop*, 2006, p. 106.
- [92] A. Prasad and A. Basu, “Dielectric and impedance properties of sintered magnesium aluminum silicate glass-ceramic,” *Journal of Advanced Ceramics*, vol. 2, no. 1, pp. 71–78, 2013.
- [93] S. P. S. Badwal, “Electrical conductivity of single crystal and polycrystalline yttria-stabilized zirconia,” *J Mater Sci*, vol. 19, no. 6, pp. 1767–1776, 1984.
- [94] N. Nallamuthu, I. Prakash, N. Satyanarayana, and M. Venkateswarlu, “Electrical conductivity studies of nanocrystalline lanthanum silicate synthesized by sol–gel route,” *J Alloys Compd*, vol. 509, no. 4, pp. 1138–1145, 2011.
- [95] Y. Akgöl, C. Hofmann, Y. Karatas, C. Cramer, H.-D. Wiemhöfer, and M. Schönhoff, “Conductivity spectra of polyphosphazene-based polyelectrolyte multilayers,” *J Phys Chem B*, vol. 111, no. 29, pp. 8532–8539, 2007.
- [96] J. Habasaki, C. Leon, and K. L. Ngai, “Dynamics of glassy, crystalline and liquid ionic conductors,” *Top Appl Phys*, vol. 132, pp. 355–410, 2017.
- [97] O. N. Verma, N. K. Singh, and P. Singh, “Study of ion dynamics in lanthanum aluminate probed by conductivity spectroscopy,” *RSC Adv*, vol. 5, no. 28, pp. 21614–21619, 2015.

- [98] P. Heitjans, E. Tobschall, and M. Wilkening, "Ion transport and diffusion in nanocrystalline and glassy ceramics," *Eur Phys J Spec Top*, vol. 161, no. 1, pp. 97–108, 2008.
- [99] Y. Nojiri, S. Tanase, M. Iwasa, H. Yoshioka, Y. Matsumura, and T. Sakai, "Ionic conductivity of apatite-type solid electrolyte material,  $\text{La}_{10-x}\text{Ba}_x\text{Si}_6\text{O}_{27-x/2}$  ( $x=0-1$ ), and its fuel cell performance," *J Power Sources*, vol. 195, no. 13, pp. 4059–4064, 2010.
- [100] O. N. Verma, P. A. Jha, A. Melkeri, and P. Singh, "A comparative study of aqueous tape and pellet of  $(\text{La}_{0.89}\text{Ba}_{0.01})\text{Sr}_{0.1}\text{Al}_{10.9}\text{Mg}_{0.1}\text{O}_{3-\delta}$  electrolyte material," *Physica B Condens Matter*, vol. 521, pp. 230–238, 2017.
- [101] K. Hoang and M. D. Johannes, "Defect physics in complex energy materials," *Journal of Physics: Condensed Matter*, vol. 30, no. 29, p. 293001, 2018.
- [102] O. N. Verma, S. Singh, V. K. Singh, M. Najim, R. Pandey, and P. Singh, "Influence of Ba doping on the electrical behaviour of  $\text{La}_{0.9}\text{Sr}_{0.1}\text{Al}_{10.9}\text{Mg}_{0.1}\text{O}_{3-\delta}$  system for a solid electrolyte," *J Electron Mater*, vol. 50, no. 3, pp. 1010–1021, 2021.
- [103] K. Imaizumi, K. Toyoura, A. Nakamura, and K. Matsunaga, "Strong correlation in 1D oxygen-ion conduction of apatite-type lanthanum silicate," *Journal of Physics: Condensed Matter*, vol. 27, no. 36, p. 365601, 2015.
- [104] O. Masson *et al.*, "Local structure and oxide-ion conduction mechanism in apatite-type lanthanum silicates," *Sci Technol Adv Mater*, vol. 18, no. 1, pp. 644–653, 2017.

- [105] M. Novy, H. Avila-Paredes, S. Kim, and S. Sen, “Communication: Dimensionality of the ionic conduction pathways in glass and the mixed-alkali effect,” *J Chem Phys*, vol. 143, no. 24, p. 241104, 2015.
- [106] J. Swenson and S. Adams, “Mixed alkali effect in glasses,” *Phys Rev Lett*, vol. 90, no. 15, p. 155507, 2003.
- [107] L. L. Wong, K. C. Phuah, R. Dai, H. Chen, W. S. Chew, and S. Adams, “Bond Valence Pathway Analyzer—An Automatic Rapid Screening Tool for Fast Ion Conductors within softBV,” *Chemistry of Materials*, vol. 33, no. 2, pp. 625–641, 2021.
- [108] H. Salimkhani, E. Erdem, S. Alkan Gursel, and A. Yurum, “Unveiling the presence of mixed oxidation states of Europium in  $\text{Li}_{7+\delta}\text{Eu}_x\text{La}_{3-\delta}\text{Zr}_{2-\delta}\text{O}_{12-\delta}$  garnet and its impact on the Li-ion conductivity,” *Journal of the American Ceramic Society*, vol. 104, no. 8, pp. 4257–4271, Aug. 2021, doi: 10.1111/jace.17846.
- [109] E. Erdem, H. Kungl, M. J. Hoffmann, A. Ozarowski, J. van Tol, and L. C. Brunel, “Characterization of (Fe Zr, Ti-V o ldrldr) ldr defect dipoles in (La, Fe)-codoped PZT 52.5/47.5 piezoelectric ceramics by multifrequency electron paramagnetic resonance spectroscopy,” *IEEE Trans Ultrason Ferroelectr Freq Control*, vol. 55, no. 5, pp. 1061–1068, 2008.
- [110] K. Kendall and M. Kendall, *High-temperature solid oxide fuel cells for the 21st century : fundamentals, design and applications*.

- [111] A. B. Stambouli, E. Traversa, and A. Stambouli, "Solid oxide fuel cells (SOFCs): a review of an environmentally clean and efficient source of energy," 2002. [Online]. Available: [www.elsevier.com/locate/rser](http://www.elsevier.com/locate/rser)
- [112] Z. Sun, E. Fabbri, L. Bi, and E. Traversa, "Electrochemical properties and intermediate-temperature fuel cell performance of dense yttrium-doped barium zirconate with calcium addition," *Journal of the American Ceramic Society*, vol. 95, no. 2, pp. 627–635, Feb. 2012, doi: 10.1111/j.1551-2916.2011.04795.x.
- [113] H. Shi, C. Su, R. Ran, J. Cao, and Z. Shao, "Electrolyte materials for intermediate-temperature solid oxide fuel cells," *Progress in Natural Science: Materials International*, vol. 30, no. 6. Elsevier B.V., pp. 764–774, Dec. 01, 2020. doi: 10.1016/j.pnsc.2020.09.003.
- [114] Y. Susumu Nakayama, T. Kageyama, H. Aonob, and Y. Sadaokac, "Ionic Conductivity of Lanthanoid Silicates, Ln<sub>2</sub>(SiO<sub>4</sub>)GO, (Ln," 1995.
- [115] H. Okudera, Y. Masubuchi, S. Kikkawa, and A. Yoshiasa, "Structure of oxide ion-conducting lanthanum oxyapatite, La<sub>9.33</sub>(SiO<sub>4</sub>)<sub>6</sub>O<sub>2</sub>," *Solid State Ion*, vol. 176, no. 15–16, pp. 1473–1478, May 2005, doi: 10.1016/j.ssi.2005.02.014.
- [116] B. Ballinger, J. Motuzas, C. R. Miller, S. Smart, and J. C. Diniz da Costa, "Nanoscale assembly of lanthanum silica with dense and porous interfacial structures," *Sci Rep*, vol. 5, no. 1, p. 8210, Feb. 2015, doi: 10.1038/srep08210.

- [117] C. Yamagata, D. R. Elias, M. R. S. Paiva, A. M. Misso, and S. R. H. M. Castanho, “Facile preparation of apatite-type lanthanum silicate by a new water-based sol–gel process,” *Mater Res Bull*, vol. 48, no. 6, pp. 2227–2231, Jun. 2013, doi: 10.1016/j.materresbull.2013.02.041.
- [118] S. Tao and J. T. S. Irvine, “Preparation and characterisation of apatite-type lanthanum silicates by a sol-gel process,” 2001.
- [119] L. León-Reina, E. R. Losilla, M. Martínez-Lara, S. Bruque, and M. A. G. Aranda, “Interstitial oxygen conduction in lanthanum oxy-apatite electrolytes,” *J Mater Chem*, vol. 14, no. 7, pp. 1142–1149, Apr. 2004, doi: 10.1039/b315257j.
- [120] S. S. Pramana, W. T. Klooster, and T. J. White, “Framework interstitial oxygen in  $\text{La}_{10}(\text{GeO}_4)_5(\text{GeO}_5)_2\text{O}_2$  apatite electrolyte,” *Acta Crystallogr B*, vol. 63, no. 4, pp. 597–602, Jul. 2007, doi: 10.1107/S0108768107024317.
- [121] K. Fukuda *et al.*, “Anisotropy of oxide-ion conduction in apatite-type lanthanum silicate,” *Solid State Ion*, vol. 217, pp. 40–45, Jun. 2012, doi: 10.1016/j.ssi.2012.04.018.
- [122] K. Fukuda, R. Watanabe, M. Oyabu, R. Hasegawa, T. Asaka, and H. Yoshida, “Oxide-Ion Conductivity Enhancement of Polycrystalline Lanthanum Silicate Oxyapatite Induced by BaO Doping and Grain Alignment,” *Cryst Growth Des*, vol. 16, no. 8, pp. 4519–4525, Aug. 2016, doi: 10.1021/acs.cgd.6b00638.

- [123] S. Guillot, S. Beaudet-Savignat, S. Lambert, R. N. Vannier, P. Roussel, and F. Porcher, "Evidence of local defects in the oxygen excess apatite  $\text{La}_{9.67}(\text{SiO}_4)_6\text{O}_{2.5}$  from high resolution neutron powder diffraction," *J Solid State Chem*, vol. 182, no. 12, pp. 3358–3364, Dec. 2009, doi: 10.1016/j.jssc.2009.09.031.
- [124] K. Kobayashi, Y. Matsushita, M. Tanaka, Y. Katsuya, C. Nishimura, and Y. Sakka, "Electrical conductivity and X-ray diffraction analysis of oxyapatite-type lanthanum silicate and neodymium silicate solid solution," in *Solid State Ionics*, Oct. 2012, vol. 225, pp. 443–447. doi: 10.1016/j.ssi.2012.02.008.
- [125] S. Lambert *et al.*, "Structural investigation of  $\text{La}_{9.33}\text{Si}_6\text{O}_{26}$ - and  $\text{La}_9\text{AESi}_6\text{O}_{26+\delta}$ -doped apatites-type lanthanum silicate (AE=Ba, Sr and Ca) by neutron powder diffraction," *J Solid State Chem*, vol. 179, no. 8, pp. 2602–2608, Aug. 2006, doi: 10.1016/j.jssc.2006.04.056.
- [126] J. Felsche, "Rare Earth Silicates with the Apatite Structure," 1972.
- [127] S. Nakayama *et al.*, "Oxide Ionic Conductivity of Apatite Type  $\text{Nd}_{9.33}(\text{SiO}_4)_6\text{O}_2$  Single Crystal."
- [128] L. O. Si, L. O. Sr Si, J. Sansom, D. Richings, and P. Slater, "A powder neutron diffraction study of the oxide-ion-conducting apatite-type phases," 2001. [Online]. Available: [www.elsevier.com/locate/ssi](http://www.elsevier.com/locate/ssi)
- [129] S. Ide, H. Takahashi, I. Yashima, K. Suematsu, K. Watanabe, and K. Shimanoe, "Effect of Boron Substitution on Oxide-Ion Conduction in c-Axis-Oriented Apatite-

- Type Lanthanum Silicate,” *Journal of Physical Chemistry C*, vol. 124, no. 5, pp. 2879–2885, Feb. 2020, doi: 10.1021/acs.jpcc.9b11454.
- [130] C. Y. Ma, P. Briois, J. Böhlmark, F. Lapostolle, and A. Billard, “La<sub>9.33</sub>Si<sub>6</sub>O<sub>26</sub> electrolyte thin films for IT-SOFC application deposited by a HIPIMS/DC hybrid magnetron sputtering process,” *Ionics (Kiel)*, vol. 14, no. 6, pp. 471–476, Nov. 2008, doi: 10.1007/s11581-008-0239-7.
- [131] J. E. H. Sansom, A. Najib, and P. R. Slater, “Oxide ion conductivity in mixed Si/Ge-based apatite-type systems,” in *Solid State Ionics*, Nov. 2004, vol. 175, no. 1–4, pp. 353–355. doi: 10.1016/j.ssi.2003.12.030.
- [132] C. Bonhomme, S. Beaudet-Savignat, T. Chartier, A. Maître, A. L. Sauvet, and B. Soulestin, “Sintering kinetics and oxide ion conduction in Sr-doped apatite-type lanthanum silicates, La<sub>9</sub>Sr<sub>1</sub>Si<sub>6</sub>O<sub>26.5</sub>,” *Solid State Ion*, vol. 180, no. 36–39, pp. 1593–1598, Dec. 2009, doi: 10.1016/j.ssi.2009.10.009.
- [133] active 2nd century. Ptolemy, Anne. Tihon, Raymond. Mercier, Union académique internationale., and Institut orientaliste de Louvain., *Ptolemaiou procheiroi kanones*. Université catholique de Louvain, Institut orientaliste, 2011.
- [134] O. N. Verma, P. K. Jha, and P. Singh, “A structural-electrical property correlation in A-site double substituted lanthanum aluminate,” *J Appl Phys*, vol. 122, no. 22, Dec. 2017, doi: 10.1063/1.4999002.

- [135] O. N. Verma, P. A. Jha, P. Singh, P. K. Jha, and P. Singh, "Influence of iso-valent 'Sm' double substitution on the ionic conductivity of  $\text{La}_{0.9}\text{Sr}_{0.1}\text{Al}_{0.9}\text{Mg}_{0.1}\text{O}_{3-\delta}$  ceramic system," *Mater Chem Phys*, vol. 241, Feb. 2020, doi: 10.1016/j.matchemphys.2019.122345.
- [136] S. Ide, H. Takahashi, I. Yashima, K. Suematsu, K. Watanabe, and K. Shimanoe, "Effect of Boron Substitution on Oxide-Ion Conduction in c-Axis-Oriented Apatite-Type Lanthanum Silicate," *Journal of Physical Chemistry C*, vol. 124, no. 5, pp. 2879–2885, Feb. 2020, doi: 10.1021/acs.jpcc.9b11454.
- [137] H. Yoshioka, "Enhancement of ionic conductivity of apatite-type lanthanum silicates doped with cations," *Journal of the American Ceramic Society*, vol. 90, no. 10, pp. 3099–3105, Oct. 2007, doi: 10.1111/j.1551-2916.2007.01862.x.
- [138] S. Lambert *et al.*, "Structural investigation of  $\text{La}_{9.33}\text{Si}_6\text{O}_{26}$ - and  $\text{La}_9\text{AESi}_6\text{O}_{26+\delta}$ -doped apatites-type lanthanum silicate (AE=Ba, Sr and Ca) by neutron powder diffraction," *J Solid State Chem*, vol. 179, no. 8, pp. 2602–2608, Aug. 2006, doi: 10.1016/j.jssc.2006.04.056.
- [139] Y. Nojiri, S. Tanase, M. Iwasa, H. Yoshioka, Y. Matsumura, and T. Sakai, "Ionic conductivity of apatite-type solid electrolyte material,  $\text{La}_{10-X}\text{Ba}_X\text{Si}_6\text{O}_{27-X/2}$  ( $X = 0-1$ ), and its fuel cell performance," *J Power Sources*, vol. 195, no. 13, pp. 4059–4064, Jul. 2010, doi: 10.1016/j.jpowsour.2010.01.050.

- [140] S. Beaudet-Savignat, A. Vincent, S. Lambert, and F. Gervais, "Oxide ion conduction in Ba, Ca and Sr doped apatite-type lanthanum silicates," *J Mater Chem*, vol. 17, no. 20, pp. 2078–2087, 2007, doi: 10.1039/b615104c.
- [141] H. Yoshioka, Y. Nojiri, and S. Tanase, "Ionic conductivity and fuel cell properties of apatite-type lanthanum silicates doped with Mg and containing excess oxide ions," *Solid State Ion*, vol. 179, no. 38, pp. 2165–2169, Nov. 2008, doi: 10.1016/j.ssi.2008.07.022.
- [142] E. Béchade *et al.*, "Synthesis of lanthanum silicate oxyapatite materials as a solid oxide fuel cell electrolyte," *J Eur Ceram Soc*, vol. 28, no. 14, pp. 2717–2724, Oct. 2008, doi: 10.1016/j.jeurceramsoc.2008.03.045.
- [143] Y. Ogura, T. Yokoi, K. Fujii, M. Yashima, and K. Matsunaga, "First-Principles Analysis of the Oxide-Ion Conduction Mechanism in Si-Deficient Lanthanum Silicate Apatite," *The Journal of Physical Chemistry C*, vol. 126, no. 13, pp. 5805–5812, 2022.
- [144] T. Liao, T. Sasaki, and Z. Sun, "The oxygen migration in the apatite-type lanthanum silicate with the cation substitution," *Physical Chemistry Chemical Physics*, vol. 15, no. 40, pp. 17553–17559, Oct. 2013, doi: 10.1039/c3cp52245h.
- [145] S. Abboudy, "A quasi-universal percolation approach of hopping activation energy and metal-nonmetal transition in semiconductors," *Physica B Condens Matter*, vol. 212, no. 2, pp. 175–180, Jul. 1995, doi: 10.1016/0921-4526(95)00012-X.

- [146] A. Yadav, P. A. Jha, P. K. Jha, N. Jha, and P. Singh, "Overlapping large polaron tunnelling in lanthanum silicate oxyapatite," *Journal of Physics: Condensed Matter*, vol. 35, no. 9, p. 095702, Mar. 2023, doi: 10.1088/1361-648X/acad53.
- [147] H. Shi, C. Su, R. Ran, J. Cao, and Z. Shao, "Electrolyte materials for intermediate-temperature solid oxide fuel cells," *Progress in Natural Science: Materials International*, vol. 30, no. 6. Elsevier B.V., pp. 764–774, Dec. 01, 2020. doi: 10.1016/j.pnsc.2020.09.003.
- [148] Y. Susumu Nakayama, T. Kageyama, H. Aonob, and Y. Sadaokac, "Ionic Conductivity of Lanthanoid Silicates, Ln,(SiO<sub>2</sub>)GO, (Ln," 1995.
- [149] O. N. Verma, P. K. Jha, and P. Singh, "A structural-electrical property correlation in A-site double substituted lanthanum aluminate," *J Appl Phys*, vol. 122, no. 22, Dec. 2017, doi: 10.1063/1.4999002.
- [150] O. N. Verma, P. A. Jha, P. Singh, P. K. Jha, and P. Singh, "Influence of iso-valent 'Sm' double substitution on the ionic conductivity of La<sub>0.9</sub>Sr<sub>0.1</sub>Al<sub>10.9</sub>Mg<sub>0.1</sub>O<sub>3-δ</sub> ceramic system," *Mater Chem Phys*, vol. 241, Feb. 2020, doi: 10.1016/j.matchemphys.2019.122345.
- [151] P. Singh, P. K. Jha, A. S. K. Sinha, P. A. Jha, and P. Singh, "Ion dynamics of non-stoichiometric Na<sub>0.5+x</sub>Bi<sub>0.5-x</sub>TiO<sub>3-δ</sub>: A degradation study," *Solid State Ion*, vol. 345, Feb. 2020, doi: 10.1016/j.ssi.2019.115158.

- [152] active 2nd century. Ptolemy, Anne. Tihon, Raymond. Mercier, Union académique internationale., and Institut orientaliste de Louvain., *Ptolemaiou procheiroi kanones*. Université catholique de Louvain, Institut orientaliste, 2011.
- [153] H. Yoshioka, “Enhancement of ionic conductivity of apatite-type lanthanum silicates doped with cations,” *Journal of the American Ceramic Society*, vol. 90, no. 10, pp. 3099–3105, Oct. 2007, doi: 10.1111/j.1551-2916.2007.01862.x.
- [154] S. Lambert *et al.*, “Structural investigation of La<sub>9.33</sub>Si<sub>6</sub>O<sub>26</sub>- and La<sub>9</sub>AE<sub>Si</sub><sub>6</sub>O<sub>26</sub>+ $\delta$ -doped apatites-type lanthanum silicate (AE=Ba, Sr and Ca) by neutron powder diffraction,” *J Solid State Chem*, vol. 179, no. 8, pp. 2602–2608, Aug. 2006, doi: 10.1016/j.jssc.2006.04.056.
- [155] Y. Nojiri, S. Tanase, M. Iwasa, H. Yoshioka, Y. Matsumura, and T. Sakai, “Ionic conductivity of apatite-type solid electrolyte material, La<sub>10-X</sub>Ba<sub>X</sub>Si<sub>6</sub>O<sub>27-X/2</sub> (X = 0-1), and its fuel cell performance,” *J Power Sources*, vol. 195, no. 13, pp. 4059–4064, Jul. 2010, doi: 10.1016/j.jpowsour.2010.01.050.
- [156] H. Yoshioka, Y. Nojiri, and S. Tanase, “Ionic conductivity and fuel cell properties of apatite-type lanthanum silicates doped with Mg and containing excess oxide ions,” *Solid State Ion*, vol. 179, no. 38, pp. 2165–2169, Nov. 2008, doi: 10.1016/j.ssi.2008.07.022.

- [157] L. León-Reina, E. R. Losilla, M. Martínez-Lara, S. Bruque, and M. A. G. Aranda, “Interstitial oxygen conduction in lanthanum oxy-apatite electrolytes,” *J Mater Chem*, vol. 14, no. 7, pp. 1142–1149, Apr. 2004, doi: 10.1039/b315257j.
- [158] E. Béchade *et al.*, “Synthesis of lanthanum silicate oxyapatite materials as a solid oxide fuel cell electrolyte,” *J Eur Ceram Soc*, vol. 28, no. 14, pp. 2717–2724, Oct. 2008, doi: 10.1016/j.jeurceramsoc.2008.03.045.
- [159] S. Beaudet-Savignat, A. Vincent, S. Lambert, and F. Gervais, “Oxide ion conduction in Ba, Ca and Sr doped apatite-type lanthanum silicates,” *J Mater Chem*, vol. 17, no. 20, pp. 2078–2087, 2007, doi: 10.1039/b615104c.
- [160] K. Fukuda *et al.*, “Anisotropy of oxide-ion conduction in apatite-type lanthanum silicate,” *Solid State Ion*, vol. 217, pp. 40–45, Jun. 2012, doi: 10.1016/j.ssi.2012.04.018.
- [161] K. Fukuda, R. Watanabe, M. Oyabu, R. Hasegawa, T. Asaka, and H. Yoshida, “Oxide-Ion Conductivity Enhancement of Polycrystalline Lanthanum Silicate Oxyapatite Induced by BaO Doping and Grain Alignment,” *Cryst Growth Des*, vol. 16, no. 8, pp. 4519–4525, Aug. 2016, doi: 10.1021/acs.cgd.6b00638.
- [162] K. Matsunaga and K. Toyoura, “First-principles analysis of oxide-ion conduction mechanism in lanthanum silicate,” *J Mater Chem*, vol. 22, no. 15, pp. 7265–7273, Apr. 2012, doi: 10.1039/c2jm16283k.

- [163] X. G. Cao and S. P. Jiang, “Synthesis and characterization of lanthanum silicate oxyapatites co-doped with A (A = Ba, Sr, and Ca) and Fe for solid oxide fuel cells,” *J Mater Chem A Mater*, vol. 2, no. 48, pp. 20739–20747, Dec. 2014, doi: 10.1039/c4ta04616a.
- [164] K. Kobayashi, K. Hirai, T. Uchikoshi, Y. Sakka, T. Akashi, and T. S. Suzuki, “Production of crystal-oriented lanthanum silicate oxyapatite ceramics with anisotropic electrical conductivity and thermal expansion,” *Open Ceramics*, vol. 6, Jun. 2021, doi: 10.1016/j.oceram.2021.100100.
- [165] Y. Zhao, L. Dai, Z. He, L. Wang, and J. Cao, “Synthesis and characterization of Ba<sup>2+</sup> and W<sup>6+</sup> co-doped apatite-type lanthanum silicate electrolytes,” *Ceram Int*, vol. 46, no. 4, pp. 5420–5429, Mar. 2020, doi: 10.1016/j.ceramint.2019.10.299.
- [166] K. Matsunaga and K. Toyoura, “First-principles analysis of oxide-ion conduction mechanism in lanthanum silicate,” *J Mater Chem*, vol. 22, no. 15, pp. 7265–7273, 2012.
- [167] K. Imaizumi, K. Toyoura, A. Nakamura, and K. Matsunaga, “Strong correlation in 1D oxygen-ion conduction of apatite-type lanthanum silicate,” *Journal of Physics Condensed Matter*, vol. 27, no. 36, Sep. 2015, doi: 10.1088/0953-8984/27/36/365601.
- [168] S. Nakayama, A. Ikesue, Y. Higuchi, M. Sugawara, and M. Sakamoto, “Growth of single-crystals of apatite-type oxide ionic conductor from sintered ceramics by a

- seeding method,” *J Eur Ceram Soc*, vol. 33, no. 2, pp. 207–210, Feb. 2013, doi: 10.1016/j.jeurceramsoc.2012.09.013.
- [169] H. J. Kulik, “Perspective: Treating electron over-delocalization with the DFT+U method,” *Journal of Chemical Physics*, vol. 142, no. 24, Jun. 2015, doi: 10.1063/1.4922693.
- [170] J. Emery, O. Bohnke, J. L. Fourquet, J. Y. Buzaré, P. Florian, and D. Massiot, “Polaronic effects on lithium motion in intercalated perovskite lithium lanthanum titanate observed by  $^7\text{Li}$  NMR and impedance spectroscopy,” 1999. [Online]. Available: <http://iopscience.iop.org/0953-8984/11/50/330>
- [171] M. Kick, C. Scheurer, and H. Oberhofer, “Polaron-Assisted Charge Transport in Li-Ion Battery Anode Materials,” *ACS Appl Energy Mater*, vol. 4, no. 8, pp. 8583–8591, 2021.
- [172] K. Wakamura, “Roles of phonon amplitude and low-energy optical phonons on superionic conduction,” 1997.
- [173] L. Bindi, M. Evain, A. Pradel, S. Albert, M. Ribes, and S. Menchetti, “Fast ion conduction character and ionic phase-transitions in disordered crystals: The complex case of the minerals of the pearceite-polybasite group,” *Phys Chem Miner*, vol. 33, no. 10, pp. 677–690, Dec. 2006, doi: 10.1007/s00269-006-0117-7.
- [174] A. K. Jonscher, “Dielectric Relaxation in Solids Chelsea Dielectric Press, London,” *Jonscher AK*, 1983.

- [175] O. Bidault, M. Maglione, M. Actis, and M. Kchikech, “Polaronic relaxation in perovskites,” 1995.
- [176] P. K. Jha, P. A. Jha, V. Singh, P. Kumar, K. Asokan, and R. K. Dwivedi, “Diffuse phase ferroelectric vs. Polomska transition in  $(1-x)\text{BiFeO}_3-(x)\text{BaZr}_{0.025}\text{Ti}_{0.975}\text{O}_3$  ( $0.1 \leq x \leq 0.3$ ) solid solutions,” *J Appl Phys*, vol. 117, no. 2, Jan. 2015, doi: 10.1063/1.4905715.
- [177] R. J. Moreira Toja, N. M. Rendtorff, E. F. Aglietti, T. Uchikoshi, Y. Sakka, and G. Suárez, “Influence of the porosity caused by incomplete sintering on the mechanical behaviour of lanthanum silicate oxyapatite,” *Ceram Int*, vol. 44, no. 12, pp. 14348–14354, Aug. 2018, doi: 10.1016/j.ceramint.2018.05.043.
- [178] A. S. Bangwal *et al.*, “Compositional effect on oxygen reduction reaction in Pr excess double perovskite  $\text{Pr}_{1+x}\text{Ba}_{1-x}\text{Co}_2\text{O}_{6-\delta}$  cathode materials,” *Int J Hydrogen Energy*, vol. 45, no. 43, pp. 23378–23390, Sep. 2020, doi: 10.1016/j.ijhydene.2020.06.087.
- [179] S. R. Elliott, “A.c. conduction in amorphous chalcogenide and pnictide semiconductors,” *Adv Phys*, vol. 36, no. 2, pp. 135–217, Jan. 1987, doi: 10.1080/00018738700101971.
- [180] A. R. Long, “Frequency-dependent loss in amorphous semiconductors,” *Adv Phys*, vol. 31, no. 5, pp. 553–637, Jan. 1982, doi: 10.1080/00018738200101418.
- [181] A. R. Long, N. Balkan, W. R. Hogg, and R. P. Ferrier, “A.C. loss in sputtered hydrogenated amorphous germanium measurements at around liquid-nitrogen

- temperatures,” *Philosophical Magazine B: Physics of Condensed Matter; Statistical Mechanics, Electronic, Optical and Magnetic Properties*, vol. 45, no. 5, pp. 497–518, 1982, doi: 10.1080/13642818208246415.
- [182] D. Emin and T. Holstein, “UME 36, NUMBER 6 PHYSICAL REVIEW LETTERS,” 1976.
- [183] D. Emin, “Optical properties of large and small polarons and bipolarons,” 1993.
- [184] M. Imada, A. Fujimori, and Y. Tokura, “Metal-insulator transitions,” 1998.
- [185] Y. K. Saurabh, P. A. Jha, P. K. Dubey, P. K. Jha, and P. Singh, “Bandgap engineering in TiO<sub>2</sub>/rGO 1D photonic metasurfaces as broadband solar absorber,” *J Appl Phys*, vol. 131, no. 2, p. 023106, 2022.
- [186] P. C. Bharti, P. K. Jha, P. A. Jha, and P. Singh, “Hysteresis in centrosymmetric CuPbI<sub>3</sub> perovskite halide: apolar dielectric or orientable dielectric?,” *Journal of Physics: Condensed Matter*, vol. 33, no. 15, p. 155703, 2021.

## Publications

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1. A. Yadav, O. N. Verma, R. Pandey, N. Jha, and P. Singh, "Ion dynamics and electrical transport in lanthanum silicate apatite ( $\text{La}_{9.67}\text{Si}_6\text{O}_{26.5}$ )," *Appl Phys A Mater Sci Process*, vol. 128, no. 10, Oct. 2022, DOI: 10.1007/s00339-022-05963-6.
2. A. Yadav, P. A. Jha, P. K. Jha, N. Jha, and P. Singh, "Influence of ionic radii on the conduction mechanism in lanthanum silicate oxyapatite," *Mater Chem Phys*, vol. 297, p. 127444, Mar. 2023, DOI: 10.1016/j.matchemphys.2023.127444.
3. A. Yadav, P. A. Jha, P. K. Jha, N. Jha, and P. Singh, "Overlapping large polaron tunnelling in lanthanum silicate oxyapatite," *J Phys Condensed Matter*, vol. 35, no. 9, Dec. 2022, DOI: 10.1088/1361-648X/acad53.