Chapter

Introductory Chapter: Basics and Importance of Ferroelectric Materials for Applications

Dipti Ranjan Sahu

1. Introduction

Multifunctional advanced materials are the building block of new device for different application. In recent years research on different fields ranging from cross disciplinarity to multidisciplinary fields including nanotechnology, materials science, physical and biological, increases rapidly based on the growth and development off new and novel materials. Concept of designing and fabricating new and exotic multifunctional materials relating to electronic, spintronics and magnetoelectric dated back to the original work [1, 2] of James Clerks Maxwell (1865) and M. Curie (1894). Among these materials, ferroelectric materials have got its own special technological status for its intriguing properties due to charge and exploiting the coupling of charge with other basic material parameter through electric and magnetic field which make these materials very much promising for future generation devices based on electronics, photonics, opto-electronics and spintronics, etc.

1.1 Definition of ferroelectrics and its basics

Ferroelectrics are known by its stable polarization state [3, 4]. There is a hysteresis effect associated with ferroelectric materials [5–7]. Different type of interactions between electrical, thermal and mechanical properties shown by ferroelectric materials has wealth of functionalities. Ferroelectric materials behavior and properties changes with temperature, electric field, pressure, strain, etc. which make variety of application in different devices.

In addition, some basic requirements of a ferroelectric materials are enumerated as follows:

1.1.1 Symmetry

Ferroelectricity requires the condition of non-centro symmetric and allows an electric polarization [8].

1.1.2 Electrical properties

Ferroelectrics shows spontaneous electric polarization, which can switch direction with an applied electric field.

1.1.3 Chemistry of "d^0-ness"

The ferroelectric materials with ABO_3-type perovskite structure have d^{0}' electron configuration on the B-site cation [8].

1.1.4 Structural anisotropy and distortions

The structural anisotropy responsible for the ferroelectricity due to position of different ions in the crystal lattice [9]. In some cases, the distortion creates in materials due to the position of the certain 'd' orbital occupancies cations shows ferroelectricity [10]. These materials produce a ferroelectric state in a magnetically ordered state.

1.2 Types of ferroelectric materials

Depending on the mechanism of ferroelectricity, one can as well as single out four major types of ferroelectrics, although there are certainly others [11], which are ferroelectricity by mixed perovskite, ferroelectricity by ordering of lone pair d^0 ions, ferroelectricity by charge ordered system, ferroelectricity by geometric arrangement of atoms and shown in (**Figure 1**).

In addition to above four types of ferroelectric material, there are other types of ferroelectrics.

1.2.1 Spiral type ferroelectrics

Specific magnetic spiral is responsible for ferroelectric (Ex. $TbMnO_3$, $Ni_3V_2O_6$, and $MnWO_4$) [11].

Collinear Magnetic Structures ferroelectrics: In this materials ferroelectricity appears in collinear magnetic structure. These ferroelectrics are generally known as magnetically driven ferroelectrics [12]. The simplest example is Ca_3CoMnO_6.

1.3 Key challenges of ferroelectic materials

In order to bring these materials for applications, one has to control the state of the material system by phase control [13–15] or by domain control [16–18]. It is also evident from the literature that several theory and models are proposed to create

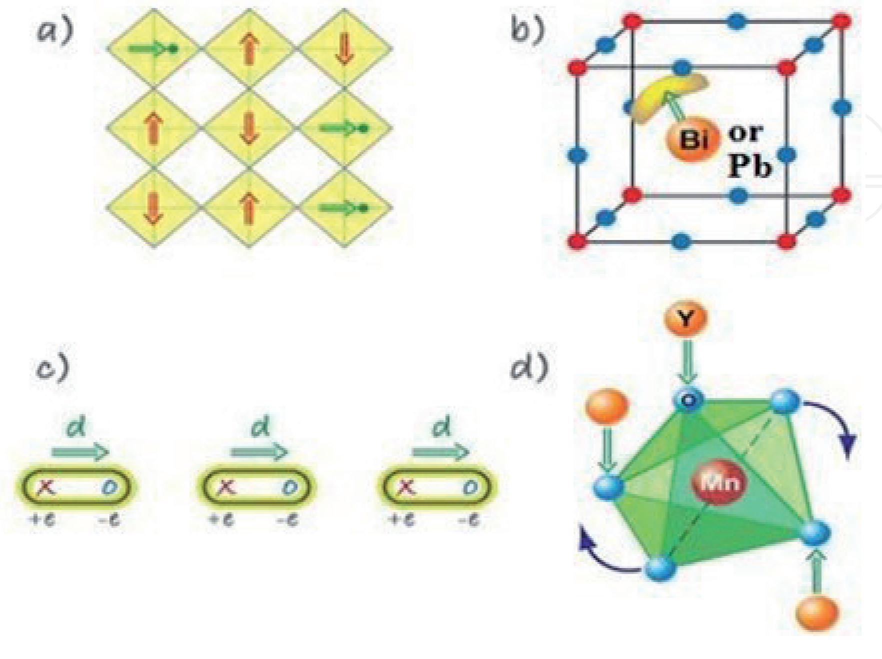

Figure 1.
(a) ferroelectricity by mixed perovskite, (b) ferroelectricity by ordering of lone pair do ions, (c) ferroelectricity by charge ordered system, and (d) ferroelectricity by geometric arrangement of atoms. Figure adopted from Khomskii D. [11].

magnetically-induced ferroelectricity for electronic applications which are generally caused by the presence of spin–orbit interaction [19, 20]. In some cases, spin–orbit coupling is not a requisite [21, 22] rather ferroelectric distortion can cause a small magnetization which can apply to spintronic devices.

For long time there is active research going on ferroelectric materials, still the exact nature and value of spontaneous polarization for application in some of the ferroelectric materials is the matter of long-standing discussion [22]. On the other hand, the mechanism of ferroelectric phase transitions in some ferroelectric materials is not understood clearly and information related to its properties are also not available [23]. Therefore, it is the need of the hour to study and develop novel ferroelectric material for applications.

1.4 Application of ferroelectric materials

Ferroelectric materials show interesting behavior and properties which can be manipulated for design and development of different types of devices. These materials can be used in information storage, spintronic, computing, communications, memories, actutators, motors and sensors [24, 25]. Ferroelectric materials can be used as insulators and semiconductor process integration materials in industry [26–29]. Recent success studies on ferroelectric materials for integrated circuits creates great interest in researcher for development of new ferroelectric materials with different functionalities [30] and address the problem associated with the materials for applications. Still there is plenty of opportunities ahead for ferroelectric material for wide variety of applications.

Acknowledgements

Author highly acknowledges the financial and admirative support of department of Natural and Applied Sciences, Namibia University of Science and Technology, Windhoek. Namibia for this work.

Author details

Dipti Ranjan Sahu
Department of Natural and Applied Sciences, Namibia University of Science and Technology, Windhoek, Namibia

*Address all correspondence to: dsahu@nust.na

References

[1] Curie, P., J. Phys. Theor. Appl. 1894;3:393-415.

[2] Maxwell, J. C., Phil. Trans. R. Soc. Lond. 1865;155:459-512.

[3] Fiebig, M., J. Phys. D: Appl. Phys. 2005;38:R123.

[4] Mitsui, T., "Ferroelectrics and antiferroelectrics," in Springer Handbook of Condensed Matter and Materials Data, edited by W. Martienssen and H. Warlimont (Springer, Heidelberg, 2005), pp. 903-938.

[5] Xu, Y., Ferroelectric Materials and their Applications (Elsevier, 1991).

[6] Trolier-McKinstry, S., Am. Ceram. Soc. Bull. 2020;99(1):22-23.

[7] Mikolajick, T., Schroeder, U., Slesazeck, S., IEEE Trans. Electron Devices 2020;67(4):1434-1443.

[8] Hill, N. A., J. Phys. Chem. B 2000;104:6694.

[9] Schmid, H., Int. J. Magn. 1973;4:337.

[10] Mizokawa, T., Khomskii, D. I., Sawatzky, G. A., Phys. Rev. B 1999;60:7309.

[11] Khomskii, D., Physics 2009;2:20.

[12] Choi, Y. J., Phys. Rev. Lett. 2008;100:047601.

[13] Kimura, T., Goto, T., Shintani, H., Ishizaka, K., Arima, T., Tokura, T., Nature 2003;426:55-58.

[14] Lottermoser, T., Lonkai, T., Amann, U., Hohlwein, D., Ihringer, J., Fiebig, M., Nature (London) 2004;430: 541-544.

[15] Hur, H., Park, S., Sharma, P. A., Ahn, J. S., Guha, S., Cheong, S. W., Nature 2004;429: 392-395.

[16] Fiebig, M., Lottermoser, T., Frohlich, D., Goltsev, A. V., Pisarev, R. V., Nature (London) 2002;419:818-820.

[17] Zhao, T., Scholl, A., Zavaliche, F., Ramesh, R., Nature Materials 2008;5(10):823-839.

[18] Katsura, H., Nagaosa, N., Balatsky, A. V., Phys. Rev. Lett. 2005;95:057205.

[19] Sergienko, I. A., Dagotto, E., Phys. Rev. B 2006;73:094434.

[20] Sergienko, I. A., Sen, C., Dagotto, E., Phys. Rev. B 2006;97:227204.

[21] Picozzi, S., Yamauchi, K., Sanyal, B., Sergienko, I. A., Dagotto, E., Phys. Rev. Lett. 2007;99:227201.

[22] Neaton, J. B., Ederer, C., Waghmare, U. V., Spaldin, N. A., Rabe, K. M., Phys. Rev. B 2005;71:014113.

[23] Vasudevan, R. K., Balke, N., Maksymovych., Jesse, S., Kalinin, S. V. Appl. Phys. Revs 2017;4:021302.

[24] MacDonald, A. H., Schiffer, P., Samarth, M., Nature Materials 2005;4:195-202.

[25] Coey, J. M. D., Venkatesan, M., J. Appl. Phys., 2002;91:8345-8350.

[26] Moodera, J. S., Kinder, L. R., Wong, T. M., Meservey, R., Phys. Rev. Lett. 1995;74:3273-3276.

[27] Zhang, X. Y., Lai, C. W., Zhao, X., Wang, D. Y., Dai, J. Y., Appl. Phys. Lett. 2005;87:143102(1-3).

[28] Wang, Y. P., Zhou, L., Zhang, M. F., Chen, X. Y., Liu, J. M., Liu, Z. G. Appl. Phys. Lett. 2004;84(10):1731-1733.

[29] Kim, T. Y., Kim, S. K., Kim, S. W., Nano Convergence 2018;5:30(1-16).

[30] Mikolajick, T., Slesazeck., Mulaosmanovic, H., Park, M. H., Fichtner, S., Lomenzo, P. D., Hoffmann, J. Appl. Physics 2021;129:1009011-21.