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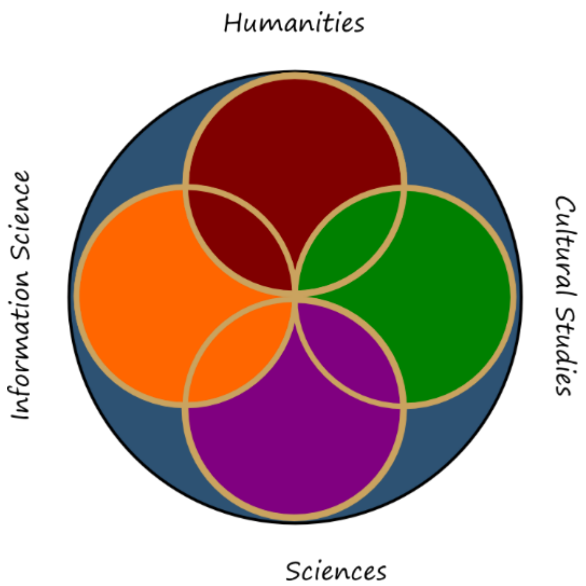

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Innovative Applications of ABO_3 Perovskite Compounds: A Comprehensive Review

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ABSTRACT

Perovskite compounds in the ABO_3 class have become a popular area of study due to their remarkable properties and wide range of applications. The ABO_3 formula consists of elements A and B, which can appear in various valence states, along with oxygen atoms. Perovskite materials are crucial for the progress of various industries, including microelectronics, telecommunications, solar cells, LASER technology, LEDs, and gas sensing applications. In addition, these perovskites exhibit a wide range of electrical, dielectric, ferroelectric, piezoelectric, pyroelectric, magnetic, thermal properties, colossal magnetoresistance (CMR), and photovoltaic characteristics. This article provides a thorough analysis of the different methods used to synthesize oxide perovskites and highlights their wide range of applications in various fields. This review article aims to provide readers with a comprehensive understanding of the synthesis and application of ABO_3 perovskite compounds.

Keywords: *ABO_3 Perovskites, Synthesis, Applications, etc.*

Innovative Applications of ABO_3 Perovskite Compounds: A Comprehensive Review

Dr. Kawale R.S.

Introduction

Perovskite compounds with the formula ABO_3 are a fascinating class of materials that are distinguished by their molecular structure. The field of oxide materials is something that piques their interest to a great extent. Fuel cells, pressure-based electricity generation devices, materials with spontaneous electric polarization, water splitting into hydrogen and oxygen, and electronic components are just some of the many practical applications that these compounds have. They also have a wide range of other applications in a variety of fields. The remarkable stability of these compounds, even in the presence of cation replacements, has sparked a wave of enthusiasm, which is driving the exploration for novel compounds that hold a great deal of promise. In part, the stability of this structure can be attributed to the presence of a 12-fold coordinated A site. This site is capable of accommodating a wide variety of low-valent and large-sized oxides, which also contributes to the structure's stability. In addition to having the ability to modify their structure, the materials have their own set of distinctive characteristics.

It is important to point out that the search for perovskite materials is currently being conducted using methods that take advantage of machine learning. A wide variety of ABO_3 compositions can be analyzed using these techniques, which offer novel approaches to the question. In an intriguing study that was carried out by Liu and colleagues, the researchers utilized machine learning techniques in order to estimate the potential of perovskite structures to take on a variety of shapes. In order to provide evidence in support of their findings, they gathered information from known ABO_3 compounds. In a very efficient manner, their model classified 891 compounds that are classified as belonging to the ABO_3 category. In spite of this, the fascination with achieving an unprecedented level of precision in materials and electronics at the atomic level predates the development of machine learning. In 1959, the renowned physicist Richard Feynman envisioned a future in which the manipulation of individual atoms would become a reality. He believed that this would be possible. The scientific community is still captivated by this fascinating concept, and it continues to be a prominent area of research even in the twentieth century. In spite of this, the story that surrounds perovskite compounds goes back even further than that. In 1839, Gustav Rose made a fascinating discovery: he discovered a mineral compound that was referred to as ABX_3. This compound is similar to the perovskite family of materials. Later on, the well-known Russian mineralogist L. A. Perovski was the one who came up with the name "perovskite" for this particular compound. This straightforward framework has expanded to encompass a wide variety of substances over the course of its evolution. These substances include oxides, carbides, nitrides, halides, and hydrides, among others. Through the study of physics, we are able to delve into the complexities of the atomic realm and establish meticulous benchmarks for materials and electronics. The capabilities of physics appear to be limitless.

Due to the fact that they are utilized in electro-ceramic devices, perovskite compounds hold a significant amount of practical importance in our world. PZT is a remarkable material that is utilized in a wide variety of devices, such as generators, motors, transducers, actuators, capacitors, and memories, amongst others. When it comes to the manufacturing of resistors that exhibit an increase in resistance as the temperature rises, as well as capacitors that are composed of multiple ceramic layers, BTO is an essential component. Perovskites, such as BTO, have been demonstrated to be of great significance in a wide variety of applications around the world. In light of the background information that has been presented, the article delves into a number of significant studies that investigate perovskite materials. Through the publication of their article, A. Ries and colleagues provide insightful information regarding the manufacturing of barium strontium titanate. They highlight the significance of avoiding the use of barium carbonate as an additive. By employing a modified combustion technique, C.N. George and his colleagues were able to successfully produce nanocrystalline barium titanate in a single step. In order to determine the material's conductivity and purity, the researchers investigated it across a range of frequencies. According to the findings of their research, Y.B. Khollam and colleagues utilized an innovative method to generate particles of barium-strontium titanate. The particles are of minuscule dimensions, exhibit exceptional purity, contain the exact number of elements, and have a cubic shape. Additionally, the particles are uniform in size throughout their entirety. An assortment of techniques, such as micro- and chemical analysis, differential thermal analysis (DTA)/thermo-gravimetric analysis (TGA), X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), X-ray fluorescence (XRF), and scanning electron microscopy (SEM), were utilized in order to investigate the characteristics of BST ceramics that were manufactured from these particles [4]. An investigation into the fascinating world of lanthanum-doped barium titanate ceramics was carried out by M.M. Vijatovi and colleagues in a study that was published some time ago. By shedding light on the intriguing phenomenon of these ceramics transitioning from a classical to a diffuse BT ferro-paraphrase state as the concentration of lanthanum is increased, their findings shed light on the phenomenon. The findings of their investigation into impedance indicate that the resistance of grains has a significant influence on the resistance of the material as a whole. These grains have the potential to overlap, which would result in the occurrence of an intriguing phenomenon known as the PTCR effect. Taking into consideration this effect, it can be concluded that the resistance at the boundaries between the grains is quite significant.

This article delves into the captivating research on ABO_3 perovskite compounds and their immense potential. As we delve into these various regions, individuals will encounter fresh approaches to researching and understanding these extraordinary materials and their boundless applications.

2. Perovskite synthesis techniques and their impact on properties and structures.

The choice of synthesis methods has a significant influence on the characteristics and potential uses of perovskite materials. Various methods, including chemical, physical, and optical approaches, have a significant influence on the properties and morphology of perovskite materials. These methods have the ability to modify the shape and crystal structure of the materials. Deciding on the appropriate synthesis technique is a critical choice that relies on the desired material characteristics you seek to achieve.

The ceramic method is a popular technique that is commonly employed to produce perovskite, known for its exceptional solid-state properties. In this study, two significant techniques, namely mechanical ball milling and high-energy ball milling, are employed. In the realm of mechanical ball milling, a motorized hand mixer grinder is a widely utilized tool. Nevertheless, when it comes to high-energy ball milling, specific equipment with a range of rotation speeds (100-1000 rpm) is utilized to attain remarkably tiny particle sizes [12]. The ceramic method, renowned for its connection to ceramics manufacturing, employs solid-state raw materials such as carbonates and oxides. The initial materials undergo mechanical mixing and repeated grinding. Typically, these materials do not exhibit any chemical reactivity. Significant chemical reactions occur at elevated temperatures, typically between 700-1500 °C [13]. Although the ceramic method has demonstrated its effectiveness in perovskite synthesis, it does present a number of challenges. The conditions observed during the process can sometimes yield surprising outcomes. Under certain conditions of temperature and time, the calcination process led to the development of unwanted porous materials [14]. In their study, Nagai et al. showcased the emergence of secondary phases in compounds like $SrCo_{0.9}X_{0.1}O_3$, with X representing a range of different elements. The limited solubility of certain cations within the solid solution is believed to be the cause of this phenomenon [15]. In addition, the presence of specific components, like Ga in $La_{1-x}Sr_xFe_{1-\gamma}Ga_\gamma O_3$, resulted in the emergence of small secondary phases such as La_2O_3, which were not completely integrated into the A-site [17]. Observations were made on the sintering process of materials such as $BaCo_{0.7}Fe_{0.2}Ta_{0.1}O_3$ at various temperatures, providing insights into the impact of the perovskite crystal structure. The study examined the formation of pure perovskite structures at high temperatures, while also noting the presence of unreacted precursors at lower temperatures [18]. These examples showcase the complex interplay between synthesis techniques and the resulting properties and structures of perovskite materials. Having a strong command of the ceramic technique is essential in order to fully unlock the capabilities of perovskite materials. It is crucial to meticulously select the most appropriate synthesis method to achieve the desired properties. The co-precipitation method involves adding a solution with metal cations to a precipitation agent when it is supersaturated. Various factors, including temperature, mixing rate, pH, and concentration, can have an impact on the morphology and particle size distribution of the final product[19]. Cushing et al. highlight the importance of carefully controlling reaction parameters to attain the desired physical characteristics[19]. Co-precipitation is well-known for producing perovskites of outstanding quality. The article emphasizes the significance of careful monitoring of chemical processes. Through careful monitoring, the production of compounds is carried out to prevent any depletion of metal cations[20, 21]. The solubility of strontium hydroxide is affected by various pH levels, which can potentially impede the smooth incorporation of strontium into the perovskite structure while washing. It is important to highlight the importance of effectively controlling this chemical reaction[22]. Perovskite synthesis offers a range of techniques to choose from, such as Pechini, Alkoxide, and Alkoxide-Salt methods. The Pechini technique is highly regarded for its versatility and widespread use in creating perovskites. This method utilizes the combination of EDTA-Citrate and ethylene glycol, resulting in a more intricate process. It is crucial to maintain the ideal pH levels to achieve perovskite structures of outstanding quality, consistency, and precise composition control[23]. The Pechini technique is known for its ability to create a robust connection between the metal cation and EDTA through the formation of six strong bonds. The formation of these bonds is made possible by the presence of electron-donating groups, such as carboxylic and aliphatic amine. The incorporation of citric acid enhances the bonding mechanism, leading to a robust network that effectively inhibits the metal separation [24, 25]. The interactions of metal ions can be effectively inhibited by chelating agents, which helps to prevent any potential segregation [25]. The synthesis process is completed by subjecting the solution to heat, which leads to the formation of interconnected chains of metal atoms bonded to organic radicals [26]. The hydrothermal method utilizes high pressure and temperatures within the range of the material's critical temperature to the boiling point of water. The method employed in this study enables accurate manipulation of particle size, akin to the sol-gel technique [27]. Upon careful examination of $CaTiO_3$ at different temperatures spanning from 15 °C to 150 °C, and comparing the uncalcined and calcined materials at 1300 °C, it was noted that both samples exhibited a complete absence of any impurities. The cell characteristics of the phases were discovered to be quite similar, thus eliminating the need for any post-hydrothermal calcination in this material [28, 29]. The hydrothermal method has shown remarkable advancements and offers immense potential for the precise fabrication of perovskite materials. This extensive analysis of perovskite synthesis techniques delves into various pathways, each presenting its own set of possibilities and challenges. These factors play a crucial role in shaping the progress of perovskite materials.

3. Applications of ABO_3 Perovskite Materials: A Multifaceted Exploration

Perovskite materials have gained significant recognition for their numerous advantages and wide range of versatile properties, making them a force to be reckoned with in various applications. Their ability to be modified through various vacancies has greatly enhanced their physical-chemical characteristics, leading to significant improvements in their performance across various fields. The future of perovskite materials looks promising, thanks to their exceptional properties and the ongoing innovative research efforts. These materials have the potential to bring about significant transformations across various applications.

3.1 Photocatalytic Activity

The photocatalytic activity of ABO_3 perovskite materials can be influenced by their composition. In their study, Zhang et al. (2023a) explored the photocatalytic properties of different compositions of ABO_3 perovskites, such as $LaBO_3$ and $ATiO_3$. A study conducted by Yang et al. in 2006 found that the inclusion of cation A in $ATiO_3$ perovskites (A = Zn, Cd, Pb) results in notable changes to the structure, ultimately affecting the photocatalytic activity. Furthermore, the optical properties and photocatalytic performance of perovskite materials can be greatly affected by the energy levels of the B cation, as shown in a study by Amdouni et al. (2023). Several methods have been explored to enhance the photocatalytic activity of ABO_3 perovskites, such as doping, creating heterostructures, and modifying the surface (Grabowska, 2016). When evaluating ABO_3 perovskite materials, the composition plays a crucial role in determining their photocatalytic activity. Modifications can greatly improve their performance in various applications, including wastewater treatment and solar energy conversion (Shi et al., 2018).

Dive into the captivating realm of ABO_3 perovskite materials, where their remarkable potential in photocatalytic activity is revealed. Jiang Yinwe presents $BaZn_{1}/_{3}Nb_{2}/_{3}O_{3}$, a remarkable perovskite photocatalyst that demonstrates its ability to split water into hydrogen and oxygen when exposed to UV light. These exciting advancements demonstrate great promise for the development of eco-friendly energy [30]. Zhi-Xian Wei's research highlights the impressive capabilities of $LaFe_{0.5}Mn_{0.5}O_{3}$-δ as a photocatalyst, specifically in its ability to break down pollutants such as methyl orange when exposed to sunlight. This offers a promising and long-lasting strategy for tackling environmental remediation [31]. Shuhu a Dong explores the photodegradation of methylene blue, uncovering impressive degradation rates and providing valuable insights into the potential of perovskite in tackling water pollution problems [32].

The photocatalytic properties of ABO_3 perovskites are heavily influenced by their composition and structure. Perovskite materials have shown remarkable properties, including exceptional light absorption, extended excited-state lifetime, and impressive photoluminescence quantum yield. These characteristics make them highly promising for driving photocatalytic organic reactions and facilitating solar energy conversion (Das et al., 2021). Metal oxides with d^0-configuration metal ions, especially those with the perovskite structure, show great potential for photocatalytic water splitting due to their remarkable stability. The materials have a suitable conduction band minimum and show excellent carrier mobility, as emphasized by Mohd Kaus et al. (2022). In a recent study conducted by Zhang et al. (2023b), it was discovered that the band gaps of ABO_3 perovskites have a significant impact on their solar absorbance. It is worth noting that perovskites with magnetic and distorted crystal structures have a tendency to exhibit higher solar absorptivity. This relationship resembling a Gaussian distribution provides insight into the distinct characteristics exhibited by these materials. Research has shown that the use of perovskite materials in heterojunction formation can greatly enhance the separation of charge carriers, resulting in a significant boost in photocatalytic performance (Kanhere & Chen, 2014). Researchers have discovered methods to improve the photocatalytic activity of perovskite materials by modifying their internal, morphological, and surface structure (Mamba et al., 2022).

3.2 Photovoltaic Solar Cells

ABO_3 perovskite-based photovoltaic solar cells have demonstrated significant potential for a wide range of applications. In their recent publication, Hang Yang et al. introduced an innovative technique for creating perovskite films on a large scale. The method they proposed involves a one-step blade coating process, resulting in high-performance films. This research by Yue et al. showcases the potential of this approach. In their recent publication, Qingyuan Li and colleagues used a molecular self-assembly approach to enhance the power conversion efficiency of $FAPbBr_3$ perovskite solar cells. This advancement renders these cells highly suitable for underwater applications, as demonstrated in their study (Li et al., 2023). In their recent publication, Jong-Hyun Seo and colleagues provide a comprehensive analysis of the advancements in perovskite-based photovoltaic power generation. The authors delve into various strategies aimed at enhancing efficiency, stability, and environmental sustainability (Seo et al., 2023). In their study, Chang-Hyun Lee et al. explored the properties of $CsPbI_3$ perovskite as a light absorber and put forward various approaches to minimize nonradiative recombination, ultimately leading to enhanced performance (Lee et al., 2023). In a recent study, Minhajjudin Ahmad and colleagues employed machine learning techniques to forecast the formability and crystal structure of ABO_3 perovskites. This groundbreaking research has the potential to greatly expedite the discovery and synthesis of desired perovskite structures (Ahmad et al., 2022).

ABO_3 perovskite materials have become the center of attention in the world of photovoltaic solar cells. The increasing popularity of Photoanode-Based Dye-Sensitized Solar Cells (DSSC) photoanodes is driven by their exceptional physicochemical properties, excellent photovoltaic performance, and the ability to easily modify them by changing the atomic composition. These qualities make them extremely promising candidates for advancing solar energy technology. In a recent article, B. Mouhib explores the possibilities of using S, Se, or Te doped perovskite $ATiO_3$ materials in solar cells. The findings shed light on the promising optical conductivity and absorption coefficients of these materials, especially in the case of $BaTiO_3Te$. This research opens up new avenues for developing more efficient solar devices.

The commercialization of ABO_3 perovskite solar cells is hindered by the instability of the perovskite layer when exposed to moisture, light, and thermal variables, as highlighted by Hu et al. (2023). The black α-phase $FAPbI_3$ perovskite poses a significant hurdle due to its poor structural stability. At room temperature, it has the tendency to undergo a spontaneous transformation into the photoinactive δ-phase, which is further accelerated by ambient moisture (Cui et al., 2022). Researchers have made progress in stabilizing the α-phase $FAPbI_3$ by incorporating small ions into the perovskite lattice. However, this approach has also introduced phase segregation issues that pose challenges for long-term stability (Wei et al., 2018). There are several challenges that low-dimensional perovskites need to overcome before they can be widely implemented. These challenges include environmental concerns, toxicity, stability, and issues with charge transport. It is crucial to address these challenges in order to scale up the use of low-dimensional perovskites (Diouf et al., 2023). There are several challenges that need to be addressed in this area, such as ensuring material and structural stability, maintaining device performance under harsh conditions, extending the lifetime of the devices, and reducing manufacturing costs (Wang, 2023). In order to address these challenges, it is crucial for future research to prioritize enhancing the inherent stability of perovskite, refining the design of the device, and discovering long-lasting encapsulation materials (Carmona-Monroy et al., 2022).

3.3 Other Applications

Perovskite materials have made an impact in a wide range of applications. The potential seems limitless. Recent studies have brought attention to the promising use of ABO_3 cathodes with a perovskite structure in solid oxide fuel cells (SOFCs). The cathodes mentioned in the study have shown impressive catalytic properties and have proven to be highly effective in the oxygen reduction reaction (ORR) (Shaheen et al., 2023). Various dopants, such as Ba^{2+}, Bi^{3+}, and $Nd_{1-x}Ba_x$, have been investigated by researchers to enhance the electrochemical performance of these cathodes (Desta et al., 2022). Tong et al. (2022) reported that the inclusion of Ba^{2+} and Bi^{3+} in $LaFeO_3$ resulted in an increase in surface oxygen vacancies and a significant improvement in catalytic activity. In a recent study conducted by Sikstrom et al. (2023), the researchers made an interesting discovery regarding the $Nd_{1-x}Ba_xCo_{0.8}Fe_{0.2}O_3$-δ (NBCF) cathodes. They found that these cathodes exhibited exceptional conductivity and remarkably low polarization resistance when utilized for the oxygen reduction reaction (ORR). A study conducted by Liu et al. (2023) showcased how the addition of Fe through B-site doping can significantly enhance the electrocatalytic activity and power density of $Ba_{0.9}K_{0.1}CoO_3$-δ (BKC) cathodes. A recent study conducted by Desta et al. (2022) revealed a noteworthy finding regarding the performance of composite cathodes made of $La_{0.8}Sr_{0.2}FeO_3$-δ-$Gd_{0.2}Ce_{0.8}O_2$-δ (LSF-GDC). The study found that the incorporation of $BaCO_3$ nanoparticles had a beneficial effect on the cathodes' performance. The inclusion of these nanoparticles led to a reduction in area-specific resistance and a boost in peak power density. A study conducted by Tao et al. in 2009 revealed an interesting finding regarding cathodes with varying compositions of $BaCe_xFe_{1-x}O_3$-δ (x = 0.36, 0.43, and 0.50). These cathodes exhibited triple conductivity and showcased remarkable performance in proton-conducting solid oxide fuel cells (SOFCs). The article by SJ Skinner et al. explores the possibilities of utilizing perovskite-type materials, specifically $Gd_{0.7}Ca_{0.3}Co_{1-\gamma}Mn_\gamma O_3$, in solid oxide fuel cells. The authors emphasize the potential of these materials in driving advancements in clean energy technology. In their study, Uchino K. et al. delve into the application of piezoelectric perovskite materials, particularly $PbZr_xTi_{1-x}O_3$, within the realm of sensors and actuators. Their research has made notable progress in sensing technology [24]. Mir and Frontera explore the possibilities of perovskite materials in magnetic memory devices, offering intriguing prospects for progress in data storage and retrieval [25]. Xu Y and Memmert investigate the use of perovskite materials, specifically $La_{0.67}Sr_{0.33}MnO_3$ and $La_{0.67}Ba_{0.33}MnO_3$, for magnetic field sensors. Their research is centered around achieving precise magnetic field detection [26]. Zhao T et al. investigate the possibilities of using colossal magnetoresistive manganite-based ferroelectric field-effect transistors to improve electric field effect devices, resulting in the advancement of electronic devices [27]. Mitra C and Raychaudhuri's research highlights the immense potential of ferroelectric and piezoelectric devices like $BaTiO_3$ and $PbTiO_3$, opening up thrilling opportunities for innovation in various fields [28]. In their study, Munoz JLG et al. made a significant contribution to the field of electronic components by investigating the use of lanthanum manganites as semiconducting electronic devices [29]. The study conducted by Sleight et al. explores the characteristics of $Bi_{1-x}Sr_xMnO_3$ manganites with a high-dielectric constant, indicating a potential for the advancement of electrical devices [30]. The study conducted by Ding et al. explores the field of high-temperature superconductivity in the $BaPb_{1-x}Bi_xO_3$ system, offering promising prospects for the advancement of groundbreaking superconductive technologies [31]. In their study, Manh DH and Phong delve into the characteristics of $La_{0.7}Sr_{0.3}MnO_3$ and explore its potential uses in hyperthermia treatment. Their research primarily centers around the AC magnetic heating capabilities of this material [32]. The research conducted by Ding et al. sheds light on the promising capabilities of perovskite nanocrystals $KNi_{0.8}Co_{0.2}F_3$ in the realm of supercapacitors, presenting intriguing prospects for the advancement of energy storage technologies [33].

In the intricate web of applications for ABO_3 perovskite materials, their unique properties and capabilities continue to inspire innovation and propel the advancement of numerous scientific fields. Researchers are compelled to investigate new frontiers in technology and industry by the limitless potential of these materials.

Conclusion

This review explores the world of ABO_3 perovskite compounds, their properties, synthesis methods, and applications. These compounds are at the intersection of scientific discovery and technological advancement, with their exceptional stability and ability to fine-tune properties making them potential catalysts for change in industries like energy production, sensing technology, and catalysis. Synthesis methods, including chemical methods, co-precipitation, sol-gel, and hydrothermal approaches, allow researchers to create materials tailored for their intended applications. ABO_3 perovskite materials have applications in photocatalytic activity, photovoltaic solar cells, solid oxide fuel cells, sensors, memory devices, magnetic devices, high dielectric constant materials, and supercapacitors. These compounds represent the promise of innovation, the hope for a sustainable future, and the potential to address pressing challenges. The promises exciting breakthroughs as researchers harness the power of these versatile materials.

References

R.H. Mitchell, Perovskites: modern and ancient, (2002).

Ries, A. Simoes, M. Cilense, M. Zaghete, J.A. Varela, Barium strontium titanate powder obtained by polymeric precursor method, Materials characterization, 50 (2003) 217-221.

George, J. Thomas, H. Kumar, M. Suresh, V. Kumar, P. Wariar, R. Jose, J. Koshy, Characterization, sintering and dielectric properties of nanocrystalline barium titanate synthesized through a modified combustion process, Materials Characterization, 60 (2009) 322-326.

Y. Khollam, S. Deshpande, H. Potdar, S. Bhoraskar, S. Sainkar, S. Date, Simple oxalate precursor route for the preparation of barium–strontium titanate: $Ba_{1-x}Sr_xTiO_3$ powders, Materials Characterization, 54 (2005) 63-74.

M.V. Petrović, J. Bobić, T. Ramoška, J. Banys, B. Stojanović, Electrical properties of lanthanum doped barium titanate ceramics, Materials Characterization, 62 (2011) 1000-1006.

W. Li, Z. Xu, R. Chu, P. Fu, G. Zang, Structural and dielectric properties in the $(Ba_{1-x}Ca_x)(Ti_{0.95}Zr_{0.05})O_3$ ceramics, Current Applied Physics, 12 (2012) 748-751.

P. Julphunthong, T. Bongkarn, Phase formation, microstructure and dielectric properties of $Ba(Zr_{0.1}Ti_{0.9})O_3$ ceramics prepared via the combustion technique, Current Applied Physics, 11 (2011) S60-S65. 20

S M. Aparna, T. Bhimasankaram, S. Suryanarayana, G. Prasad, G. Kumar, Effect of lanthanum doping on electrical and electromechanical properties of $Ba_{1-x}La_xTiO_3$, Bulletin of Materials Science, 24 (2001) 497-504.

K. Sharma, V. Varadan, V. Varadan, Dielectric properties of tape cast Ba0. 65Sr0. 35TiO3 derived from sol–gel for application in multilayered capacitors, Smart materials and structures, 12 (2003) 749.

P. Shcheglov, S. Men'shikh, L. Rybakova, Y.Y. Tomashpol'skii, Modified sol-gel process for the preparation of $BaTiO_3$ and $PbTiO_3$ ferroelectric films, Inorganic Materials, 36 (2000) 380-384.

D.P. Dutta, M. Roy, N. Maiti, A.K. Tyagi, Phase evolution in sonochemically synthesized Fe^{3+} doped $BaTiO_3$ nanocrystallites: structural, magnetic and ferroelectric characterization, Physical Chemistry Chemical Physics, 18 (2016) 9758-9769.

Joshi Siddharth 1 et all Elsevier x-ray diffraction a simplistic approach for perovskite-based solar cell studies doi.org/10.1016/j.matpr.2019.05

Sadhukhan, P., Kundu, S., Roy, A., Ray, A., Maji, P., Dutta, H., Pradhan, S.K. and Das, S., 2018. Solvent-free solid-state synthesis of high-yield mixed halide perovskites for easily tunable composition and band gap. Crystal Growth & Design, 18(6), pp.3428-3432

Waindich, A. Möbius, M. Müller, Corrosion of $Ba_{1-x}Sr_xCo_{1-y}Fe_yO_{3-\delta}$ and $La_{0.3}Ba_{0.7}Co_{0.2}Fe_{0.8}O_{3-\delta}$ materials for oxygen separating membranes under Oxycoal conditions, J. Memb. Sci. 337 (2009) 182–187. 29

T. Nagai, W. Ito, T. Sakon, Relationship between cation substitution and stability of perovskite structure in $SrCoO_{3-\delta}$ - based mixed conductors, Solid State Ionics. 177 (2007) 3433–3444.

E. Juste, A. Julian, G. Etchegoyen, P.M. Geffroy, T. Chartier, N. Richet, et al., Oxygen permeation, thermal and chemical expansion of (La, Sr)(Fe, Ga)O_{3-d} perovskite membranes, J. Memb. Sci. 319 (2008) 185–191.

H. Luo, Y. Wei, H. Jiang, W. Yuan, Y. Lv, J. Caro, et al., Performance of a ceramic membrane reactor with high oxygen flux Ta-containing perovskite for the partial oxidation of methane to syngas, J. Memb. Sci. 350 (2010) 154–160.

Y. Cheng, H. Zhao, D. Teng, F. Li, X. Lu, W. Ding, Investigation of Ba fully occupied A-site $BaCo_{0.7}Fe_{0.3-x}Nb_xO_{3-\delta}$ perovskite stabilized by low concentration of Nb for oxygen permeation membrane, J. Memb. Sci. 322 (2008) 484–490.

Yin, Jiang; Zou, Zhigang; Ye, Jinhua (2004).The Journal of Physical Chemistry B, 108(34), 12790–12794.

Zhi-Xian Wei, Yan Wang, Ji-Ping Liu, Cai-Mei Xiao, Wei-Wei Zeng, Materials Chemistry and Physics, Volume 136, Issues 2–3, 2012.

Bhojanaa, K. B., et al. "Account of Structural, Theoretical, and Photovoltaic Properties of ABO_3 Oxide Perovskites Photoanode-Based Dye-Sensitized Solar Cells." *Solar RRL* 6.2 (2022): 2100792.

Mouhib, B., et al. "Theoretical investigations of electronic structure and optical properties of S, Se or Te doped perovskite $ATiO_3$ (A= Ca, Ba, and Sr) materials for eco-friendly solar cells." *Micro and Nanostructures* 163 (2022): 107124.

Skinner SJ. Recent advances in perovskite-type materials for solid oxide fuel cell cathodes. International Journal of Inorganic Materials. 2001;3:113-121

Uchino K. Glory of piezoelectric perovskites. Science and Technology of Advanced Materials.2015;**16**:046001-0460016

Mir LL, Frontera C, Aramberri H, Bouzehouane K, Fernandez JC, Bozzo B, et al. Anisotropic sensor and memory device with a ferromagnetic tunnel **19** *Synthesis Techniques and Applications of Perovskite Materials* barrier as the only magnetic element. Scientific Reports. 2018;**8**:861-870

Xu Y, Memmert U, Hartmann U. Magnetic field sensors from polycrystalline manganites. Sensors and Actuators A. 2001;**91**:26-29

Zhao T, Ogale SB, Shinde SR, Ramesh R, Droopad R, Yu J, et al. Colossal magnetoresistive manganite-based ferroelectric field-effect transistor on Si. Applied Physics Letters. 2004; **84**:750-752

Nuraje N, Su K. Perovskite ferroelectric nanomaterials. Nanoscale. 2013;**5**:8752-8780

Mitra C, Raychaudhuri P, Kobernik G, Dorr K, Muller KH, Schultz L, et al. p-n diode with hole and electron-doped lanthanum manganites. Applied Physics Letters. 2001;**79**:2408-2410

Munoz JLG, Frontera C, Murias BR, Mira J. Dielectric properties of Bi1-x $SrxMnO_3$ (x = 0.40, 0.50) manganites: Influence of room temperature charge order. Journal of Applied Physics.2009;**105**:084116-084120

Sleight AW, Gillson JL, Bierstedt PE. High-temperature superconductivity in the $BaPb1{-}xBixO_3$ system. Solid State Communications. 1993;**88**:841-842

Manh DH, Phong PT, Nam PH, Tung DK, Phuc NX, Lee IJ. Structural and magnetic study of $La0.7Sr0.3MnO_3$ nanoparticles and AC magnetic heating characteristics for hyperthermia applications. Physica B. 2014;**444**:94-102

Ding R, Li X, Shi W, Xu Q , Han X, Zhou Y, et al. Perovskite $KNi0.8Co0.2F_3$ nanocrystals for supercapacitors. Materials Chemistry A. 2017;**5**:17822-17827

Amdouni, W., Otoničar, M., Gemeiner, P., Butin, V., Guiblin, N., Maghraoui-Meherzi, H., & Dkhil, B. (2023). A General Synthetic Route to High-Quality

Perovskite Oxide Nanoparticles and Their Enhanced Solar Photocatalytic Activity. Angewandte Chemie - International Edition, 62(7). https://doi.org/10.1002/anie.202215700

Das, A., Mahata, D., & Kanti Adak, M. (2021). Perovskite Based Photocatalyst for Wastewater Treatment: Green Approach of Environmental Sustainability. American Journal of Biological and Environmental Statistics, 7(1). https://doi.org/10.11648/j.ajbes.20210701.11

Grabowska, E. (2016). Selected perovskite oxides: Characterization, preparation and photocatalytic properties-A review. In Applied Catalysis B: Environmental (Vol. 186). https://doi.org/10.1016/j.apcatb.2015.12.035

Kanhere, P., & Chen, Z. (2014). A review on visible light active perovskite-based photocatalysts. In Molecules (Vol. 19, Issue 12). https://doi.org/10.3390/molecules191219995

Mamba, G., Mafa, P. J., Muthuraj, V., Mashayekh-Salehi, A., Royer, S., Nkambule, T. I. T., & Rtimi, S. (2022). Heterogeneous advanced oxidation processes over stoichiometric ABO3 perovskite nanostructures. In Materials Today Nano (Vol. 18). https://doi.org/10.1016/j.mtnano.2022.100184

Mohd Kaus, N. H., Ibrahim, M. L., Imam, S. S., Mashuri, S. I. S., & Kumar, Y. (2022). Efficient Visible-Light-Driven Perovskites Photocatalysis: Design, Modification and Application. https://doi.org/10.1007/978-3-030-77371-7_13

Shi, L., Chang, D., Ji, X., & Lu, W. (2018). Using Data Mining to Search for Perovskite Materials with Higher Specific Surface Area. Journal of Chemical Information and Modeling, 58(12). https://doi.org/10.1021/acs.jcim.8b00436

Yang, Y., Sun, Y., & Jiang, Y. (2006). Structure and photocatalytic property of perovskite and perovskite-related compounds. Materials Chemistry and Physics, 96(2–3). https://doi.org/10.1016/j.matchemphys.2005.07.007

Zhang, H., Ji, X., Xu, H., Zhang, R., & Zhang, H. (2023a). Design and modification of perovskite materials for photocatalytic performance improvement. Journal of Environmental Chemical Engineering, 11(1). https://doi.org/10.1016/j.jece.2022.109056

Zhang, H., Ji, X., Xu, H., Zhang, R., & Zhang, H. (2023b). Design and modification of perovskite materials for photocatalytic performance improvement. Journal of Environmental Chemical Engineering, 11(1). https://doi.org/10.1016/j.jece.2022.109056

Ahmad, M. U., Akib, A. R., Raihan, M. M. S., & Shams, A. Bin. (2022). ABO3 Perovskites' Formability Prediction and Crystal Structure Classification using Machine Learning. 2022 International Conference on Innovations in Science, Engineering and Technology, ICISET 2022. https://doi.org/10.1109/ICISET54810.2022.9775906

Carmona-Monroy, P., Vargas, B., & Solis-Ibarra, D. (2022). Challenges and future prospects. In Low-Dimensional Halide Perovskites: Structure, Synthesis, and Applications. https://doi.org/10.1016/B978-0-323-88522-5.00004-1

Cui, X., Jin, J., Tai, Q., & Yan, F. (2022). Recent Progress on the Phase Stabilization of FAPbI3 for High-Performance Perovskite Solar Cells. In Solar RRL (Vol. 6, Issue 10). https://doi.org/10.1002/solr.202200497

Diouf, B., Muley, A., & Pode, R. (2023). Issues, Challenges, and Future Perspectives of Perovskites for Energy Conversion Applications. In Energies (Vol. 16, Issue 18). https://doi.org/10.3390/en16186498

Hu, J., Yang, L., & Zhang, J. (2023). A Review on Strategies to Fabricate and Stabilize Phase-Pure α-FAPbI3 Perovskite Solar Cells. In Solar RRL (Vol. 7, Issue 13). https://doi.org/10.1002/solr.202300187

Lee, C., Lee, C., Chae, K., Kim, T., Park, S., Ko, Y., & Jun, Y. (2023). Amorphous BaTiO3 Electron Transport Layer for Thermal Equilibrium-Governed γ-CsPbI3 Perovskite Solar Cell with High Power Conversion Efficiency of 19.96%. Energy and Environmental Materials. https://doi.org/10.1002/eem2.12625

Li, Q., Zheng, Y., Guo, X., Zhang, G., Ding, G., Shi, Y., Li, F., Sun, M., & Shao, Y. (2023). Interface Engineering Enhances the Photovoltaic Performance of Wide Bandgap FAPbBr3 Perovskite for Application in Low-Light Environments. Advanced Functional Materials, 33(40). https://doi.org/10.1002/adfm.202303729

Seo, J., Song, T., Rasool, S., Park, S., & Kim, J. Y. (2023). An Overview of Lead, Tin, and Mixed Tin–Lead-Based ABI3 Perovskite Solar Cells. In Advanced Energy and Sustainability Research (Vol. 4, Issue 5). https://doi.org/10.1002/aesr.202200160

Wang, Y. (2023). Advances and Challenges When Commercializing Perovskite Solar Cells. Highlights in Science, Engineering and Technology, 43. https://doi.org/10.54097/hset.v43i.7480

Wei, Q., Zi, W., Yang, Z., & Yang, D. (2018). Photoelectric performance and stability comparison of MAPbI3 and FAPbI3 perovskite solar cells. Solar Energy, 174. https://doi.org/10.1016/j.solener.2018.09.057

Yue, W., Yang, H., Cai, H., Xiong, Y., Zhou, T., Liu, Y., Zhao, J., Huang, F., Cheng, Y. B., & Zhong, J. (2023). Printable High-Efficiency and Stable FAPbBr3 Perovskite Solar Cells for Multifunctional Building-Integrated Photovoltaics. Advanced Materials, 35(36). https://doi.org/10.1002/adma.202301548

Desta, H. G., Yang, Y., Teketel, B. S., Yang, Q., Song, K., Zhu, S., Tian, D., Chen, Y., Luo, T., & Lin, B. (2022). Enhanced Performance of La0.8Sr0.2FeO3-δ-Gd0.2Ce0.8O2-δ Cathode for Solid Oxide Fuel Cells by Surface Modification with BaCO3 Nanoparticles. Micromachines, 13(6). https://doi.org/10.3390/mi13060884

Liu, J., Jing, Y., Zhu, D., Zhang, Y., Li, X., Jia, X., Ouyang, Y., Gao, X., Luan, H., Li, Z., & Zhu, C. (2023). Fe-Doped Ba0.9K0.1FexCo1-xO3−δ Perovskite Cathode Material for Low-Temperature Solid Oxide Fuel Cells. ACS Applied Energy Materials, 6(13). https://doi.org/10.1021/acsaem.3c00314

Shaheen, N., Chen, Z., Nong, Y., Su, T., Yousaf, M., Lu, Y., & Li, L. (2023). Enhancing ORR Catalytic Activity and Electrochemical Investigation of La1−2xBaxBixFeO3 Cathode for Low-Temperature Solid Oxide Fuel Cell. Crystals, 13(5). https://doi.org/10.3390/cryst13050822

Sikstrom, D., Javed, A., Shoaib, M., & Thangadurai, V. (2023). Perovskite-Type Nd 1-X Ba x Co 0.8 Fe 0.2 O 3-δ ($0 \leq x \leq 0.7$) Cathodes for Intermediate Temperature Solid Oxide Fuel Cells . ECS Transactions, 111(6). https://doi.org/10.1149/11106.2397ecst

Tong, H., Fu, M., Yang, Y., Chen, F., & Tao, Z. (2022). A Novel Self-Assembled Cobalt-Free Perovskite Composite Cathode with Triple-Conduction for Intermediate Proton-Conducting Solid Oxide Fuel Cells. Advanced Functional Materials, 32(48). https://doi.org/10.1002/adfm.202209695

Tao, Z., Bi, L., Zhu, Z., & Liu, W. (2009). Novel cobalt-free cathode materials BaCexFe1-xO3-δ for proton-conducting solid oxide fuel cells. Journal of Power Sources, 194(2). https://doi.org/10.1016/j.jpowsour.2009.06.071