INFLUENCE OF HEATING TEMPERATURE ON Nd-Sr-Mn-O MANGANITES SYNTHESISED VIA THERMAL TREATMENT AND SOL-GEL METHOD

By

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Mixed-valence manganites have garnered significant interest owing to their intriguing colossal magnetoresistance effect. In the realm of manganites, the primary challenge is achieving remarkable magnetoresistance (MR) values even with weak magnetic fields, rendering these materials applicable for the utilisation of magnetic sensors near room temperatures. The selection of preparation methods and synthesis routes is crucial as it can alter the grain size formation and/or distribution, subsequently affecting the magnetic and electrical behaviour of manganite materials. In this project, a newly developed approach known as the thermal treatment method (TT) was employed to synthesise $Nd_{0.7}Sr_{0.3}MnO_3$ (NSMO) manganites. Given the novelty of this approach, optimisation and fine-tuning of heat treatment parameters are imperative to achieve the utmost desirable physical properties. The first part of this investigation focuses on assessing the impact of calcination temperatures on the NSMO samples. Higher crystallinity was achieved when NSMO was calcined at 500 °C and 900 °C. However, an unfavorable morphology was observed in sample calcined at 900 °C and sintered at 1200 °C. Besides, the NSMO samples exhibited distinct magnetic phase transition when calcined at 500 °C. Regarding magneto-transport behaviour, the intrinsic MR is more predominant in the sample calcined at 500 °C and sintered at 1200 °C. Thus, it can be deduced that 500 °C is the optimum calcination temperature. The next part of this thesis aims to explore the grain size effect on the NSMO samples synthesised via thermal treatment and sol-gel (SG) methods at various sintering temperatures (700 °C to 1200 °C). While the sol-gel method yielded a single NSMO phase, minor phases were detected in the NSMO samples prepared using the thermal treatment method at a lower sintering temperature. XRD result indicated larger crystallite size formation and better crystallinity in SG, but SEM analysis revealed a greater variation of grain size in TT. Additionally, TT exhibited a broader magnetic phase transition due to the existence of nonferromagnetic clusters resulting from the detected minor phases. In both series of samples, the presence of MR peaks suggests the prevalence of intrinsic MR, with peak intensity increasing as the

sintering temperature rises. Interestingly, contrary to prior research, the intrinsic MR is more dominant in SG samples with smaller grain sizes, which can be attributed to the microstructure change and morphology variations. In conclusion, this study highlights the significance of structural and microstructural formation resulting from various synthesis methods in governing the physical properties of manganite samples. This study stands out as the pioneer in preparing Nd-based manganites using the thermal treatment method. It offers the advantages of being cost-effective and environmentally friendly, while also featuring a simplified preparation method for manganites.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENGARUH SUHU PEMANASAN PADA MANGANIT Nd-Sr-Mn-O YANG DISINTESISKAN MELALUI KAEDAH RAWATAN TERMA DAN SOL-GEL

Oleh

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Manganit valensi campuran telah menarik perhatian yang ketara kerana ia mempamerkan kesan magnetorintangan kolosal yang menarik. Dalam bidang manganit, cabaran utama ialah mencapai nilai magnetorintangan (MR) yang luar biasa walaupun dengan medan magnet yang lemah, menjadikan bahan ini boleh digunakan dalam aplikasi sensor medan magnet berhampiran dengan suhu bilik. Pemilihan kaedah penyeliaan dan laluan sintesis adalah penting kerana ia boleh mengubah pembentukan dan/atau taburan saiz butiran, seterusnya menjejaskan tingkah laku magnet dan elektrik bahan manganit. Dalam projek ini, pendekatan baru yang dikenali sebagai kaedah rawatan terma (TT) telah digunakan untuk mensintesiskan manganit $Nd_{0.7}Sr_{0.3}MnO_3$ (NSMO). Memandangkan kebaharuan pendekatan ini, pengoptimuman dan penalaan halus parameter rawatan haba adalah penting untuk mencapai sifat fizikal yang paling diingini. Bahagian pertama penyiasatan ini memberi tumpuan kepada kesan suhu pengkalsinan pasa sampel NSMO. Kehabluran yang lebih tinggi telah dicapai apabila NSMO dikalsin pada 500 °C dan 900 °C. Walau bagaimanapun, morfologi yang kurang baik telah diperhatikan dalam sampel yang dikalsin pada 900 °C dan disinter pada 1200 °C. Selain itu, sampel NSMO mempamerkan peralihan fasa magnet yang berbeza apabila dikalsin pada 500 °C. Mengenai tingkah laku magneto-pengangkutan, MR intrinsik didapati lebih pradominan dalam sampel yang dikalsin pada 500 °C dan disinter pada 1200 °C. Oleh itu, boleh disimpulkan bahawa 500 °C ialah suhu pengkalsinan yang optimum. Bahagian seterusnya tesis ini bertujuan untuk meneroka kesan saiz butiran pada sampel NSMO yang disintesiskan melalui kaedah rawatan terma dan kaedah sol-gel (SG) pada suhu pensinteran yang berbeza (700 °C hingga 1200 °C). Kaedah sol-gel telah menghasilkan fasa tunggal NSMO, manakala fasar minor pula dikesan dalam sampel NSMO yang disediakan oleh kaedah rawatan terma apabila disinter pada suhu yang lebih rendah. Keputusan XRD menunjukkan pembentukan saiz hablur yang lebih besar dan kehabluran yang lebih baik dalam SG, tetapi analisis SEM mendedahkan variasi saiz butiran yang lebih besar dalam TT. Selain itu, TT mempamerkan peralihan fasa magnet yang lebih lebar kerana kewujudan kelompok bukan feromagnet yang terhasil daripada fasa minor yang dikesan. Dalam kedua-dua siri sampel, kehadiran puncak MR menunjukkan kelaziman MR intrinsik, dengan keamatan puncak meningkat apabila suhu pensinteran

meningkat. Menariknya, bertentangan dengan penyelidikan terdahulu, MR intrinsik lebih dominan dalam sampel SG dengan saiz butiran yang lebih kecil, yang boleh dikaitkan dengan perubahan mikrostruktur dalam variasi morfologi. Kesimpulannya, kajian ini mengetengahkan kepentingan pembentukan struktur dan mikrostruktur hasil daripada kaedah sintesis yang berbeza dalam mengawal sifat fizikal sampel manganit. Kajian ini menonjol sebagai perintis dalam penyediaan manganit berasaskan Nd menggunakan kaedah rawatan terma. Ia menawarkan kelebihan seperti kos efektif dan mesra alam, sementara memaparkan kaedah penyediaan manganit yang ringkas.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AFI	Antiferromagnetic insulating
AFM	Antiferromagnetic metallic
BSE	Backscattered electrons
CP	Co-precipitation
CMR	Colossal magnetoresistance
DE	Double exchange
E_A	Activation energy
FESEM	Field emission scanning electron microscopy
FI	Ferromagnetic insulating
FM	Ferromagnetic
FWHM	Full width at half maximum
GMR	Giant magnetoresistance
H	Magnetic field
H_C	Coercivity
HMS	Hall effect measurement system
ICSD	Inorganic Crystal Structure Database
J-T	Jahn-Teller
LFMR	Low field magnetoresistance
LSMO	Lanthanum strontium manganese oxide
M	Magnetisation
MR	Magnetoresistance
MR (%)	Magnetoresistance value
M_S	Saturation magnetisation

NSMO	$Nd_{0.7}Sr_{0.3}MnO_3$
PI	Paramagnetic insulating
PM	Paramagnetic
PVP	Polyvinylpyrrolidone
R	Resistance
R^2	Squared linear correlation coefficient
SE	Secondary electrons
SEM	Scanning electron microscopy
SG	Sol-gel
SPH	Small polaron hopping
SS	Solid-state
T	Temperature
T_C	Curie temperature
T_{MI}	Metal-insulator transition temperature
T_S	Sintering temperature
TT	Thermal treatment
VRH	Variable range hopping
VSM	Vibrating sample magnetometer
XPS	X-ray photoelectron spectroscopy
XRD	X-ray diffraction
θ_D	Debye's temperature
ρ	Resistivity
ρ_{peak}	Peak resistivity
χ^2	Goodness of fit

CHAPTER 1

INTRODUCTION

This chapter begins with an overview of manganite research, then addresses the problem statement, and explores the research gaps. Furthermore, the objectives of this work are clearly outlined.

1.1 Background

The rich history of manganite studies can be traced back to 1950 when Jonker and Van Santen (1950) initiated their pioneering investigations by introducing alkaline earth metals such as $SrMnO_3$, into the structure of $LaMnO_3$. Their groundbreaking research discovered that manganites evinced marvellous traits by experiencing metal-insulator transition as well as ferromagnetism in the presence of mixed valency of manganese ions in the system. Building on these seminal findings, Volger (1954) embarked on further comprehensive experimental investigations on ferromagnetic manganese oxide with perovskite structures. His study revealed the emergence of the negative magnetoresistance (MR) effect in $La_{0.8}Sr_{0.2}MnO_3$ near its Curie temperature, T_C. The 1900s witnessed a resurgence of interest in mixed-valence manganite, culminating in the advancement of Chahara et al. (1993) and von Helmolt et al. (1993) by developing high-quality thin films with giant magnetoresistance (GMR). However, the true breakthrough occurred when Jin et al. (1994) made a remarkable discovery by unveiling an impressively strong negative isotropic MR effect, famously known as colossal magnetoresistance (CMR) in La-Ca-Mn-O thin films. This CMR effect surpassed the typical GMR effect observed in such films by more than three orders of magnitude.

At the core of manganite studies lies the perovskite structure, defined by a cubic crystal lattice where oxygen atoms surround manganese ions in octahedral arrangements (Pavone et al., 2014). This structure holds the key to understanding the complex electronic and magnetic properties of manganites. Within this crystal framework, some influential theories come to the forefront, including the double exchange (DE) mechanism and the Jahn-Teller distortion (J-T) effect (Shimomura et al., 1999). These theories have unlocked the secrets behind CMR and the diverse electronic behaviours, leading them to find their way into the practical world, revolutionising fields such as magnetic sensors, magnetic data storage, and spintronic devices (Xia et al., 2020).

Manganites exhibit a fascinating interplay between intrinsic and extrinsic MR effects. The former originates from the grain properties while the latter emerges from the spin-dependent scattering or spin-polarised tunnelling near grain boundaries (Panwar et al., 2007). Thus, the magneto-transport properties are closely associated with the microstructural behaviour of the sample, which can be influenced by the specific preparation methods utilised (Raddaoui et al., 2021). This marks the significance of the synthesis route in shaping the physical properties of these materials.

In summary, manganite perovskites have garnered worldwide attention thanks to their captivating electronic and magnetic attributes. These materials hold the promise to bring about significant advancements across various fields, rendering them an exceptionally fascinating area of study within the science community.

1.2 Problem Statement

Extensive research efforts have been committed to the study of CMR materials. This dedication is motivated not only by their diverse physical characteristics but also by their promising roles in applications. Thus, the key challenge revolved around achieving significant MR values under low magnetic fields, particularly at or near room temperature (Acharya et al., 2017). While lanthanum-based manganites have been extensively studied in the past, recent research has shifted its focus towards exploring different types of perovskite manganites. This brought neodymium-based manganites into the spotlight as a primary area of interest in current studies. Among the perovskite manganites investigated thus far, the neodymium-based manganite system with narrow bandwidth stands out for displaying intriguing phenomena distinct from those observed in lanthanum-based manganite systems (Bhargav et al., 2022).

The physical traits of manganites are intricately shaped by the preparation methods and processing conditions. Among these methods, the solid-state reaction method stands out for its simplicity (Amin et al., 2022). It provides a quick route to synthesise perovskite materials with high purity and excellent crystallinity (Sujiono et al., 2018). However, it does have its drawbacks, including the requirement for extremely high temperatures and prolonged heating duration. Additionally, it is necessary to go through multiple rounds of milling and heating cycles to achieve the desired phase and chemical compositions. Thus, researchers have embraced the wet chemical approach, specifically the sol-gel method, to tackle this shortcoming (M'nassri et al., 2015). Moreover, this wet chemical approach permits better stoichiometry, shorter heating time, and smaller particle size (Brinker & Scherer, 2013; Danks et al., 2016; Zhao et al., 2017). In this project, a newly developed synthesis method, known as the thermal treatment method, is employed for NSMO preparation. Since this is a novel approach, optimisation and fine-tuning of heat treatment parameters are essential to attain the best possible physical properties.

Previous studies proposed that physical properties are strongly governed by controlling both the grain size and distribution. This can be accomplished by adjusting the calcination and sintering temperatures. The sintering behaviour of manganite samples was discovered to be highly sensitive to the calcination conditions. Calcination serves as the initial stage where the precursor material undergoes controlled heating at temperatures typically below the melting point of the desired product in order to facilitate the decomposition of nitrates and the formation of the oxide (Jiang, 2012). On the other hand, sintering involves the elevated heating of the materials at significantly high temperatures (typically near the melting point of the desired compound) resulting in diffusion between the particles and forming a compact structure (Bhattacharya & Basak, 2016; Lim et al., 2009). These crucial steps can induce alterations in microstructure as well as a reduction in grain size, subsequently influencing their physical behaviour.

1.3 Objectives

Building on the existing manganite research background and addressing its research gap, it is crucial to emphasise that the physical properties of manganites are strongly dependent on the preparation methods as well as the microstructure modification. Thus, the objectives of this project are delineated as follows:

1. To determine the effect of calcination and sintering temperatures on the NSMO samples synthesised via the thermal treatment method.
2. To investigate the influence of sintering temperatures on the structural, microstructural, magnetic, electrical and magneto-transport properties of NSMO samples prepared by thermal treatment and sol-gel methods.
3. To evaluate the grain size effect on the physical properties of NSMO samples prepared by thermal treatment and sol-gel methods.

1.4 Thesis Content

The thesis starts with Chapter 1 by providing an introduction to the research project. Subsequently, Chapter 2 offers an extensive literature review encompassing prior work on perovskite manganites and the analysis theory underpinning this project. Moving forward, Chapter 3 covers the methodology of sample preparation, the material and equipment used, as well as the characterisation techniques employed. This is followed by the result and discussion in Chapter 4, while Chapter 5 concludes the research with recommendations for future investigations.

REFERENCES

Abassi, M., Dhahri, N., Dhahri, J., & Hlil, E. (2014). Percolation model of $La_{0.67-x}Y_xBa_{0.23}Ca_{0.1}MnO_3$ ($0 \leqslant x \leqslant 0.15$) composites. *Chemical Physics, 436*, 40-45.

Abassi, M., Zaidi, A., Dhahri, J., & Hlil, E. (2016). Critical scaling and percolation model in $La_{0.57}Gd_{0.1}Sr_{0.33}Mn_{0.9}In_{0.1}O_3$ manganite. *Journal of Alloys and Compounds, 688*, 1251-1259.

Acharya, D., Bhargav, A., Tank, T. M., & Sanyal, S. P. (2017). Effect of Ru substitution on temperature coefficient of resistance and magnetoresistance properties of $Nd_{0.67}Sr_{0.33}MnO_3$. *Journal of Metastable and Nanocrystalline Materials, 28*, 85-92.

Ahmed, A., Mohamed, H., Diab, A., Mohamed, S. A., García-Granda, S., & Martínez-Blanco, D. (2016). Influence of heat treatment on the magnetic and magnetocaloric properties in $Nd_{0.6}Sr_{0.4}MnO_3$ compound. *Solid State Sciences, 57*, 1-8.

Akimoto, T., Moritomo, Y., Nakamura, A., & Furukawa, N. (2000). Observation of anomalous single-magnon scattering in half-metallic ferromagnets by chemical pressure control. *Physical Review Letters, 85*(18), 3914.

Akimov, G. Y., Novokhatskaya, A., Zhebel', A., & Revenko, Y. F. (2013). Properties of ceramic manganite $(La_{0.65}Sr_{0.35})_{1-x}Mn_{1+x}O_{3\pm\Delta}$ (x = 0, 0.1, 0.2) sintered at a temperature of 1500 °C. *Physics of the Solid State, 55*, 2479-2481.

Al-Hada, N. M., Kamari, H. M., Shaari, A. H., & Saion, E. (2019). Fabrication and characterization of Manganese–Zinc Ferrite nanoparticles produced utilizing heat treatment technique. *Results in Physics, 12*, 1821-1825.

Al-Hada, N. M., Saion, E. B., Shaari, A. H., Kamarudin, M. A., Flaifel, M. H., Ahmad, S. H., & Gene, A. (2014a). A facile thermal-treatment route to synthesize the semiconductor CdO nanoparticles and effect of calcination. *Materials Science in Semiconductor Processing, 26*, 460-466.

Al-Hada, N. M., Saion, E. B., Shaari, A. H., Kamarudin, M. A., Flaifel, M. H., Ahmad, S. H., & Gene, S. A. (2014b). A facile thermal-treatment route to synthesize ZnO nanosheets and effect of calcination temperature. *PLOS ONE, 9*(8), e103134.

Alkaabi, Z. K., & Al-Shakarchi, E. K. (2021). Studying the physical properties of Bi-2223 nanostructure prepared thermal treatment method. *Materials Science Forum, 1039*, 269-273.

Amin, A. M., Soliman, Y. M., El-Dek, S., Ahmed, Y. M., & Zaki, A. (2022). Valorization of industrial iron and zinc sludges for the synthesis of $ZnFe_2O_4$ ceramics. *Journal of Magnetism and Magnetic Materials, 544*, 168681.

Aparicio, M., Jitianu, A., & Klein, L. C. (2012). *Sol-gel processing for conventional and alternative energy*. New York: Springer Science & Business Media.

Arun, B., Suneesh, M. V., & Vasundhara, M. (2016). Comparative study of magnetic ordering and electrical transport in bulk and nano-grained $Nd_{0.67}Sr_{0.33}MnO_3$ manganites. *Journal of Magnetism and Magnetic Materials, 418*, 265-272.

Ayadi, F., Ammar, S., Nowak, S., Cheikhrouhou-Koubaa, W., Regaieg, Y., Koubaa, M., Monnier, J., & Sicard, L. (2018). Importance of the synthesis and sintering methods on the properties of manganite ceramics: The example of $La_{0.7}Ca_{0.3}MnO_3$. *Journal of Alloys and Compounds, 759*, 52-59.

Ayadi, F., Cheikhrouhou-Koubaa, W., Koubaa, M., Nowak, S., Sicard, L., Ammar, S., & Cheikhrouhou, A. (2014). Effect of synthesis method on structural, magnetic and magnetocaloric properties of $La_{0.7}Sr_{0.2}Ag_{0.1}MnO_3$ manganite. *Materials Chemistry and Physics, 145*(1-2), 56-59.

Baaziz, H., Maaloul, N., Tozri, A., Rahmouni, H., Mizouri, S., Khirouni, K., & Dhahri, E. (2015a). Effect of sintering temperature and grain size on the electrical transport properties of $La_{0.67}Sr_{0.33}MnO_3$ manganite. *Chemical Physics Letters, 640*, 77-81.

Baaziz, H., Tozri, A., Dhahri, E., & Hlil, E. (2015b). Effect of particle size reduction on the structural, magnetic properties and the spin excitations in ferromagnetic insulator $La_{0.9}Sr_{0.1}MnO_3$ nanoparticles. *Ceramics International, 41*(2), 2955-2962.

Bafrooei, H. B., Ebadzadeh, T., & Majidian, H. (2014). Microwave synthesis and sintering of forsterite nanopowder produced by high energy ball milling. *Ceramics International, 40*(2), 2869-2876.

Balcells, L., Fontcuberta, J., Martinez, B., & Obradors, X. (1998). Magnetic surface effects and low-temperature magnetoresistance in manganese perovskites. *Journal of Physics: Condensed Matter, 10*(8), 1883.

Banerjee, A., Pal, S., Bhattacharya, S., Chaudhuri, B., & Yang, H. (2002). Particle size and magnetic field dependent resistivity and thermoelectric power of $La_{0.5}Pb_{0.5}MnO_3$ above and below metal–insulator transition. *Journal of Applied Physics, 91*(8), 5125-5134.

Banerjee, A., Pal, S., & Chaudhuri, B. (2001). Nature of small-polaron hopping conduction and the effect of Cr doping on the transport properties of rare-earth manganite $La_{0.5}Pb_{0.5}Mn_{1-x}Cr_xO_3$. *The Journal of Chemical Physics, 115*(3), 1550-1558.

Banik, S., Das, K., Paramanik, T., Lalla, N. P., Satpati, B., Pradhan, K., & Das, I. (2018). Huge magnetoresistance and ultrasharp metamagnetic transition in polycrystalline $Sm_{0.5}Ca_{0.25}Sr_{0.25}MnO_3$. *NPG Asia Materials, 10*(9), 923-930.

Berger, D., Matei, C., Papa, F., Macovei, D., Fruth, V., & Deloume, J. (2007). Pure and doped lanthanum manganites obtained by combustion method. *Journal of the European Ceramic Society, 27*(13-15), 4395-4398.

Bhalodia, J. A., & Mankadia, S. R. (2014). Sintering temperature effect on the structural and electrical transport properties of nanophasic $Nd_{0.7}Sr_{0.3}MnO_3$ manganite. *Solid State Phenomena, 209*, 216-219.

Bhargav, A., Chandel, V., Haque, F. Z., & Sanyal, S. P. (2022). Comparative study on electrical-transport behaviors of Mn-site substituted $Nd_{0.67}Sr_{0.33}Mn_{0.9}TM_{0.1}O_3$ (where TM= Co, Ni) manganites. *Materials Today: Proceedings, 65*, 2871-2874.

Bhattacharya, M., & Basak, T. (2016). A review on the susceptor assisted microwave processing of materials. *Energy, 97*, 306-338.

Blundell, S. (2001). *Magnetism in Condensed Matter*. New York: Oxford University Press.

Bochu, B., Buevoz, J., Chenavas, J., Collomb, A., Joubert, J., & Marezio, M. (1980). Bond lengths in $[CaMn_3](Mn_4)O_{12}$: A new Jahn-Teller distortion of Mn^{3+} octahedra. *Solid State Communications, 36*(2), 133-138.

Boricha, H., Kansara, S., Rajyaguru, B., Solanki, S., Rathod, K., Dhruv, D., Solanki, P., & Shah, N. (2020). Charge conduction mechanisms and MR behaviour of sol–gel-grown nanostructured $La_{0.6}Nd_{0.1}Sr_{0.3}MnO_3$ manganites. *Bulletin of Materials Science, 43*, 1-12.

Breternitz, J., & Schorr, S. (2018). What defines a perovskite? *Advanced Energy Materials, 8*(34), 1802366.

Brey, L. (2007). Electronic phase separation in manganite-insulator interfaces. *Physical Review B, 75*(10), 104423.

Brinker, C. J., & Scherer, G. W. (2013). *Sol-gel science: the physics and chemistry of sol-gel processing*. San Diego: Academic Press.

Bull, C., Gleeson, D., & Knight, K. (2003). Determination of B-site ordering and structural transformations in the mixed transition metal perovskites La_2CoMnO_6 and La_2NiMnO_6. *Journal of Physics: Condensed Matter, 15*(29), 4927.

Burns, R. G. (1993). *Mineralogical applications of crystal field theory*. United States of America: Cambridge University Press.

Burrola Gándara, L. A., Vázquez Zubiate, L., Carrillo Flores, D. M., Elizalde Galindo, J. T., Ornelas, C., & Ramos, M. (2020). Tuning magnetic entropy change and relative cooling power in $La_{0.7}Ca_{0.23}Sr_{0.07}MnO_3$ electrospun nanofibers. *Nanomaterials, 10*(3), 435.

Chahara, K. i., Ohno, T., Kasai, M., & Kozono, Y. (1993). Magnetoresistance in magnetic manganese oxide with intrinsic antiferromagnetic spin structure. *Applied Physics Letters, 63*(14), 1990-1992.

Chand, U., Yadav, K., Gaur, A., & Varma, G. D. (2010). Effect of different synthesis techniques on structural, magnetic and magneto-transport properties of $Pr_{0.7}Sr_{0.3}MnO_3$ manganite. *Journal of Rare Earths, 28*(5), 760-764.

Chang, S. C., Halim, S. A., Navasery, M., Talib, Z. A., Lim, K. P., Chen, S. K., & Kechik, M. M. A. (2014). Structural, electrical and magnetic properties of polycrystalline $La_{0.67}(Ca_{1-x}Sr_x)_{0.33}MnO_3$ manganites. *Journal of Materials Science: Materials in Electronics, 25*, 2843-2849.

Coey, J., Viret, M., von, & Von Molnar, S. (1999). Mixed-valence manganites. *Advances in Physics, 48*(2), 167-293.

da Conceição, L., Ribeiro, N. F., & Souza, M. M. (2011). Synthesis of $La_{1-x}Sr_xMnO_3$ powders by polymerizable complex method: Evaluation of structural, morphological and electrical properties. *Ceramics International, 37*(7), 2229-2236.

da Conceição, L., Silva, C. R., Ribeiro, N. F., & Souza, M. M. (2009). Influence of the synthesis method on the porosity, microstructure and electrical properties of $La_{0.7}Sr_{0.3}MnO_3$ cathode materials. *Materials Characterization, 60*(12), 1417-1423.

Dagotto, E., Hotta, T., & Moreo, A. (2001). Colossal magnetoresistant materials: the key role of phase separation. *Physics Reports, 344*(1-3), 1-153.

Danks, A. E., Hall, S. R., & Schnepp, Z. (2016). The evolution of 'sol–gel'chemistry as a technique for materials synthesis. *Materials Horizons, 3*(2), 91-112.

Das, K., Dasgupta, P., Poddar, A., & Das, I. (2016). Significant enhancement of magnetoresistance with the reduction of particle size in nanometer scale. *Scientific Reports, 6*(1), 20351.

Davaasuren, B., & Tietz, F. (2019). Impact of sintering temperature on phase formation, microstructure, crystallinity and ionic conductivity of $Li_{1.5}Al_{0.5}Ti_{1.5}(PO_4)_3$. *Solid State Ionics, 338*, 144-152.

Dey, P., & Nath, T. (2006). Effect of grain size modulation on the magneto-and electronic-transport properties of $La_{0.7}Ca_{0.3}MnO_3$ nanoparticles: The role of spin-polarized tunneling at the enhanced grain surface. *Physical Review B, 73*(21), 214425.

Dhokiya, V., Vadgama, V., Dadhich, H., Hirpara, B., Goswami, H., Venkateshwarlu, D., Joshi, A., Venkatesh, R., Ganesan, V., & Solanki, P. (2022). Structural, electrical transport and magnetoresistance properties of $La_{0.7}Ca_{0.3}MnO_3$: ZnO nanocomposites. *Materials Chemistry and Physics, 277*, 125430.

Dimesso, L. (2016). Pechini processes: an alternate approach of the sol–gel method, preparation, properties, and applications. *Handbook of Sol-Gel Science and Technology, 2*, 1-22.

Dronskowski, R., Kikkawa, S., & Stein, A. (2017). *Handbook of Solid State Chemistry*. Germany: Wiley-VCH.

Dubourdieu, C., Audier, M., Roussel, H., Senateur, J., & Pierre, J. (2002). Crystallization and related magnetotransport properties of amorphous manganite films grown by metalorganic chemical vapor deposition. *Journal of Applied Physics, 92*(1), 379-384.

Ebata, K., Takizawa, M., Maekawa, K., Fujimori, A., Kuwahara, H., Tomioka, Y., & Tokura, Y. (2008). Chemical potential shift induced by double-exchange and polaronic effects in $Nd_{1-x}Sr_xMnO_3$. *Physical Review B, 77*(9), 094422.

Eckert, M. (2012). Max von Laue and the discovery of X-ray diffraction in 1912. *Annalen der Physik, 524*(5), A83-A85.

Ehsani, M., Kameli, P., & Ghazi, M. (2012). Influence of grain size on the electrical properties of the double-layered $LaSr_2Mn_2O_7$ manganite. *Journal of Physics and Chemistry of Solids, 73*(6), 744-750.

Ehsani, M., Kameli, P., Ghazi, M., Razavi, F., & Taheri, M. (2013). Tunable magnetic and magnetocaloric properties of $La_{0.6}Sr_{0.4}MnO_3$ nanoparticles. *Journal of Applied Physics, 114*(22).

Elghoul, A., Krichene, A., Chniba Boudjada, N., Fettar, F., Gay, F., & Boujelben, W. (2020). Magnetotransport mechanisms and magnetoresistive properties in $La_{0.75}Dy_{0.05}Sr_{0.2}MnO_3$ polycrystalline manganite. *Journal of Materials Science: Materials in Electronics, 31*(9), 7076-7083.

Ezaami, A., Sfifir, I., Cheikhrouhou-Koubaa, W., Koubaa, M., & Cheikhrouhou, A. (2017). Critical properties in $La_{0.7}Ca_{0.2}Sr_{0.1}MnO_3$ manganite: A comparison between sol-gel and solid state process. *Journal of Alloys and Compounds, 693*, 658-666.

Gadani, K., Dhruv, D., Joshi, Z., Boricha, H., Rathod, K., Keshvani, M., Shah, N., & Solanki, P. (2016). Transport properties and electroresistance of a manganite based heterostructure: role of the manganite–manganite interface. *Physical Chemistry Chemical Physics, 18*(26), 17740-17749.

Gadani, K., Keshvani, M., Rajyaguru, B., Dhruv, D., Kataria, B., Joshi, A., Asokan, K., Shah, N., & Solanki, P. (2017). Current–voltage characteristics and electroresistance in $LaMnO_{3-\delta}/La_{0.7}Ca_{0.3}MnO_3/LaAlO_3$ thin film composites. *Physical Chemistry Chemical Physics, 19*(43), 29294-29304.

Gao, H., Ma, C., & Sun, B. (2014). Preparation and characterization of $NiMn_2O_4$ negative temperature coefficient ceramics by solid-state coordination reaction. *Journal of Materials Science: Materials in Electronics, 25*, 3990-3995.

Gaur, A., & Varma, G. D. (2006). Sintering temperature effect on electrical transport and magnetoresistance of nanophasic $La_{0.7}Sr_{0.3}MnO_3$. *Journal of Physics: Condensed Matter, 18*(39), 8837.

Ghaffari, S., Ebadzadeh, T., Alizadeh, M., Asadian, K., Ganjkhanlou, Y., & Shafeeyan, M. S. (2018). The effects of high-energy ball milling on the synthesis, sintering and microwave dielectric properties of Li_2TiO_3 ceramics. *Journal of Materials Science: Materials in Electronics, 29*, 10933-10941.

Ghosh, A., Sahu, A., Gulnar, A., & Suri, A. (2005). Synthesis and characterization of lanthanum strontium manganite. *Scripta Materialia, 52*(12), 1305-1309.

Glas, J.-E. (1960). Studies on the ultrastructure of dental enamel: 1. Size and shape of the apatite crystallites as deduced from X-ray diffraction data. *Journal of Ultrastructure Research, 3*(3), 334-344.

Golay, M. J. (1957). A performance index for gas chromatographic columns. *Nature, 180*(4583), 435-436.

Goodenough, J. B. (1955). Theory of the role of covalence in the perovskite-type manganites [La, M(II)]MnO_3. *Physical Review, 100*(2), 564.

Haemers, J., Gusmão, R., & Sofer, Z. (2020). Synthesis protocols of the most common layered carbide and nitride MAX phases. *Small Methods, 4*(3), 1900780.

Hapishah, A., Azis, R., Hashim, M., Ismayadi, I., Hassan, J., Syazwan, M., & Idza, R. (2017). Influence of temperature on microstructure, structural and ferroelectricity evolution properties with nano and micrometer grain size in multiferroic $HoMnO_3$ ceramics. *Journal of Materials Science: Materials in Electronics, 28*, 16053-16061.

Hassanien, A. S., Akl, A. A., & Sáaedi, A. (2018). Synthesis, crystallography, microstructure, crystal defects, and morphology of $Bi_xZn_{1-x}O$ nanoparticles prepared by sol–gel technique. *CrystEngComm, 20*(12), 1716-1730.

Hcini, S., Hcini, F., Bouazizi, M. L., & Zemni, S. (2020). Correlation between magnetic and electrical properties of $La_{0.7}Ba_{0.15}Ag_{0.15}MnO_3$ manganite prepared by sol gel method. *Applied Physics A, 126*, 1-10.

Hcini, S., Khadhraoui, S., Zemni, S., Triki, A., Rahmouni, H., Boudard, M., & Oumezzine, M. (2013). Percolation model of the temperature dependence of resistivity in $Pr_{0.67}A_{0.33}MnO_3$ (A= Ba or Sr) manganites. *Journal of Superconductivity and Novel Magnetism, 26*, 2181-2185.

Hizi, W., Rahmouni, H., Gorji, N. E., Guesmi, A., Ben Hamadi, N., Khezami, L., Dhahri, E., Khirouni, K., & Gassoumi, M. (2022). Impact of sintering temperature on the electrical properties of $La_{0.9}Sr_{0.1}MnO_3$ manganite. *Catalysts, 12*(3), 340.

Holstein, T. (1959). Studies of polaron motion: Part I. The molecular-crystal model. *Annals of Physics, 8*(3), 325-342.

Holzwarth, U., & Gibson, N. (2011). The Scherrer equation versus the'Debye-Scherrer equation'. *Nature Nanotechnology*, *6*(9), 534-534.

Hong, C. S., Kim, W. S., Chi, E. O., Lee, K. W., & Hur, N. H. (2000). Colossal magnetoresistance in $La_{0.7}Ca_{0.3}MnO_{3-\delta}$: Comparative study of single-crystal and polycrystalline material. *Chemistry of Materials, 12*(11), 3509-3515.

Hübschen, G., Altpeter, I., Tschuncky, R., & Herrmann, H.-G. (2016). *Materials characterization using nondestructive evaluation (NDE) methods*. Cambridge: Woodhead publishing.

Irshad, M., Khalid, M., Rafique, M., Ahmad, N., Siraj, K., Raza, R., Sadiq, M., Ahsan, M., Ghaffar, A., & Ashfaq, A. (2021). Evaluation of $BaCo_{0.4}Fe_{0.4}Zr_{0.2-x}Ni_xO_{3-\delta}$ perovskite cathode using nickel as a sintering aid for IT-SOFC. *RSC Advances, 11*(24), 14475-14483.

Ishizaka, S., & Ishihara, S. (1999). Temperature dependence of the resistivity in the double-exchange model. *Physical Review B, 59*(13), 8375.

Jadhav, L., Pawar, S., & Chourashiya, M. (2007). Effect of sintering temperature on structural and electrical properties of gadolinium doped ceria ($Ce_{0\cdot9}Gd_{0\cdot1}O_{1\cdot95}$). *Bulletin of Materials Science, 30*, 97-100.

Jakob, G., Westerburg, W., Martin, F., & Adrian, H. (1998). Small-polaron transport in $La_{0.67}Ca_{0.33}MnO_3$ thin films. *Physical Review B, 58*(22), 14966.

Jiang, S. P. (2012). Nanoscale and nano-structured electrodes of solid oxide fuel cells by infiltration: advances and challenges. *International Journal of Hydrogen Energy, 37*(1), 449-470.

Jin, S., Gu, X., Yu, X., Guan, X., Li, H., Chu, K., Pu, X., Sun, S., Zhu, Y., & Liu, X. (2021). Improved room-temperature TCR of $La_{0.7}Ag_{0.125}K_{0.175}MnO_3$ films by optimizing sintering temperatures. *Applied Surface Science*, *570*, 151222.

Jin, S., Tiefel, T. H., McCormack, M., Fastnacht, R., Ramesh, R., & Chen, L. (1994). Thousandfold change in resistivity in magnetoresistive La-Ca-Mn-O films. *Science*, *264*(5157), 413-415.

Jithin, P., Bitla, Y., Patidar, M. M., Ganesan, V., Sankaran, K., & Kurian, J. (2023). Structural, magnetic and electrical transport properties of the sol-gel derived $La_{1-x}Ca_xMnO_3$ ($0 \leq x \leq 0.3$) nanoparticles. *Materials Chemistry and Physics, 301*, 127651.

Jonker, G., & Van Santen, J. (1950). Ferromagnetic compounds of manganese with perovskite structure. *Physica, 16*(3), 337-349.

Ju, H., Kwon, C., Li, Q., Greene, R., & Venkatesan, T. (1994). Giant magnetoresistance in $La_{1-x}Sr_xMnO_z$ films near room temperature. *Applied Physics Letters, 65*(16), 2108-2110.

Kannan, R., Vanidha, D., & ArunKumar, A. (2013). High temperature electrical transport properties of nanophasic $Ba_{1-X}Sb_XMnO_3$. *International Journal of Engineering Science and Technology, 5*(6), 1211.

Kansara, S., Dhruv, D., Joshi, Z., Pandya, D., Rayaprol, S., Solanki, P., Kuberkar, D., & Shah, N. (2015a). Structure and microstructure dependent transport and magnetic properties of sol–gel grown nanostructured $La_{0.6}Nd_{0.1}Sr_{0.3}MnO_3$ manganites: role of oxygen. *Applied Surface Science, 356*, 1272-1281.

Kansara, S., Dhruv, D., Kataria, B., Thaker, C., Rayaprol, S., Prajapat, C., Singh, M., Solanki, P., Kuberkar, D., & Shah, N. (2015b). Structural, transport and magnetic properties of monovalent doped $La_{1-x}Na_xMnO_3$ manganites. *Ceramics International, 41*(5), 7162-7173.

Katz, E. A. (2020). Perovskite: name puzzle and German-Russian odyssey of discovery. *Helvetica Chimica Acta, 103*(6), e2000061.

Khan, M. H., & Pal, S. (2015). Magneto-transport characteristics of electron-doped $Ca0_{.85}Sm_{0.15}MnO_3$ manganite: Hopping and tunneling. *Journal of Magnetism and Magnetic Materials, 393*, 110-115.

Khlifa, H. B., Ayadi, F., M'nassri, R., Cheikhrouhou-Koubaa, W., Schmerber, G., & Cheikhrouhou, A. (2017). Screening of the synthesis route on the structural, magnetic and magnetocaloric properties of $La_{0.6}Ca_{0.2}Ba_{0.2}MnO_3$ manganite: A comparison between solid-solid state process and a combination polyol process and Spark Plasma Sintering. *Journal of Alloys and Compounds, 712*, 451-459.

Kilian, R., & Khaliullin, G. (1999). Orbital polarons in the metal-insulator transition of manganites. *Physical Review B, 60*(19), 13458.

Kilpadi, D. V., & Lemons, J. E. (1994). Surface energy characterization of unalloyed titanium implants. *Journal of Biomedical Materials Research, 28*(12), 1419-1425.

Klang, V., Valenta, C., & Matsko, N. B. (2013). Electron microscopy of pharmaceutical systems. *Micron, 44*, 45-74.

Krishna, D., Lakshmi, Y. K., Sreedhar, B., & Reddy, P. V. (2009). Magnetic transport behavior of nanocrystalline $Nd_{0.67}A_{0.33}MnO_3$ (A= Ca, Sr, Pb and Ba). *Solid State Sciences, 11*(8), 1312-1318.

Kubo, K., & Ohata, N. (1972). A quantum theory of double exchange. I. *Journal of the Physical Society of Japan, 33*(1), 21-32.

Kugel, K. I., & Khomskiĭ, D. (1982). The Jahn-Teller effect and magnetism: transition metal compounds. *Soviet Physics Uspekhi, 25*(4), 231.

Kundu, S., & Nath, T. (2010). Size-induced metallic state in nanoparticles of ferromagnetic insulating $Nd_{0.8}Sr_{0.2}MnO_3$. *Journal of Physics: Condensed Matter, 22*(50), 506002.

Kusters, R. M., Singleton, J., Keen, D., McGreevy, R., & Hayes, W. (1989). Magnetoresistance measurements on the magnetic semiconductor $Nd_{0.5}Pb_{0.5}MnO_3$. *Physica B: Condensed Matter, 155*(1-3), 362-365.

Laouyenne, M., Baazaoui, M., Farah, K., Hlil, E., & Oumezzine, M. (2019). A large magnetocaloric effect of $La_{0.8}Na_{0.2}Mn_{0.97}Bi_{0.03}O_3$ manganite synthesized by Pechini Sol-Gel method and compared to the sample synthesized by solid-state route. *Journal of Magnetism and Magnetic Materials, 474*, 393-399.

Lau, L. N., Lim, K. P., Chok, S. Y., Ishak, A. N., Hon, X. T., Wong, Y. J., Awang Kechik, M. M., Chen, S. K., Ibrahim, N. B. y., & Miryala, M. (2021). Effect of NiO nanoparticle addition on the structural, microstructural, magnetic, electrical, and magneto-transport properties of $La_{0.67}Ca_{0.33}MnO_3$ nanocomposites. *Coatings, 11*(7), 835.

Lee, P. J., Saion, E., Al-Hada, N. M., & Soltani, N. (2015). A simple up-scalable thermal treatment method for synthesis of ZnO nanoparticles. *Metals, 5*(4), 2383-2392.

Li, C., Lu, X., Ding, W., Feng, L., Gao, Y., & Guo, Z. (2008). Formability of ABX_3 (X= F, Cl, Br, I) halide perovskites. *Acta Crystallographica Section B: Structural Science, 64*(6), 702-707.

Li, G., Zhou, H.-D., Feng, S., Fan, X.-J., Li, X.-G., & Wang, Z. (2002). Competition between ferromagnetic metallic and paramagnetic insulating phases in manganites. *Journal of Applied Physics, 92*(3), 1406-1410.

Li, L., Liang, L., Wu, H., & Zhu, X. (2016). One-dimensional perovskite manganite oxide nanostructures: recent developments in synthesis, characterization, transport properties, and applications. *Nanoscale Research Letters, 11*, 1-17.

Lim, K., Ng, S., Halim, S., Chen, S., & Wong, J. (2009). Effect of divalent Ions (A= Ca, Ba and Sr) substitution in La-A-Mn-O manganite on structural, magnetic and electrical transport properties. *American Journal of Applied Sciences, 6*(6), 1153.

Lim, K., Ng, S., Lau, L., Kechik, M. A., Chen, S., & Halim, S. (2019). Unusual electrical behaviour in sol–gel-synthesised PKMO nano-sized manganite. *Applied Physics A, 125*, 1-10.

Liu, D., & Liu, W. (2012). Room temperature ultrahigh magnetoresistance nanostructure $(La_{2/3}Sr_{1/3})MnO_3$ films growth on $SrTiO_3$ substrate. *Ceramics International, 38*(3), 2579-2581.

Liu, K., Li, C., Wu, D., & Wang, Y. (2011). Effects of sintering temperature on physical properties of nanocrystalline $La_{0.85}Na_{0.15}MnO_3$ ceramics. *The European Physical Journal-Applied Physics, 56*(3), 30602.

M'nassri, R., Boudjada, N. C., & Cheikhrouhou, A. (2015). Impact of sintering temperature on the magnetic and magnetocaloric properties in $Pr_{0.5}Eu_{0.1}Sr_{0.4}MnO_3$ manganites. *Journal of Alloys and Compounds, 626*, 20-28.

Ma, J., Theingi, M., Chen, Q., Wang, W., Liu, X., & Zhang, H. (2013). Influence of synthesis methods and calcination temperature on electrical properties of $La_{1-x}Ca_xMnO_3$ (x= 0.33 and 0.28) ceramics. *Ceramics International*, *39*(7), 7839-7843.

Mabrouki, W., Krichene, A., Chniba Boudjada, N., & Boujelben, W. (2020a). Sintering temperature effect on the magnetic properties of $Pr_{0.67}Sr_{0.33}MnO_3$ manganite. *Applied Physics A, 126*, 1-12.

Mabrouki, W., Krichene, A., Chniba Boudjada, N., & Boujelben, W. (2020b). Size effects on charge transport mechanisms and magnetotransport properties of $Pr_{0.67}Sr_{0.33}MnO_3$ Nanoparticles. *Journal of Electronic Materials, 49*, 7024-7035.

Makoed, I., Liedienov, N., Pashchenko, A., Levchenko, G., Tatarchuk, D., Didenko, Y., Amirov, A., Rimski, G., & Yanushkevich, K. (2020). Influence of rare-earth doping on the structural and dielectric properties of orthoferrite $La_{0.50}R_{0.50}FeO_3$ ceramics synthesized under high pressure. *Journal of Alloys and Compounds, 842*, 155859.

Markovich, V., Fita, I., Mogilyansky, D., Wisniewski, A., Puzniak, R., Titelman, L., Vradman, L., Herskowitz, M., & Gorodetsky, G. (2007). Magnetic properties of nanocrystalline $La_{1-x}MnO_{3+\delta}$ manganites: size effects. *Journal of Physics: Condensed Matter*, *19*(34), 346210.

Markovich, V., Jung, G., Fita, I., Mogilyansky, D., Wu, X., Wisniewski, A., Puzniak, R., Froumin, N., Titelman, L., & Vradman, L. (2008). Magnetotransport in granular $LaMnO_{3+\delta}$ manganite with nano-sized particles. *Journal of Physics D: Applied Physics*, *41*(18), 185001.

Massoudi, J., Smari, M., Khirouni, K., Dhahri, E., & Bessais, L. (2021). Impact of particle size on the structural and magnetic properties of superparamagnetic Li-ferrite nanoparticles. *Journal of Magnetism and Magnetic Materials, 528*, 167806.

Massoudi, J., Smari, M., Nouri, K., Dhahri, E., Khirouni, K., Bertaina, S., & Bessais, L. (2020). Magnetic and spectroscopic properties of Ni–Zn–Al ferrite spinel: from the nanoscale to microscale. *RSC Advances*, *10*(57), 34556-34580.

Maurin, I., Barboux, P., Lassailly, Y., Boilot, J.-P., & Villain, F. (2000). Charge-carrier localization in the self-doped $La_{1-y}Mn_{1-y}O_3$ system. *Journal of Magnetism and Magnetic Materials*, *211*(1-3), 139-144.

McCall, K. M., Stoumpos, C. C., Kostina, S. S., Kanatzidis, M. G., & Wessels, B. W. (2017). Strong electron–phonon coupling and self-trapped excitons in the defect halide perovskites $A_3M_2I_9$ (A= Cs, Rb; M= Bi, Sb). *Chemistry of Materials, 29*(9), 4129-4145.

Millis, A. J., Littlewood, P. B., & Shraiman, B. I. (1995). Double exchange alone does not explain the resistivity of $La_{1-x}Sr_xMnO_3$. *Physical Review Letters, 74*(25), 5144.

Mnefgui, S., Zaidi, N., Dhahri, N., Dhahri, J., & Hlil, E. (2015). Electrical transport properties and transport–entropy correlations in $La_{0.57}Nd_{0.1}Sr_{0.33}MnO_3$ manganite. *Journal of Magnetism and Magnetic Materials, 384*, 219-223.

Mostafa, A., Abdel-Khalek, E., Daoush, W., & Moustfa, S. (2008). Study of some co-precipitated manganite perovskite samples-doped iron. *Journal of Magnetism and Magnetic Materials, 320*(24), 3356-3360.

Muthuselvam, I. P., & Bhowmik, R. (2012). Grain size dependent magnetization, electrical resistivity and magnetoresistance in mechanically milled $La_{0.67}Sr_{0.33}MnO_3$. *Journal of Alloys and Compounds, 511*(1), 22-30.

Navas, D., Fuentes, S., Castro-Alvarez, A., & Chavez-Angel, E. (2021). Review on sol-gel synthesis of perovskite and oxide nanomaterials. *Gels, 7*(4), 275.

Navin, K., & Kurchania, R. (2018). Structural, magnetic and transport properties of the $La_{0.7}Sr_{0.3}MnO_3$-ZnO nanocomposites. *Journal of Magnetism and Magnetic Materials, 448*, 228-235.

Navin, K., & Kurchania, R. (2021). The effect of shell layer on magnetic, transport, and electrochemical properties of $La_{0.7}Sr_{0.3}MnO_3$ nanoparticles. *Ceramics International, 47*(11), 15859-15867.

Ng, S., Lim, K., Halim, S., & Jumiah, H. (2018). Grain size effect on the electrical and magneto-transport properties of nanosized $Pr_{0.67}Sr_{0.33}MnO_3$. *Results in Physics, 9*, 1192-1200.

Ngida, R. E., Zawrah, M., Khattab, R., & Heikal, E. (2019). Hydrothermal synthesis, sintering and characterization of nano La-manganite perovskite doped with Ca or Sr. *Ceramics International, 45*(4), 4894-4901.

Novokhatska, A., & Akimov, G. Y. (2018). Role of excess manganese in formation of the structure and transport properties of manganite $(Nd_{0.67}Sr_{0.33})_{1-x}Mn_{1+x}O_3$ (x= 0, 0.2) sintered at 1273–1473 K. *Physics of the Solid State, 60*, 1394-1397.

Öpik, U., & Pryce, M. H. L. (1957). Studies of the Jahn-Teller effect. I. A survey of the static problem. *Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences, 238*(1215), 425-447.

Oumezzine, M., Hcini, S., Baazaoui, M., Sales, H. B., dos Santos, I. M. G., & Oumezzine, M. (2013). Crystallite size effect on the structural, microstructure, magnetic and electrical transport properties of $Pr_{0.7}Sr_{0.3}Mn_{0.9}Cr_{0.1}O_3$ nanocrystalline via a modified Pechini method. *Journal of Alloys and Compounds, 571*, 79-84.

Oumezzine, M., Peña, O., Guizouarn, T., Lebullenger, R., & Oumezzine, M. (2012). Impact of the sintering temperature on the structural, magnetic and electrical transport properties of doped $La_{0.67}Ba_{0.33}Mn_{0.9}Cr_{0.1}O_3$ manganite. *Journal of Magnetism and Magnetic Materials, 324*(18), 2821-2828.

Pan, K., Halim, S., Lim, K., Daud, W., Chen, S., & Navasery, M. (2013). Microstructure, electrical and magnetic properties of polycrystalline $La_{0.85}K_{0.15}MnO_3$ manganites prepared by different synthesis routes. *Journal of Materials Science: Materials in Electronics, 24*, 1869-1874.

Panwar, N., Pandya, D., & Agarwal, S. (2007). Magnetotransport, magnetization and thermoelectric power of $Pr_{2/3}Ba_{1/3}MnO_3$: PdO composite manganites. *Journal of Physics D: Applied Physics, 40*(23), 7548.

Pavone, M., Munoz-Garcia, A. B., Ritzmann, A. M., & Carter, E. A. (2014). First-principles study of lanthanum strontium manganite: Insights into electronic structure and oxygen vacancy formation. *The Journal of Physical Chemistry C, 118*(25), 13346-13356.

Phong, P., Dai, N., Manh, D., Khiem, N., & Phuc, N. (2014). Magnetic surface effects and magnetoresistance in manganite-based composite nanoparticles. *Journal of Superconductivity and Novel Magnetism, 27*, 1049-1058.

Phong, P., Khiem, N., Dai, N., Manh, D., Hong, L., & Phuc, N. (2009). Electrical transport of (1− x)$La_{0.7}Ca_{0.3}MnO_{3+x}Al_2O_3$ composites. *Journal of Magnetism and Magnetic Materials, 321*(19), 3330-3334.

Phong, P., Manh, D., Hoan, L., Ngai, T., Phuc, N., & Lee, I.-J. (2016). Particle size effects on $La_{0.7}Ca_{0.3}MnO_3$: Griffiths phase-like behavior and magnetocaloric study. *Journal of Alloys and Compounds, 662*, 557-565.

Raddaoui, Z., El Kossi, S., Brahem, R., Bajahzar, A., Valentinovich Trukhanov, A., Leonidovich Kozlovskiy, A., Vladimirovich Zdorovets, M., Dhahri, J., & Belmabrouk, H. (2021). Hopping conduction mechanism and impedance spectroscopy analyses of $La_{0.70}Sr_{0.25}Na_{0.05}Mn_{0.70}Ti_{0.30}O_3$ ceramic. *Journal of Materials Science: Materials in Electronics, 32*(12), 16113-16125.

Ramirez, A., Cava, R. J., & Krajewski, J. (1997). Colossal magnetoresistance in Cr-based chalcogenide spinels. *Nature, 386*(6621), 156-159.

Rana, D. S., Thaker, C., Mavani, K., Kuberkar, D., Kundaliya, D. C., & Malik, S. (2004). Magnetic and transport properties of $(La_{0.7-2x}Eu_x)(Ca_{0.3}Sr_x)MnO_3$: Effect of simultaneous size disorder and carrier density. *Journal of Applied Physics, 95*(9), 4934-4940.

Raoufi, T., Ehsani, M., & Khoshnoud, D. S. (2016). Magnetocaloric properties of $La_{0.6}Sr_{0.4}MnO_3$ prepared by solid state reaction method. *Journal of Alloys and Compounds, 689*, 865-873.

Razi, Z. J., Sebt, S., & Khajehnezhad, A. (2018). Magnetoresistance temperature dependence of LSMO and LBMO perovskite manganites. *Journal of Theoretical and Applied Physics, 12*(4), 243-248.

Rostamnejadi, A., Salamati, H., Kameli, P., & Ahmadvand, H. (2009). Superparamagnetic behavior of $La_{0.67}Sr_{0.33}MnO_3$ nanoparticles prepared via sol–gel method. *Journal of Magnetism and Magnetic Materials, 321*(19), 3126-3131.

Sagar, S., & Anantharaman, M. (2012). On conduction mechanism in paramagnetic phase of Gd based manganites. *Bulletin of Materials Science, 35*, 41-45.

Sahadevan, J., Sivaprakash, P., Esakki Muthu, S., Kim, I., Padmanathan, N., & Eswaramoorthi, V. (2023). Influence of Te-incorporated $LaCoO_3$ on structural, morphology and magnetic properties for multifunctional device applications. *International Journal of Molecular Sciences, 24*(12), 10107.

Salamon, M. B., & Jaime, M. (2001). The physics of manganites: Structure and transport. *Reviews of Modern Physics, 73*(3), 583.

Saleem, M., & Varshney, D. (2018). Structural, thermal, and transport properties of $La_{0.67}Sr_{0.33}MnO_3$ nanoparticles synthesized via the sol–gel auto-combustion technique. *RSC Advances, 8*(3), 1600-1609.

Saptari, S. A., Tjahjono, A., Winarsih, S., Prasetyo, P., & Kurniawan, B. (2017). Effect of Ni-doping on structure and morphology of $La_{0.7}Ba_{0.3}Mn_{1-x}Ni_xO_3$ compounds by sol-gel method. *International Journal of Basic & Applied Sciences IJBAS-IJENS, 7*(06), 12-16.

Satpathy, S., Popović, Z. S., & Vukajlović, F. R. (1996). Density-functional studies of the electronic structure of the perovskite oxides: $La_{1-x}Ca_xMnO_3$. *Journal of Applied Physics, 79*(8), 4555-4557.

Scherrer, P. (1918). Bestimmung der Grosse und inneren Struktur von Kolloidteilchen mittels Rontgenstrahlen. *Nach Ges Wiss Gottingen, 2*, 8-100.

Schiffer, P., Ramirez, A., Bao, W., & Cheong, S.-W. (1995). Low temperature magnetoresistance and the magnetic phase diagram of $La_{1-x}Ca_xMnO_3$. *Physical Review Letters, 75*(18), 3336.

Schroder, D. K. (2015). *Semiconductor material and device characterization*. Hoboken: John Wiley & Sons.

Seshendra Reddy, C., Ashoka Reddy, C., Sivasankar Reddy, A., & Sreedhara Reddy, P. (2016). Investigations of LBMO thin films deposited on different substrates by electron beam evaporation. *Applied Nanoscience, 6*, 461-466.

Shah, N., Solanki, P., Ravalia, A., & Kuberkar, D. (2015). Size effects in magnetotransport in sol–gel grown nanostructured manganites. *Applied Nanoscience, 5*, 135-141.

Shang, C., Xia, Z., Wang, Y., Zhai, X., Dai, H., & Liu, D. (2023). Percolative transport and metamagnetic transition in phase separated $La_{0.55}Ca_{0.45}Mn_{1-x}Al_xO_{3-\delta}$. *Journal of Alloys and Compounds, 954*, 170076.

Sharma, S., Sharma, H., Kumar, S., Thakur, S., Kotnala, R., & Negi, N. (2020). Analysis of sintering temperature effects on structural, dielectric, ferroelectric, and piezoelectric properties of $BaZr_{0.2}Ti_{0.8}O_3$ ceramics prepared by sol–gel method. *Journal of Materials Science: Materials in Electronics, 31*, 19168-19179.

Shetkar, R., & Salker, A. (2010). Electrical, magnetic and catalytic investigations on some manganite perovskites prepared by combustion method. *Journal of Materials Science & Technology, 26*(12), 1098-1102.

Shimomura, S., Wakabayashi, N., Kuwahara, H., & Tokura, Y. (1999). X-ray diffuse scattering due to polarons in a colossal magnetoresistive manganite. *Physical Review Letters, 83*(21), 4389.

Shu, Q., Zhang, J., Liu, J., & Zhang, M. (2005). Solid-state reaction for preparation of lanthanum manganite. *High Temperature Materials and Processes, 24*(3), 169-174.

Siwach, P., Goutam, U., Srivastava, P., Singh, H., Tiwari, R., & Srivastava, O. (2005). Colossal magnetoresistance study in nanophasic $La_{0.7}Ca_{0.3}MnO_3$ manganite. *Journal of Physics D: Applied Physics, 39*(1), 14.

Siwach, P., Prasad, R., Gaur, A., Singh, H., Varma, G. D., & Srivastava, O. (2007). Microstructure-magnetotransport correlation in $La_{0.7}Ca_{0.3}MnO_3$. *Journal of Alloys and Compounds, 443*(1-2), 26-31.

Siwach, P., Singh, H., & Srivastava, O. (2008). Low field magnetotransport in manganites. *Journal of Physics: Condensed Matter, 20*(27), 273201.

Snyder, G. J., Hiskes, R., DiCarolis, S., Beasley, M., & Geballe, T. (1996). Intrinsic electrical transport and magnetic properties of $La_{0.67}Ca_{0.33}MnO_3$ and $La_{0.67}Sr_{0.33}MnO_3$ MOCVD thin films and bulk material. *Physical Review B, 53*(21), 14434.

Solanki, P., Doshi, R., Ravalia, A., Keshvani, M., Pandya, S., Ganesan, V., Shah, N., & Kuberkar, D. (2015). Transport studies on $La_{0.8-x}Pr_{0.2}Sr_xMnO_3$ manganite films. *Physica B: Condensed Matter, 465*, 71-80.

Sujiono, E. H., Imran, R., Dahlan, M., Said, A., Samnur, S., & Ihsan, N. (2018). *Influence of High Sintering Temperature Variation on Crystal Structure and Morphology of $Nd_{1.2}FeO_3$ Oxide Alloy Material by Solid-State Reaction Method.* Paper presented at the IOP Conference Series: Materials Science and Engineering.

Sun, Y., Xu, X., & Zhang, Y. (2000). Variable-range hopping of small polarons in mixed-valence manganites. *Journal of Physics: Condensed Matter, 12*(50), 10475.

Swain, A., Kumar, P. A., & Gorige, V. (2019). Electrical conduction mechanism for the investigation of charge ordering in $Pr_{0.5}Ca_{0.5}MnO_3$ manganite system. *Journal of Magnetism and Magnetic Materials, 485*, 358-368.

Tada, M., Yamada, J., Srinivasu, V., Sreedevi, V., Kohmoto, H., Hashizume, A., Inamori, Y., Tanaka, T., Harrou, A., & Nogues, J. (2001). $La_{1-x}Ba_xMnO_z$ thin film growth by ion beam sputtering: effects of oxygen partial pressure. *Journal of Crystal Growth, 229*(1-4), 415-418.

Tanaka, H., Zhang, J., & Kawai, T. (2001). Giant electric field modulation of double exchange ferromagnetism at room temperature in the perovskite manganite/titanate *p−n* junction. *Physical Review Letters, 88*(2), 027204.

Tebano, A., Aruta, C., Sanna, S., Medaglia, P., Balestrino, G., Sidorenko, A., De Renzi, R., Ghiringhelli, G., Braicovich, L., & Bisogni, V. (2008). Evidence of orbital reconstruction at interfaces in ultrathin $La_{0.67}Sr_{0.33}MnO_3$ films. *Physical Review Letters, 100*(13), 137401.

Thombare, B., Dusane, P., Kekade, S., Salunkhe, A., Choudhary, R., Phase, D., Devan, R. S., & Patil, S. (2019). Influence of nano-dimensionality on magnetotransport, magnetic and electrical properties of $Nd_{1-x}Sr_xMnO_{3-\delta}$ ($0.3 \leq x \leq 0.7$). *Journal of Alloys and Compounds, 770*, 257-266.

Thongbai, P., Yamwong, T., & Maensiri, S. (2008). The sintering temperature effects on the electrical and dielectric properties of $Li_{0.05}Ti_{0.02}Ni_{0.93}O$ ceramics prepared by a direct thermal decomposition method. *Journal of Applied Physics, 104*(7).

Tokura, Y. (2006). Critical features of colossal magnetoresistive manganites. *Reports on Progress in Physics, 69*(3), 797.

Tokura, Y., & Tomioka, Y. (1999). Colossal magnetoresistive manganites. *Journal of Magnetism and Magnetic Materials, 200*(1-3), 1-23.

Triyono, D., Yunida, Y., & Rafsanjani, R. A. (2021). Effect of heat treatment on structural, magnetic and electrical properties of La_2FeMnO_6. *Materials, 14*(24), 7501.

Venkataiah, G., Krishna, D., Vithal, M., Rao, S., Bhat, S., Prasad, V., Subramanyam, S., & Reddy, P. V. (2005). Effect of sintering temperature on electrical transport properties of $La_{0.67}Ca_{0.33}MnO_3$. *Physica B: Condensed Matter, 357*(3-4), 370-379.

Venkataiah, G., & Reddy, P. V. (2005). Electrical behavior of sol–gel prepared $Nd_{0.67}Sr_{0.33}MnO_3$ manganite system. *Journal of Magnetism and Magnetic Materials, 285*(3), 343-352.

Viret, M., Ranno, L., & Coey, J. D. (1997). Magnetic localization in mixed-valence manganites. *Physical Review B, 55*(13), 8067.

Volger, J. (1954). Further experimental investigations on some ferromagnetic oxidic compounds of manganese with perovskite structure. *Physica, 20*(1-6), 49-66.

von Helmolt, R., Wecker, J., Holzapfel, B., Schultz, L., & Samwer, K. (1993). Giant negative magnetoresistance in perovskitelike $La_{2/3}Ba_{1/3}MnO_x$ ferromagnetic films. *Physical Review Letters, 71*(14), 2331.

Wang, B., Wang, J., Shang, D., Chang, A., & Yao, J. (2020). Sintering temperature and XPS analysis of $Co_{2.77}Mn_{1.71}Fe_{1.10}Zn_{0.42}O_8$ NTC ceramics. *Materials Chemistry and Physics*, *239*, 122098.

Wen, T.-L., Tu, H., Xu, Z., & Yamamoto, O. (1999). A study of $(Pr, Nd, Sm)_{1-x}Sr_xMnO_3$ cathode materials for solid oxide fuel cell. *Solid State Ionics, 121*(1-4), 25-30.

Williams, D. B., & Carter, C. B. (1996). *The transmission electron microscope*. New York: Springer.

Xia, W., Pei, Z., Leng, K., & Zhu, X. (2020). Research progress in rare earth-doped perovskite manganite oxide nanostructures. *Nanoscale Research Letters, 15*, 1-55.

Xia, Z., Yuan, S., Feng, W., Zhang, L., Zhang, G., Tang, J., Liu, L., Liu, D., Zheng, Q., & Chen, L. (2003). Magnetoresistance and transport properties of different impurity doped $La_{0.67}Ca_{0.33}MnO_3$ composite. *Solid State Communications, 127*(8), 567-572.

Xie, Q., Zhou, X., Qi, C., Bai, G., Chen, L., & Cheng, G. (2018). Comparative study of magneto-transport and lattice-vibrational properties of $La_{2/3}Ca_{1/3}MnO_3$ thin films grown on $SrTiO_3$ and $LaAlO_3$ substrates. *International Journal of Modern Physics B, 32*(26), 1850287.

Xiong, G., Li, Q., Ju, H., Bhagat, S., Lofland, S., Greene, R., & Venkatesan, T. (1995). Giant magnetoresistive memory effect in $Nd_{0.7}Sr_{0.3}MnO_z$ films. *Applied Physics Letters, 67*(20), 3031-3033.

Yadav, R., Anshul, A., & Shelke, V. (2011). Wide range magnetoresistance and high temperature coefficient of resistance in $La_{0.7}Sr_{0.3-x}Ag_xMnO_3$ system. *Journal of Materials Science: Materials in Electronics, 22*, 1173-1180.

Yu, X., Li, H., Chu, K., Pu, X., Gu, X., Jin, S., Guan, X., & Liu, X. (2021). A comparative study on high TCR and MR of $La_{0\cdot67}Ca_{0\cdot33}MnO_3$ polycrystalline ceramics prepared by solid-state and sol-gel methods. *Ceramics International*, *47*(10), 13469-13479.

Zener, C. (1951). Interaction between the d-shells in the transition metals. II. Ferromagnetic compounds of manganese with perovskite structure. *Physical Review, 82*(3), 403.

Zhang, N., Ding, W., Zhong, W., Xing, D., & Du, Y. (1997). Tunnel-type giant magnetoresistance in the granular perovskite $La_{0.85}Sr_{0.15}MnO_3$. *Physical Review B, 56*(13), 8138.

Zhang, T., Wang, X., Fang, Q., & Li, X. (2014). Magnetic and charge ordering in nanosized manganites. *Applied Physics Reviews, 1*(3).

Zhao, S., Yue, X., & Liu, X. (2017). Tuning room temperature T_P and MR of $La_{1-y}(Ca_{y-x}Sr_x)MnO_3$ polycrystalline ceramics by Sr doping. *Ceramics International, 43*(5), 4594-4598.

Zhong, X., Yang, B., Zhang, X., Jia, J., & Yi, G. (2012). Effect of calcining temperature and time on the characteristics of Sb-doped SnO_2 nanoparticles synthesized by the sol–gel method. *Particuology, 10*(3), 365-370.