GROWTH AND STRUCTURAL CHARACTERIZATION OF LANTHANUM-STRONTIUM-COBALT THIN FILM SYNTHESIZED BY SOL-GEL DIP COATING FOR SOLID OXIDE FUEL CELL

SHAHIRAH BINTI DERAMAN

UNIVERSITI TEKNOLOGI MALAYSIA

GROWTH AND STRUCTURAL CHARACTERIZATION OF LANTHANUM-STRONTIUM-COBALT THIN FILM SYNTHESIZED BY SOL-GEL DIP COATING FOR SOLID OXIDE FUEL CELL

SHAHIRAH BINTI DERAMAN

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Philosophy

Faculty of Science
Universiti Teknologi Malaysia

JULY 2019

DEDICATION

IN THE NAME OF ALLAH, THE ALMIGHTY

To my lovely father and mother,

Deraman Bin Abdullah and Fatimah Salwah Binti Daud who gave me endless love, trust, constant encouragement over the years, and for their prayers.

To my spouse,

Mohammad Farizuddin Bin Salebi for being very understanding and supportive in keeping me going, enduring the ups and downs during the completion of this thesis.

To my family, for their patience, support, love and prayers

Thank you for all your love and support…

This thesis is dedicated to them.

ACKNOWLEDGEMENT

In the name of Allah, the Almighty who give us the enlightenment, the truth, the knowledge and with regard to Prophet Muhammad S.A.W for His blessings and guidance for giving me the inspiration to do this thesis and done successfully. I thank to Allah for giving me the strength to do this thesis becomes a reality.

First and foremost, I would like to express my deepest thanks to those who had extended their support and advices towards the completion of this final year project. Thankfully, I am giving to my supervisor, Dr. Rosnita Binti Muhammad and my co-supervisors Ass. Prof. Dr. Sib Krishna Ghoshal and Ass. Prof. Dr. Wan Nurulhuda binti Wan Shamsuri for their guide for me to do this thesis, developed and encouraged my interest in the study of thin film. Besides, for their help, guidance, continual support, encouragement and friendship. Their patience and valuable advices will never be forgotten.

To my parents, thank you very much for the advice and supported and all my family members for their support and loving. Forget not, I am especially indebted and grateful to all my members for their support in this project from the beginning until this project successful. Lastly but not least, to my spouse Mohammad Farizuddin bin Salebi who always encouraged me to finish this project.

Sincere thanks to laboratory assistants in giving guidance and much effort during the research. I would also like to express my gratitude to all who have helped in one way or another in finishing this thesis. Thank you.

ABSTRACT

The porosity of a solid oxide fuel cell (SOFC) cathode made of lanthanum-strontium-cobalt (LSC) has not been addressed sufficiently. The LSC thin films were deposited on glass substrates by sol-gel dip coating method with different number of layers of film (1 – 4 layers), different annealing temperatures (400 – 600 ºC) at 100 ºC temperature intervals, and different solution temperatures (30 – 60 ºC) at 10 ºC temperature intervals. The dip coating solution was prepared using 40 ml of ethanol, 1 g LSC powder and 0.07 g polyvinyl alcohol (PVA). The structural properties of SOFC cathode were characterized using X-ray diffraction and Fourier transform infrared spectrophotometer. The morphology of SOFC cathode was determined using atomic force microscope and field emission scanning electron microscope. The elemental compositions of LSC films were confirmed using energy dispersive X-ray spectroscopy. The X-ray diffraction results showed that crystalline temperature of LSC was 500 ºC and crystallite size decreased as annealing temperature increased. From the atomic force microscope and field emission scanning electron microscope analysis, the LSC film became smoother as number of layers and annealing temperature increased. Fourier transformed infrared spectrophotometer results showed presence of metal-oxygen bonds at 447 cm^{-1} and 916 cm^{-1} which correspond to Co-O, Sr-O, La-O bonding at solution temperature 30 ºC. Hence, it can be concluded that annealing and solution temperature plays vital role in producing high quality LSC thin films.

ABSTRAK

Keliangan katod sel fuel oksida pepejal (SOFC) yang diperbuat daripada lanthanum-srontium-kobalt (LSC) belum dapat ditangani dengan secukupnya. Saput tipis LSC telah dienapkan pada substrat kaca dengan kaedah salutan celup sol gel dengan bilangan lapisan saput yang berlainan (1 – 4 lapisan), suhu sepuh lindap yang berlainan (400 – 600 ºC) pada selang suhu 100 ºC dan suhu larutan yang berbeza (30– 60 ºC) pada selang suhu 10 ºC. Larutan salutan celup telah disediakan menggunakan 40 ml etanol, 1 g serbuk LSC dan 0.07 g polivinil alkohol (PVA). Sifat struktur katod SOFC dicirikan dengan menggunakan pembelauan sinar-X dan spektrofotometer inframerah transformasi Fourier. Morfologi katod SOFC ditentukan dengan menggunakan mikroskop daya atom dan mikroskop elektron pengimbasan pancaran medan. Komposisi unsur saput LSC telah disahkan dengan penggunaan spektroskopi sinar-X penyebaran tenaga. Keputusan pembelauan sinar-X menunjukkan bahawa suhu hablur LSC ialah 500 ºC dan saiz hablur menurun apabila suhu sepuh lindap meningkat. Daripada analisis mikroskop daya atom dan mikroskop elektron pengimbasan pancaran medan, saput LSC menjadi lebih licin apabila bilangan lapisan dan suhu sepuh lindap meningkat. Keputusan spektrofotometer inframerah transformasi Fourier menunjukkan kehadiran ikatan logam-oksigen pada 447 cm^{-1} dan 916 cm^{-1} yang mewalili ikatan Co-O, Sr-O, La-O pada suhu larutan 30 ºC. Oleh itu, dapat disimpulkan bahawa suhu sepuh lindap dan suhu larutan memainkan peranan penting dalam menghasilkan saput tipis LSC berkualiti tinggi.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

SOFC	-	Solid Oxide Fuel Cell
IT-SOFC	-	Intermediate Temperature-Solid Oxide Fuel Cell
LSC	-	Lanthanum Strontium Cobalt
AFM	-	Atomic Force microscopy
FTIR	-	Fourier Transform Infrared
XRD	-	X-ray Diffraction
EDX	-	Energy Dispersive X-Ray
FESEM	-	Field Emission Scanning Electron Microscope
PVD	-	Physical Vapour Deposition
CVD	-	Chemical Vapour Deposition
RMS	-	Root Mean Square
RA	-	Average of Roughness
W-H	-	Williamson-Hall

LIST OF SYMBOLS

ε	-	Microstrain
d	-	Spacing between atomic planes
D	-	Mean grain size
λ	-	Wavelength
θ	-	Angle
k	-	Rate constant
Ea	-	Activation Energy
R	-	Gas constant
n	-	Integer
Å	-	Lattice parameter
β_S	-	Strain broadening
β_D	-	Size broadening

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Solid oxide fuel cell (SOFC) is a device that produce power of electrochemical transformation from oxidizing a fuel. For the electrochemically changing, over substance vitality into electrical vitality and warmth without the requirement of direct combustion as a moderate stride, the fuel cell are very suitable gadgets and giving higher transformation efficiencies than routine vitality frameworks (Sun, Hui and Roller, 2009). Fuel cells are also gadget that produces power by a mixture response. The responses that create power occur at the terminals. They are various kinds of fuel cells, two electrodes, one positive and one negative, which are the cathode and anode (Shao, Zhou and Zhu, 2012). Some of the fuel cell has an electrolyte, which conveys electrically charged particles from one anode to the next, and a catalyst, which speeds the responses at the cathodes. Power device described by their electrolyte material, the SOFC has a strong oxide or ceramic electrolyte.

Fuel cells include high efficiency, long-term stability, fuel flexibility, low emissions and relatively low cost. High temperature energy components, for thin film SOFC, work between 600 ℃ and 1000 ℃ and can use hydrogen, regular gas or hydrocarbons. They work at high temperature between to guarantee satisfactory ionic conduction in the electrolyte. Lowering the temperature of a SOFC to 550-800 °C can keep the debasement of the cell parts, diminish the manufacture cost and enhance the adaptability in cell configuration, however would expand the ohmic resistance (Bansal and Zhong, 2006). Therefore, for over 10 years, broad research has been pursued to prepare ceramic oxides with blended ionic and electronic conductivity (perovskite oxides) and to concentrate the plausibility of utilizing them as cathode materials for low temperature solid oxide energy components (Hieu, Park and Tae, 2012).

The Lanthanum Strontium Cobalt (LSC) was used as a material for the film in SOFC. Based on the other oxide material, the mixed ionic-electronic conducting Lanthanum Strontium Cobalt Ferrite (LSCF) or Lanthanum strontium cobaltite (LSC) perovskites are well known class of SOFC cathode film materials. The LSC have been demonstrated as high-performance materials for intermediate temperature SOFC (Han *et al*., 2012). LSC can upgrade oxygen reduction kinetics compared to the conventional other cathode material LSM by providing an additional pathway through the bulk of the perovskite structure (Banel *et al*., 2013). There are many methods for the LSC can be performed such as sputtering, thermal evaporation and pulsed laser deposition (PLD). Previously, many researches focused on synthesizing LSC films via Chemical Vapour Deposition (CVD) method. The chemical technique can be used such as spray pyrolysis, CVD and sol-gel method (Baque *et al*., 2006). Among all of the methods, further studies were used sol-gel method such as dip coating technique to synthesis LSC thin film because dip coating technique process was used wet chemical material which is major method of sol-gel (Bi and Traversa, 2014).

Experimental studies are bringing out at temperatures and oxygen partial pressures of suitable for IT-SOFC (Egger *et al.,* 2012). Besides, LSC have low catalytic compared than other materials for cathode film. The polarization resistance also low and have advantage of its in case to make the single chamber conditions was stable (Rembelski *et al.,* 2012). The one of the rate-determining steps for the oxygen reduction was exchanging the oxygen at the perovskite or air interface. When the thicknesses of the porous layers are expanding, it gives that increasing perovskite area and makes the larger number of sites for oxygen exchange. Therefore, the improvement of the cathode activity can be accomplished by using nonporous thin films with small grain sizes (Evans *et al*., 2015).

Meanwhile, the homogeneous and heterogeneous can be observed in many view of natural and unnatural substances. Local measurement of particle orientation and size distribution would have recognized the nucleation growth in a material system. The development of homogenous and heterogeneous can control by nucleation process and grain growth (Baniassadi *et al.,* 2011). It is clear that by using grain growth, the nucleation can be developed at certain level based on their morphology performance. Based on the random nucleation points, the growth occurs as in crystalline grain growth when the initial microstructure generation basic cells are created. As conclusion, LSC were investigated based of their, chemical stability, polarization resistance and oxygen performance in film and nucleation growth mechanism compare to other material that used for cathode of SOFC.

1.2 Problem Statement

The high efficiencies of SOFC and the usage of high energy density fuels give rise to higher energy power sources. By investigate the growth of nucleation on the films, will help the performance of the films. The cathode of SOFC must be a porous layer where the oxygen reduction reaction (ORR) takes place and transported through the porous layer of cathode as current collector to reach the reaction site. The peak must crystallites for the good structure of cathode and also for the stability of the perovskite structure meanwhile for the morphology, need get a rough surface to develop gas permeability and ionic and electronic conductivities. The crystal structure of cathode materials deviates from the ideal cubic perovskite structure, and was commonly orthorhombic or rhombohedral. Dip coating technique shows some of advantages such can control the chemical composition to get multi-component oxide film under simple innovative equipment, low temperature and also based on Aydemir and Karakaya, 2015, the method will improve cell durability and reduce the system cost.

Working with high temperature will brought many problems as state by Gwon in 2014 where will cause the decreasing the cell life time, interfacial diffusions, sealing problems. To build its aggressiveness and make SOFC innovation financially attainable, bringing down the operation temperature to the intermediate range of around 300-600 °C (Shao, Zhou and Zhu, 2012) (Richter *et al*., 2009). A decrease in temperatures would enable less expensive materials (ferritic hardened steels for interconnect) and enhance reaction to speedy start-up reshowing warm cycling from encompassing to working temperatures (Ding *et al*., 2014).

Besides, reducing the electrolyte thickness, it will give the results ohmic resistance was reducing and different of the cell performance. With that, fabrication of films of these electrolytes can boost the SOFC performance (Bi and Traversa, 2014). According to the Bu in 2013, the grain boundary and grain resistance are mainly affected to the electrolyte conductivity and caused the exchanging of grain size. The influence on the thickness of LSC electrode as a cathode as state by Evans in 2015 also give the different result of LSC thin film. The cathode layer has porous morphology that enhances oxygen diffusion depending on their thickness (Gwon *et al*., 2014). The effectiveness about solution temperature also were gave the attention in this performance. By increasing the solution temperature, the performance of the film such as particle distribution was also effected the performance on the film. Table 1.1 shows the summary of findings from previous researchers.

Table 1.1 Summary of findings from previous researchers

Authors, Year	**Finding/Result**
Benel *et al.,* 2013	Used Pulsed laser deposition. These methods are not cost-effective and not easy to scale up.
Benel *et al.,* 2013	The influence of the thickness of LSC electrodes prepared by spin coating on thin-film SOFC and found that the thickness of LSC functional layer was controlled within the range of 150-500 nm by adjusting the dispersion concentration and spin coating parameters. Below of 150 nm no further improvement of the LSC electrodes was observed.
Evens *et al.,* 2013	LSC thin film cathodes have a larger grain size at 550 °C.
da Côrte *et al.,* 2013	Smooth surface over to a high specific surface area and large number of reaction sites
Muthukrishnan *et al.,* 2016	Crystallinity and the existence of most stable hexagonal wurtzite structure using ZnO thin films by sol-gel dip coating.
Solovyev *et al.,* 2017	At temperature below 600 °C, the deposited films were amorphous and they remained amorphous until annealing at 800 and 1000 °C, the film becomes crystalline. The films also dense at low temperature.

1.3 Objectives

The objectives of the research are:

(a) To evaluate the growth mechanism of studied of Lanthanum Strontium Cobalt thin films.

(b) To characterize the structure and morphology of Lanthanum Strontium Cobalt thin films prepared using dip coating method.

(c) To determine the influence of growth parameters such as different layers (one to four), annealing temperature (300-600 °C) and solution temperature (30-60 °C) on the structure and morphology of proposed Lanthanum Strontium Cobalt thin films.

1.4 Scope of the Study

The preparations of LSC thin film will be conducted by dip coating method. Dip coating method will be used in the deposition of LSC thin film with constant withdrawal speed at 60 rpm for different coating layer onto the glass substrate, different annealing temperature and different temperature of the stirring suspension/solution of LSC. The parameters temperature of annealing and the temperature of suspension was constant for the first parameter, meanwhile the layer of thickness are changing. Second parameter was continued with constant thickness of layer and solution temperature of suspension LSC with different annealing temperature. The annealing temperature that used for second parameter was based on the optimum result from the first parameter.

For the last parameter, the optimum results of layers' thickness and annealing temperature were used to get the entire sample the optimal growth with using the different solution temperature of LSC. The properties of the structural were characterized by using X-ray Diffraction (XRD), Fourier Transform Infrared Spectral (FTIR) and Energy Dispersive X-Ray Spectroscopy (EDX). For morphological characterization were using Field Emission Scanning Electron Microscope (FESEM) and Atomic Force microscopy (AFM). This project is principally experimental.

1.5 Significant of the Study

The most important in dip coating methods was the ability to tune the microstructure of the deposited film. This study will be useful for industries since LSC cathode for SOFC application continue to play important role such as improve long term stability, high power density and high energy conversion efficiency. Furthermore, by the lowering the temperature, will low the cost in SOFC and will produce electrical energy with minimal environment impact. By using this information, it will help industrial to develop a better quality of LSC thin film. Dip coating method was one of the alternative methods that usually use in small scale for laboratory. Dip coating method for fabrication of LSC thin film is simple, non-toxic, non-vacuum system and hence suitable for large area coating. On the other hand, this method more advantageous compared to other deposition methods due to its ability to prepare high quality thin films in large scale with excellent control of stoichiometry, apparatus and raw materials (Ghodsi and Absalan, 2010).

1.6 Outline of Thesis

A general background of study and brief introduction of LSC thin film nanostructure and SOFC were discussed in Chapter 1. Then it was followed by problem statement, objective and scope of study. In Chapter 2, the elaboration of thin film, solid oxide fuel cell, LSC structure, sol-gel technique, perovskite and theory of dip coating method was presented. Chapter 3 is focused on the fabrication method and characterization technique of LSC thin film by dip coating method. The Chapter 4 was present the result and analysis on the structural properties, morphology and growth mechanism of LSC thin film. The conclusion of study was summarizing in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter explains about the hypothesis identified with our exploration, including the definition of SOFC in general, the type of SOFC, the technique using dip-coating method, some basic knowledge of thin film, perovskite and the LSC mechanisms and properties.

2.2 Solid Oxide Fuel Cell

2.2.1 Background

In the 21st century, SOFC known as green energy, because it has very high energy conversion efficiency and very low emissions of air pollution, has high fuel reforming performance (Wen *et al*., 2002) (Cebollero *et al*., 2017). According Zhou *et al*., in 2018 state, SOFC also known as an electricity generation instrument that change over chemical energy directly into electrical energy because of the higher efficiency and less environmental impact than traditional power generation methods. The routine of SOFC work was at high temperature in between of 800-1000 ℃ and the very effective, environment friendly transformation advancements, so the Chang *et al*., in 2017 was assume a key part in future vitality supply and capacity. It can produce power and warmth utilizing flexible fills including hydrogen, methane and light hydrocarbons (Wei *et al.*, 2015). Recently, significant effort has committed to the improvement of Intermediate Temperature SOFC (IT-SOFC) (Takeshita *et al.*, 2014) (Zhan *et al.*, 2015). Operating in middle or low temperature (500-700 ℃) not just diminishes the corruption of fuel cell stack parts and drags out the lifetime of fuel cell systems, it also enlarges materials choice. The poor activity of traditional cathode materials also happened that was discover by Shao and Haile, 2004 and the modest stainless steel materials can be utilized as interconnect at middle or low temperatures based on Vargas *et al*., 2012. Bringing down the temperature causes less requesting on the seals (Lee *et al*., 2002) and the equalization of-plant parts, rearranges thermal management, helps in quicker startup (Samat *et al*., 2016) and chill off, and results in less debasement of cell and stack segments.

The polar resistance (Rp) will loss of voltage or overcapacity when decreasing the SOFC operating temperature. Polarity cathodes contribute to the decline in SOFC performance and it was loss the most common voltages versus ohm polarization and polarization activation. But, these advantages of its more benefits in SOFC which is, activity in the development of SOFC capable of operating in the temperature range of 650-800 ℃ (Narottam, Bansal and Zhong, 2006) (Weber and Ivers-Tiffée, 2004) (Xia and Liu, 2002) had increased dramatically in the last few years. Besides, annealing above 600 ℃ would minimize the cracking of membrane of the sample (Angoua *et al*., 2011) because the limited temperature for the maximum processing temperatures of microscale SOFC was at 600 ℃ and continue with the increasing of the grain growth and the ratio of crystalline of the material. Moreover, the low polarization resistance for maximum of voltage and power output still can be achieved with the stability of the thin film was maintaining (Angoua *et al*., 2011). Figure 2.1 shows other advantages of lowering the temperature of cathode.

The operating temperature of a SOFC was confined by thermally actuated transport process particle and electrochemical responses, for example, the oxide particle conductivity of the strong electrolyte and distinctive reaction step in the electrodes, individually, at the cathode or electrolyte interfaces. The improvement of the cell and stacks for a middle of temperature SOFC working financially in range of 500 ℃ and 700 ℃ were required, while for new materials, the temperatures were below 600 ℃ meanwhile cell ideas, creation advancements and appropriate stack originator must be produced according to Weber and Ivers-Tiffée, 2004.

REFERENCES

Angoua, B. F. (2010). Thin film mixed conducting cathodes for intermediate temperature solid oxide fuel cells (Doctoral dissertation, Purdue University).

Angoua, B. F., Cantwell, P. R., Stach, E. A., and Slamovich, E. B. (2011). Crystallization and electrochemical performance of $La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_{3-\delta}$-$Ce_{0.8}Gd_{0.2}O_{1.9}$ thin film cathodes processed by single solution spray pyrolysis. *Solid State Ionics*, 203(1), 62-68.

An, V., Dronova, M., and Zakharov, A. (2015). Optical and AFM studies on p-sns thin films deposited by magnetron sputtering. *Chalcogenide Letters*, 12(9), 483-487.

Aydemir, S., and Karakaya, S. (2015). Effects of withdrawal speed on the structural and optical properties of sol-gel derived ZnO thin films. *Journal of Magnetism and Magnetic Materials,* 373, 33-39.

Baek, J. D., Yoon, Y. J., Lee, W., and Su, P. C. (2015). A circular membrane for nano thin film micro solid oxide fuel cells with enhanced mechanical stability. *Energy and Environmental Science*, 8(11), 3374-3380.

Baniassadi, M., Garmestani, H., Li, D. S., Ahzi, S., Khaleel, M., and Sun, X. (2011). Three-phase solid oxide fuel cell anode microstructure realization using two-point correlation functions. *Acta materialia,* 59(1), 30-43.

Bansal, N. P., and Zhong, Z. (2006). Combustion synthesis of $Sm_{0.5}Sr_{0.5}CoO_{3-x}$ and $La_{0.6}Sr_{0.4}CoO_{3-x}$ nanopowders for solid oxide fuel cell cathodes. *Journal of Power Sources,* 158(1), 148-153.

Baque, L., Serquis, A., Grunbaum, N., Prado, F. and Caneiro, A. (2006) Preparation and characterization of solid oxide fuel Cells Cathode Films, *Materials Research Society Proceedings, 9*28.

Barattin, R., and Voyer, N. (2008). Chemical modifications of AFM tips for the study of molecular recognition events. *Chemical Communications,* (13), 1513-15.

Benel, C., Darbandi, A. J., Djenadic, R., Evans, A., Tölke, R., Prestat, M., and Hahn, H. (2013). Synthesis and characterization of nanoparticulate $La_{0.6}Sr_{0.4}CoO_{3-\delta}$ cathodes for thin-film solid oxide fuel cells. *Journal of Power Sources*, 229, 258-264.

Bi, L., and Traversa, E. (2014). Synthesis strategies for improving the performance of doped-$BaZrO_3$ materials in solid oxide fuel cell applications. *Journal of Materials Research,* 29(01), 1-15.

Birkholz, M. Thin film analysis by x-ray scattering. Weinheim: *Wiley-Vch Verlag GmbH and Co KGa.* (2006).

Boukamp, B. A., Hildenbrand, N., Bouwmeester, H. J., and Blank, D. H. (2015). Impedance of thin film cathodes: thickness and current collector dependence. *Solid State Ionics,* 283, 81-90.

Brinker, C. J., and Hurd, A. J. (1994). Fundamentals of sol-gel dip coating. *Journal de Physique* III, 4(7), 1231-1242.

Bu, Y. F., Zhong, Q., Tan, W. Y., Zhou, R. J., Song, Y., and Cai, W. (2013). Synthesis and properties of samaria-doped ceria electrolyte via ultrasound-microwave assisted sol-gel method. *Materials Science in Semiconductor Processing,* 16(6), 2058-2062.

Bucher, E., Gspan, C., Höschen, T., Hofer, F., and Sitte, W. (2017). Oxygen exchange kinetics of $La_{0.6}Sr_{0.4}CoO_{3-\delta}$ affected by changes of the surface composition due to chromium and silicon poisoning. *Solid State Ionics,* 299, 26-31.

Bushroa, A. R., Rahbari, R. G., Masjuki, H. H., and Muhamad, M. R. (2012). Approximation of crystallite size and microstrain via XRD line broadening analysis in TiSiN thin films. *Vacuum,* 86(8), 1107-1112.

Cebollero, J. A., Lahoz, R., Laguna-Bercero, M. A., Peña, J. I., Larrea, A., and Orera, V. M. (2017). Characterization of laser-processed thin ceramic membranes for electrolyte-supported solid oxide fuel cells. *International Journal of Hydrogen Energy,* 42(19), 13939-13948.

Cai, Z., Kubicek, M., Fleig, J., and Yildiz, B. (2012). Chemical Heterogeneities on $La_{0.6}Sr_{0.4}CoO_{3-\delta}$ Thin Films. Correlations to Cathode Surface Activity and Stability. *Chemistry of materials*, 24(6), 1116-1127.

Chang, K. C., Ingram, B., Ilavsky, J., Lee, S., Fuoss, P., and You, H. (2017). Synchrotron x-ray studies of model SOFC cathodes, part I: thin film cathodes. *Solid State Ionics,* 311, 118-126.

Chaki, S. H., Deshpande, M. P., and Tailor, J. P. (2014). Characterization of CuS nanocrystalline thin films synthesized by chemical bath deposition and dip coating techniques. *Thin Solid Films,* 550, 291-297.

Charojrochkul, S., Choy, K. L., and Steele, B. C. H. (1999). Cathode/electrolyte systems for solid oxide fuel cells fabricated using flame assisted vapour deposition technique. *Solid State Ionics,* 121(1), 107-113.

Chen, S., Zhao, X., Xie, H., Liu, J., Duan, L., Ba, X., and Zhao, J. (2012). Photoluminescence of undoped and Ce-doped SnO_2 thin films deposited by sol-gel dip coating method. *Applied Surface Science*, 258(7), 3255-3259.

Chen, X., Yu, J., and Adler, S. B. (2005). Thermal and chemical expansion of Sr-doped lanthanum cobalt oxide ($La_{1-x}Sr_xCoO_{3-\delta}$). *Chemistry of Materials*, 17(17), 4537-4546.

Cizauskaite, S., and Kareiva, A. (2008). Sol-gel preparation and characterization of non-substituted and Sr-substituted lanthanum cobaltates. *Central European Journal of Chemistry*, 6(3), 456.

Coquoz, P., Grize, C., Ruiz, J., Bourradou, A., Diethelm, S., Singh, V., and Ihringer, R. (2015). Study of 2R-cell equipped with LSC and LSCF cathodes under thermic and redox cycling. *ECS Transactions,* 68(1), 569-577.

Da Côrte, R. V., da Conceição, L., and Souza, M. M. (2013). Structural and electrical properties of $La_{0.7}Sr_{0.3}Co_{0.5}Fe_{0.5}O_3$ powders synthesized by solid state reaction. *Ceramics International*, 39(7), 7975-7982.

Diao, Y., Shaw, L., Bao, Z., and Mannsfeld, S. C. (2014). Morphology control strategies for solution-processed organic semiconductor thin films. *Energy and Environmental Science,* 7(7), 2145-2159.

Ding, D., Li, X., Lai, S. Y., Gerdes, K., and Liu, M. (2014). Enhancing SOFC cathode performance by surface modification through infiltration. *Energy and Environmental Science,* 7(2), 552-575.

Du, Z. H., Zhang, T. S., Zhu, M. M., and Ma, J. (2009). Growth mode of sol-gel derived PLT seeding layers on glass substrates and its effect on templating the oriented growth of PLZT thin films. *Journal of Applied Physics*, 105(6), 061612.

Egger, A., Bucher, E., Yang, M., and Sitte, W. (2012). Comparison of oxygen exchange kinetics of the IT-SOFC cathode materials $La_{0.5}Sr_{0.5}CoO_{3-\delta}$ and $La_{0.6}Sr_{0.4}CoO_{3-\delta}$. *Solid State Ionics*, 225, 55-60.

Esquivias, L. Progress in sol-gel production. Switzerland: *Trans Tech Publications.* (2009).

Evans, A., Martynczuk, J., Stender, D., Schneider, C. W., Lippert, T., and Prestat, M. (2015). Low-temperature micro-solid oxide fuel cells with partially amorphous $La_{0.6}Sr_{0.4}CoO_{3-\delta}$ Cathodes. *Advanced Energy Materials*, 5(1).

Evans, A., Benel, C., Darbandi, A. J., Hahn, H., Martynczuk, J., Gauckler, L. J., and Prestat, M. (2013). Integration of spin-coated nanoparticulate-based $La_{0.6}Sr_{0.4}CoO_{3-\delta}$ cathodes into micro-solid oxide fuel cell membranes. *Fuel Cells*, 13(3), 441-444.

Floro, J. A., Chason, E., Cammarata, R. C., and Srolovitz, D. J. (2002). Physical origins of intrinsic stresses in volmer-weber thin films. *MRS Bulletin*, 27(1), 19-25.

Fluri, A., Schneider, C. W., and Pergolesi, D. (2018). In situ stress measurements of metal oxide thin films. *In Metal Oxide-Based Thin Film Structures*, 109-132 (1).

Gangopadhayay, S., Inerbaev, T., Masunov, A. E., Altilio, D., and Orlovskaya, N. (2009). Structural characterization combined with the first principles simulations of barium/strontium cobaltite/ferrite as promising material for solid oxide fuel cells cathodes and high-temperature oxygen permeation membranes. *ACS Applied Materials and Interfaces*, 1(7), 1512-1519.

Garbayo, I., Esposito, V., Sanna, S., Morata, A., Pla, D., Fonseca, L., Sabate, N and Tarancón, A. (2014). Porous $La_{0.6}Sr_{0.4}CoO_{3-\delta}$ thin film cathodes for large area micro solid oxide fuel cell power generators. *Journal of Power Sources*, *248*, 1042-1049.

Gayen, R. N., Sarkar, K., Hussain, S., Bhar, R., and Pal, A. (2011). ZnO Films Prepared by Modified Sol Gel Technique. *Indian Journal of Pure and Applied Physics*, 49, 470-477.

Ghodsi, F. E., and Absalan, H. (2010). Comparative study of ZnO thin films prepared by different sol-gel route. *Acta Physica Polonica-Series A General Physics*, 118(4), 659.

Ge, L., Shao, Z., Zhang, K., Ran, R., Diniz da Costa, J. C., and Liu, S. (2009). Evaluation of mixed-conducting lanthanum strontium cobaltite ceramic membrane for oxygen separation. *American Institute of Chemical Engineering Journal*, 55(10), 2603-2613.

Gwon, O., Yoo, S., Shin, J., and Kim, G. (2014). Optimization of $La_{1-x}Sr_xCoO_{3-\delta}$ perovskite cathodes for intermediate temperature solid oxide fuel cells through the analysis of crystal structure and electrical properties. *International Journal of Hydrogen Energy,* 39(35), 20806-20811.

Han, F., Mücke, R., Van Gestel, T., Leonide, A., Menzler, N. H., Buchkremer, H. P., and Stöver, D. (2012). Novel high-performance solid oxide fuel cells with bulk ionic conductance dominated thin-film electrolytes. *Journal of Power Sources*, 218, 157-162.

Hieu, N. T., Park, J., and Tae, B. (2012). Synthesis and characterization of nanofiber-structured $Ba_{0.5}Sr_{0.5}Co_{0.8}Fe_{0.2}O_{3-\delta}$ perovskite oxide used as a cathode material for low-temperature solid oxide fuel cells. *Materials Science and Engineering*: *B*, 177(2), 205-209.

Hossain, S., Abdalla, A. M., Jamain, S. N. B., Zaini, J. H., and Azad, A. K. (2017). A review on proton conducting electrolytes for clean energy and intermediate temperature-solid oxide fuel cells. *Renewable and Sustainable Energy Reviews,* 79, 750-764.

Hwang, H. J., Moon, J. W., Lim, Y. H., Lee, S. H., and Lee, E. A. (2006). Fabrication of a strontium-doped lanthanum chromite (LSC) thin film on SUS430 substrate. *In Key Engineering Materials* 317, 173-176.

Hwang, H., Lee, E., and Lee, S. (2006). Sol-gel derived $(La_{0.8}M_{0.2})$ CrO_3 (M= Ca, Sr) coating layer on stainless-steel substrate for use as a separator in intermediate temperature solid oxide fuel cell. *Journal of Power Sources*, 157, 709-713.

Hayd, J., Dieterle, L., Guntow, U., Gerthsen, D., and Ivers-Tiffée, E. (2011). Nanoscaled $La_{0.6}Sr_{0.4}CoO_{3-\delta}$ as intermediate temperature solid oxide fuel cell cathode: microstructure and electrochemical performance. *Journal of Power Sources*, 196(17), 7263-7270.

Huber, T. M., Navickas, E., Sasaki, K., Yildiz, B., Hutter, H., Tuller, H., and Fleig, J. (2018). Interplay of grain size dependent electronic and ionic conductivity in electrochemical polarization studies on Sr-doped $LaMnO_3$ (LSM) thin film cathodes. *Journal of the Electrochemical Society*, 165(9), 702-709.

Ishihara, T. (2016). Nanomaterials for advanced electrode of low temperature solid oxide fuel cells (SOFCs). *Journal of the Korean Ceramic Society*, 53(5), 469-477.

Irshad, M., Siraj, K., Raza, R., Ali, A., Tiwari, P., Zhu, B., and Usman, A. (2016). A brief description of high temperature solid oxide fuel cell's operation, materials, design, fabrication technologies and performance. *Applied Sciences,* 6(3), 75.

Jiang, S. P., Love, J. G., and Apateanu, L. (2003). Effect of contact between electrode and current collector on the performance of solid oxide fuel cells. *Solid State Ionics,* 160(1), 15-26.

Jiang, S. P. (2008). Development of lanthanum strontium manganite perovskite cathode materials of solid oxide fuel cells: a review. *Journal of Materials Science,* 43(21), 6799-6833.

Jung, H., Bae, K., Jang, D. Y., Lee, Y. H., Cha, S. W., and Shim, J. H. (2014). Evaluation of porous platinum, nickel, and lanthanum strontium cobaltite as electrode materials for low-temperature solid oxide fuel cells. *International Journal of Hydrogen Energy,* 39(31), 17828-17835.

Kaiser, N. (2002). Review of the fundamentals of thin-film growth. *Applied Optics,* 41(16), 3053-3060.

Karageorgakis, N. I., Heel, A., Bieberle-Hütter, A., Rupp, J. L., Graule, T., and Gauckler, L. J. (2010). Flame spray deposition of $La_{0.6}Sr_{0.4}CoO_{3-\delta}$ thin films: microstructural characterization, electrochemical performance and degradation. *Journal of Power Sources*, 195(24), 8152-8161.

Kilner, J. A., and Burriel, M. (2014). Materials for intermediate temperature solid oxide fuel cells. *Annual Review of Materials Research*, 44, 365-393.

Kim, Y. T., and Shikazono, N. (2017). Investigation of $La_{0.6}Sr_{0.4}CoO_{3-\delta}$-$Gd_{0.1}Ce_{0.9}O_{2-\delta}$ composite cathodes with different volume ratios by three dimensional reconstruction. *Solid State Ionics*, *309,* 77-85.

Kishimoto, H., Sakai, N., Horita, T., Yamaji, K., Brito, M. E., and Yokokawa, H. (2008). Interface reaction and cation transport behavior between perovskite oxides of $La_{1-x}Sr_xCoO_3$ and $La_{0.8}Sr_{0.2}FeO_3$. *Solid State Ionics*, 179(27-32), 1338-1342.

Kivi, I., Aruväli, J., Kirsimäe, K., Heinsaar, A., Nurk, G., and Lust, E. (2013). Oxygen Stoichiometry in $La_{0.6}Sr_{0.4}CoO_{3-\delta}$ and $La_{0.6}Sr_{0.4}Co_{0.2}$Fe0.8$O_{3-\delta}$ cathodes under applied potential as a function of temperature and oxygen partial pressure, measured by electrochemical in situ high-temperature XRD method. *Journal of the Electrochemical Society,* 160(9), 1022-1026.

Kivi, I., Aruväli, J., Kirsimäe, K., Heinsaar, A., Nurk, G., and Lust, E. (2013). Changes in LSC and LSCF cathode crystallographic parameters measured by electrochemical in situ high-temperature XRD. *ECS Transactions,* 57(1), 1841-1849.

Kubicek, M., Rupp, G. M., Huber, S., Penn, A., Opitz, A. K., Bernardi, J., and Fleig, J. (2014). Cation diffusion in $La_{0.6}Sr_{0.4}CoO_{3-\delta}$ below 800 °C and its relevance for Sr segregation. *Physical Chemistry Chemical Physics*, 16(6), 2715-2726.

Lassman, A., Verma, A., and Singh, P. (2010). Development of cathodes for low temperature solid oxide fuel cells. *In Meeting Abstracts, The Electrochemical Society,* (11), 719-719.

Lassman, A. M. (2011). Evaluation of cathode materials for low temperature (500-700 °C) solid oxide fuel cells.

Lee, J. H., Moon, H., Lee, H. W., Kim, J., Kim, J. D., and Yoon, K. H. (2002). Quantitative analysis of microstructure and its related electrical property of SOFC anode, Ni-YSZ cermet. *Solid State Ionics*, 148(1), 15-26.

Liu, Y., Chi, B., Pu, J., and Li, J. (2012). Performance degradation of impregnated $La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_{3+Y2}O_3$ stabilized ZrO_2 composite cathodes of intermediate temperature solid oxide fuel cells. *International Journal of Hydrogen Energy,* 37(5), 4388-4393.

Lobo, R. F. M., Pereira-da-Silva, M. A., Raposo, M., Faria, R. M., and Oliveira Jr, O. N. (2002). The morphology of layer-by-layer films of polymer/polyelectrolyte studied by atomic force microscopy. *Nanotechnology,* 14(1), 101.

Long, D., and Lequeux, F. (2001). Heterogeneous dynamics at the glass transition in van der Waals liquids, in the bulk and in thin films. *The European Physical Journal E,* 4(3), 371-387.

Macedo, D. A., Cesário, M. R., Souza, G. L., Cela, B., Paskocimas, C. A., Martinelli, A. E., and Nascimento, R. M. Infrared spectroscopy techniques in the characterization of SOFC functional ceramics. *In Infrared Spectroscopy-Materials Science, Engineering and Technology.* (2012).

Mahato, N., Banerjee, A., Gupta, A., Omar, S., and Balani, K. (2015). Progress in material selection for solid oxide fuel cell technology: a review. *Progress in Materials Science*, 72, 141-337.

Mitra, P. K. (2014). Characterizations of Materials. Delhi: PHI *Learning Private Limited.*

Miyoshi, S., Takeshita, A., Okada, S., and Yamaguchi, S. (2016). Rate determining elementary step of oxygen reduction reaction at (La, Sr)$CoO_{3-\delta}$ based cathode surface. *Solid State Ionics,* 285, 202-208.

Mori, D., Oka, H., Suzuki, Y., Sonoyama, N., Yamada, A., Kanno, R. and Takeda, Y. (2006). Synthesis, structure, and electrochemical properties of epitaxial perovskite $La_{0.8}$ $Sr_{0.2}CoO_3$ film on YSZ substrate. *Solid State Ionics*, 177(5), 535-540.

Muthukrishnan, K., Vanaraja, M., Boomadevi, S., Karn, R. K., Singh, V., Singh, P. K., and Pandiyan, K. (2016). Studies on acetone sensing characteristics of ZnO thin film prepared by sol-gel dip coating. *Journal of Alloys and Compounds,* 673, 138-143.

Narottam, P., Bansal, and Zhong, Z. (2006). Combustion synthesis of $Sm_{0.5}Sr_{0.5}CoO_{3-x}$ and $La_{0.6}Sr_{0.4}CoO_{3-x}$ nanopowders for solid oxide fuel cell cathodes. *Journal of Power Sources*, 158(1) 148-153.

Nesaraj, A. S., Raj, I. A., and Pattabiraman, R. (2007). Synthesis and characterization of $LaCoO_3$ based cathode and its chemical compatibility with CeO_2 based electrolytes for intermediate temperature solid oxide fuel cell (ITSOFC). *Indian journal of chemical technology*, 14, 154-160.

Pambianchi, M. S., Dejneka, M., Gross, T., Ellison, A., Gomez, S., Price, J., and Li, M. J. (2016). Corning incorporated: designing a new future with glass and optics. *In Materials Research for Manufacturing, Springer International Publishing,* 1-38.

Peters, C., Weber, A., and Ivers-Tiffée, E. (2008). Nanoscaled $(La_{0.5}Sr_{0.5})CoO_{3-\delta}$ thin film cathodes for SOFC application at 500 °C< T< 700 °C. *Journal of the Electrochemical Society*, 155(7), 730-737.

Ramadhani, F., Hussain, M. A., Mokhlis, H., and Hajimolana, S. (2017). Optimization strategies for Solid Oxide Fuel Cell (SOFC) application: a literature survey. *Renewable and Sustainable Energy Reviews*, 76, 460-484.

Rembelski, D., Viricelle, J. P., Combemale, L., and Rieu, M. (2012). Characterization and comparison of different cathode materials for SC-SOFC: LSM, BSCF, SSC, and LSCF. *Fuel Cells*, 12(2), 256-264.

Reichelt, K., and Jiang, X. (1990). The preparation of thin films by physical vapour deposition methods. *Thin Solid Films*, 191(1), 91-126.

Richter, J., Holtappels, P., Graule, T., Nakamura, T., and Gauckler, L. J. (2009). Materials design for perovskite SOFC cathodes. *Monatshefte Für Chemie-Chemical Monthly,* 140(9), 985-999.

Robins, J. L. (1988). Thin film nucleation and growth kinetics. *Applied Surface Science*, 33, 379-394.

Rupp, G. M., Schmid, A., Nenning, A., and Fleig, J. (2016). The superior properties of $La_{0.6}Ba_{0.4}CoO_{3-\delta}$ thin film electrodes for oxygen exchange in comparison to $La_{0.6}Sr_{0.4}CoO_{3-\delta}$. *Journal of the Electrochemical Society*, 163(6), 564-573.

Samat, A. A., Somalu, M. R., Muchtar, A., Hassan, O. H., and Osman, N. (2016). LSC cathode prepared by polymeric complexation method for proton-conducting SOFC application. *Journal of Sol-Gel Science and Technology*, 78(2), 382-393.

Samat, A. A., Somalu, M. R., Muchtar, A., & Osman, N. (2016). Preparation of lanthanum strontium cobalt oxide powder by a modified sol-gel method. *Malaysian Journal of Analytical Sciences*, 20(6), 1458-1466.

Sadykov, V. A., Muzykantov, V. S., Yeremeev, N. F., Pelipenko, V. V., Sadovskaya, E. M., Bobin, A. S., and Smirnova, A. L. (2015). Solid oxide fuel cell cathodes: importance of chemical composition and morphology. Catalysis for Sustainable Energy, 2(1), 57-70.

Samavati, A., Ghoshal, S. K., and Othaman, Z. (2012). Growth of Ge/Si (100) nanostructures by radio-frequency magnetron sputtering: the role of annealing temperature. *Chinese Physics Letters,* 29(4), 048101.

Samavati, A., Othaman, Z., Dabagh, S., and Ghoshal, S. K. (2014). Impact of annealing on surface morphology and photoluminescence of self-assembled Ge and Si quantum dots. *Journal of Nanoscience and Nanotechnology*, 14(7), 5266-5271.

Samavati, A., Mustafa, M. K., Othaman, Z., & Ghoshal, S. K. (2015). Ge nanoislands grown by radio frequency magnetron sputtering: comprehensive investigation of surface morphology and optical properties. *Journal of Nanomaterials*, 16(1), 101.

Samson, A. J., Bonanos, N., and Sogaard, M. (2012). Cathodes for Solid Oxide Fuel Cells Operating at Low Temperatures (Doctoral dissertation, Department of Energy Conversion and Storage, Technical University of Denmark).

Saranya, A. M., Pla, D., Morata, A., Cavallaro, A., Canales-Vázquez, J., Kilner, J. A., and Tarancón, A. (2015). Engineering mixed ionic electronic conduction in $La_{0.8}Sr_{0.2}MnO_{3+\delta}$ nanostructures through fast grain boundary oxygen diffusivity. *Advanced Energy Materials*, 5(11), 1500377.

Schrödl, N., Bucher, E., Egger, A., Kreiml, P., Teichert, C., Höschen, T., and Sitte, W. (2015). Long-term stability of the IT-SOFC cathode materials $La_{0.6}Sr_{0.4}CoO_{3-\delta}$ and $La_2NiO_{4+\delta}$ against combined chromium and silicon poisoning. *Solid State Ionics*, 276, 62-71.

Seo, Y., and Jhe, W. (2007). Atomic force microscopy and spectroscopy. *Reports on Progress in Physics,* 71(1), 016101.

Shao, Z., and Haile, S. M. (2004). A high-performance cathode for the next generation of solid oxide fuel cells. *Nature,* 431(7005), 170-173.

Shao, Z., Zhou, W., and Zhu, Z. (2012). Advanced synthesis of materials for intermediate temperature solid oxide fuel cells. *Progress in Materials Science,* 57(4), 804-874.

Shi, D. (2003). Functional Thin Films and Functional Materials. *New Concept and Technology*. China: Springer.

Siebert, E., Boréave, A., Gaillard, F., and Pagnier, T. (2013). Electrochemical and Raman study of $La_{0.7}Sr_{0.3}Co_{0.8}Fe_{0.2}O_{3-\delta}$ reduction. *Solid State Ionics*, 247, 30-40.

Skinner, S. J. (2001). Recent advances in perovskite-type materials for solid oxide fuel cell cathodes. *International Journal of Inorganic Materials*, 3(2), 113-121.

Song, X., Lee, S., Chen, Y., and Gerdes, K. (2015). Electrochemically influenced cation inter-diffusion and Co_3O_4 formation on $La_{0.6}Sr_{0.4}CoO_3$ infiltrated into SOFC cathodes. *Solid State Ionics*, 278, 91-97.

Stassen, I., Styles, M., Grenci, G., Van Gorp, H., Vanderlinden, W., De Feyter, S., and Ameloot, R. (2016). Chemical vapour deposition of zeolitic imidazolate framework thin films. *Nature Materials*, 15(3), 304.

Sun, C., Hui, R., and Roller, J. (2009). Cathode materials for solid oxide fuel cells: a review. *J Solid State Electrochem*, 14(7), 1125-1144.

Takeshita, A., Miyoshi, S., Yamaguchi, S., Kudo, T., and Sato, Y. (2014). High surface reactivity of La/Sr-Co perovskite based cathode with cation nonstoichiometry. *Solid State Ionics*, 262, 378-381.

Tanhaei, M., and Mozammel, M. (2017). Yttria-stabilized zirconia thin film electrolyte deposited by EB-PVD on porous anode support for SOFC applications. *Ceramics International*, 43(3), 3035-3042.

Thandavan, T. M. K., Gani, S. M. A., San Wong, C., and Nor, R. M. (2015). Evaluation of Williamson-Hall strain and stress distribution in ZnO nanowires prepared using aliphatic alcohol. *Journal of Nondestructive Evaluation*, 34(2), 14.

Taroco, H. A., Santos, J. A. F., Domingues, R. Z., and Matencio, T. (2011). Ceramic materials for solid oxide fuel cells. *INTECH Open Access Publisher*. Costas Sikalidis.

Vargas, R. A., Bonturim, E., Andreoli, M., Chiba, R., and Seo, E. S. M. (2012). Characterization of LSCF-based composite and LSCF as cathodes for intermediate temperature SOFC. *In Materials Science Forum, Trans Tech Publications*, 727, 657-662.

Venables, J. A., Spiller, G. D. T., and Hanbucken, M. (1984). *Nucleation and Growth of Thin Films, Reports on Progress in Physics*, 47(4), 399.

Verly, P. G. (2013). Optical thin films and coatings. *Optical Thin Films and Coatings.* Ottawa, Canada. Elsevier

Wang, Y., Leung, D. Y., Xuan, J., and Wang, H. (2017). A review on unitized regenerative fuel cell technologies, part B: unitized regenerative alkaline fuel cell, solid oxide fuel cell, and microfluidic fuel cell. *Renewable and Sustainable Energy Reviews*, 75, 775-795.

Weber, A., and Ivers-Tiffée, E. (2004). Materials and concepts for solid oxide fuel cells (SOFCs) in stationary and mobile applications. *Journal of Power Sources*, 127(1), 273-283.

Wei, B., Chen, K., Wang, C. C., Lü, Z., and Jiang, S. P. (2015). Cr deposition on porous $La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_{3-\delta}$ electrodes of solid oxide cells under open circuit condition. *Solid State Ionics*, 281, 29-37.

Wen, T. L., Wang, D., Chen, M., Tu, H., Lu, Z., Zhang, Z., and Huang, W. (2002). Material research for planar SOFC stack. *Solid State Ionics*, 148(3), 513-519.

Xia, C., & Liu, M. (2002). Novel Cathodes for Low-Temperature Solid Oxide Fuel Cells. *Advanced Materials*, 14(7), 521-523.

Yang, J., Huang, Y., and Xu, K. (2007). Effect of substrate on surface morphology evolution of Cu thin films deposited by magnetron sputtering. *Surface and Coatings Technology*, 201(9), 5574-5577.

Yu, Y. (2016). Surface segregation in strontium doped lanthanum cobalt ferrite: effect of composition, strain and atmospheric carbon dioxide (Doctoral dissertation), Boston University.

Zak, A. K., Majid, W. A., Abrishami, M. E., and Yousefi, R. (2011). X-ray analysis of ZnO nanoparticles by Williamson-Hall and size-strain plot methods. *Solid State Sciences*, 13(1), 251-256.

Zhan, W., Zhou, Y., Chen, T., Miao, G., Ye, X., Li, J., and Deng, Z. (2015). Long-term stability of infiltrated $La_{0.8}Sr_{0.2}CoO_{3-\delta}$, $La_{0.58}Sr_{0.4}Co_{0.2}Fe_{0.8}O_{3-\delta}$ and $SmBa_{0.5}Sr_{0.5}Co_{2.0}O_{5+\delta}$ cathodes for low temperature solid oxide fuel cells. *International Journal of Hydrogen Energy*, 40(46), 16532-16539.

Zhou, Q., Bieler, T. R., and Nicholas, J. D. (2018). Transient porous nickel interlayers for improved silver-based Solid Oxide Fuel Cell brazes. *Acta Materialia*, 148, 156-162.

Zuo, C., Liu, M., and Liu, M. (2012). Solid Oxide Fuel Cells. In: Aparicio M., Jitianu A., Klein L. (eds) Sol-Gel Processing for Conventional and Alternative Energy. Advances in Sol-Gel Derived Materials and Technologies. Springer, Boston, MA

LIST OF PUBLICATIONS

1) Shahirah Deraman, R. Muhammad & W. N. W. Syamsuri, AFM & XRD Analysis of Lanthanum Strontium Cobalt Thin Film Fabricated Using Sol Gel Dip Coating Method,3rd International Conf on the Application of Science & Mathematics (SCIEMATHIC2017), UTHM Pagoh, 24-25 Oct 2017.