STRUCTURAL, LUMINESCENCE AND ELECTRICAL CONDUCTIVITY OF STRONTIUM TITANATE THIN FILMS PREPARED BY DIP COATING METHOD

SALEHA BINTI MAAROF

A thesis submitted in fulfillment of the
requirements for the award of the degree of
Master of Science (Physics)

Faculty of Science
University Teknologi Malaysia

JUNE 2014

Dedicated to

my beloved husband, parents, family, and friends.

ACKNOWLEDGEMENT

First and foremost, I would like to acknowledge my supervisor, Associate Professor Dr. Karim Deraman for his guidances during this study. I would like to thank our research group colleagues, Associate Professor Dr. Rosli Husin, Associate Dr. Mohd Nor Yusof, Dr. Wan Nurulhuda and others research group student for their assistance and relationship.

I am also thankful to the Department of Physics, Faculty of Science, Universiti Teknologi Malaysia, Johor, the financial support from Ministry of Higher Education (MOHE) under the vote 4F005 for funding the project.

ABSTRACT

Strontium titanate ($SrTiO_3$) sol-gel was deposited onto glass substrates by dip coating method. The effects of deposition parameters such as different annealing temperatures and number of coating layers were studied. Strontium nitrate anhydrous ($Sr(NO_3)_2$), titanium isopropoxide ($C_{12}H_{28}O_4Ti$), ethylene glycol ($HOCH_2CH_2OH$) and nitric acid (HNO_3) were used to prepare sol-gel of strontium titanate. Ethylene glycol was added to promote polymerization between $C_{12}H_{28}O_4Ti$ and $Sr(NO_3)_2$. The samples structure were characterized by X-ray diffraction (XRD), atomic force microscopy (AFM), Fourier transform infra red (FT-IR) and photoluminescence (PL) spectroscopy. XRD analysis showed the process of the intermediate crystalline phase of $Sr(NO_3)_2$ with lattice parameter a = b = c = 0.78 nm for as-prepared sample. An amorphous inorganic phase was found for samples annealed at 300 and 400 °C. The samples began to change to $SrTiO_3$ phase after being annealed at 500 °C with lattice parameter a = b = c = 0.39 nm and peak orientation at planes (110), (111), (200) and (211). Thin films with double coating layers showed clearer peaks orientation. The microstructure study using AFM revealed the grain size in the range 220 – 460 nm and surface roughness in the range 33 – 69 nm at 500 ºC for different number of coating layers. FT-IR analysis shows that $SrTiO_3$ crystallization phase was completely formed at higher temperatures of 500, 600 and 700 ºC. PL spectroscopy of $SrTiO_3$ thin films appeared to have spectra emission in the region of 310 - 510 nm wavelength. The spectra also showed the different peaks appearing at different annealed temperatures. Van der Pauw technique was used to measure the electrical conductivity and activation energy for single and four coating layers samples at 500 ºC annealing temperature. The results showed that the electrical conductivity for single layer was higher than the four coating layers. Activation energy in high temperature region were in the range of 0.656 meV and 0.446 meV whereas activation energy in low temperature region were in the range of 0.162 meV and 0.105 meV for single and four coating layers samples, respectively.

ABSTRAK

Sol-gel strontium titanat ($SrTiO_3$) telah dimendapkan ke atas substrat kaca dengan menggunakan kaedah salutan celupan. Kesan parameter pemendapan seperti perbezaan suhu penyepuhlindapan dan bilangan salutan lapisan telah dikaji. Anhitrat strontium nitrat ($Sr(NO_3)_2$,) titanium isoproposida ($C_{12}H_{28}O_4Ti$), etilena glikol ($HOCH_2CH_2OH$) dan asid nitrik (HNO_3) telah digunakan untuk menghasilkan sol-gel strontium titanat. Etilena glikol telah ditambah untuk menggalakkan pempolimeran diantara $C_{12}H_{28}O_4Ti$ dan $Sr(NO_3)_2$. Struktur sampel telah dicirikan dengan menggunakan pembelauan X-ray (XRD), mikroskopi daya atom (AFM), transformasi Fourier infra merah (FT-IR) dan spektroskopi fotopendarcahaya (PL). Analisis XRD telah menunjukkan proses fasa pertengahan kristal bagi $Sr(NO_3)_2$ dengan parameter kekisi a = b = c = 0.78 nm untuk sampel pra-persediaan. Fasa bukan organik amorfus telah diperolehi bagi sampel sepuhlindapan pada 300 and 400 °C. Sampel mula berubah kepada fasa $SrTiO_3$ selepas sepuhlindapan pada 500 ºC dengan parameter kekisi a = b = c = 0.39 nm dan orentasi puncak pada satah (110), (111), (200) dan (211). Saput tipis dengan dwi lapisan salutan menunjukkan puncak-puncak orentasi yang paling jelas. Kajian mikrostruktur melalui AFM menunjukkan saiz butiran pada julat 220 – 460 nm dan permukaan kasar pada julat 33 – 69 nm pada suhu 500 ºC untuk bilangan lapisan salutan yang berbeza-beza. Analisis FT-IR menunjukkan fasa kristal $SrTiO_3$ telah terhasil secara menyeluruh pada suhu lebih tinggi 500, 600 and 700 ºC. Spektroskopi PL untuk saput tipis $SrTiO_3$ menunjukkan pancaran spektra pada panjang gelombang dalam lingkungan 310 – 510 nm. Spektra yang dihasilkan juga menunjukkan kemunculan puncak yang berbeza pada suhu sepuhlindapan yang berbeza. Teknik Van der Pauw telah digunakan untuk mengukur konduktiviti elektrik dan tenaga aktif untuk sampel satu dan empat lapisan salutan pada suhu penyepuhlindapan 500 ºC. Keputusan menunjukkan konduktiviti pada sampel satu lapisan adalah lebih tinggi berbanding sampel empat lapisan. Tenaga aktif pada julat suhu tinggi berada dalam lingkungan 0.656 meV dan 0.446 meV manakala tenaga aktif pada julat suhu rendah berada dalam lingkungan 0.162 meV dan 0.105 meV masing-masing untuk sampel satu dan empat lapisan salutan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

FT-IR	-	Fourier Transform Infrared Spectroscopy
XRD	-	X-ray Diffraction
AFM	-	Atomic Force Microscopy
PL	-	Photoluminescence
VDP	-	Van der Pauw
$SrTiO_3$	-	Strontium Titanate
$Sr(NO_3)_2$	-	Strontium Nitrate
$OHCH_2CH_2OH$	-	Ethylene Glycol
$C_{12}H_{28}O_4Ti$	-	Titanium Isopropoxide
JCPDS	-	Joint Center Power Diffraction Standard card
σ	-	Electrical Conductivity
σ_o	-	Pre-exponential of Electrical Conductivity
E_a	-	Activation Energy
k	-	Boltzmann constant
d	-	Spacing between the planes in the atomic lattice
d_{hkl}	-	Interplanar spacing for planes with Miler indicates (hkl)
λ	-	Wavelength
θ	-	Angle between the incident ray and the scattering planes
v	-	Frequency (Hz)
k	-	Force constant of the bond (Nm^{-1})
μ	-	Reduce mass (kg)
m_1	-	Relative atomic mass of M_1 x u
m_2	-	Relative atomic mass of M_2 x u
u	-	atomic mass unit = 1.66 x 10^{-27} kg
h	-	Plank's constant
c	-	Speed of light

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Phenomenon of thin film can be describe when a layer of oxide appeared on a material. Thus, scientist used thin as a term to explain about a very thin layer appeared on a material that can be characterize and applied in technology development. This phenomenon has been discovered by Faraday last 1838 using an electrolysis process, followed by Bunsen & Grove on 1852 using chemical reaction, in 1857 Faraday have discovered thermal evaporation process and further studied have been carried out intensively after world war two (Samsudi Sakrani, 2002).

Thin film is a layer of solid material such as metal, semiconductor or insulator deposited on a substrate with appropriate thickness in range from 10-1000 nm (Suriani, 2005). For layer greater than 1000 nm, it will be grouped as a thick film or film. It will be known as ultra film for layer thinner than 100 nm. In thin films study, variable of thickness shown different characterization result. A substrate is use as a medium to deposit thin film. To produce a good quality and interact with film in hygiene surface. The main applications in thin film development are in electronic devices and optical coatings.

Generally thin film can be prepared either in chemical (Desai *et al*., 2006) or physical method (Dantus *et al.*, 2011). Examples of chemical method are dip coating and spray pyrolysis techniques. Other examples of physical method are sputtering and vacuum evaporation techniques. There are various methods of preparing nanostructure thin films such as sol-gel process (known as dip coating method and spin coating method), metal organic decomposition (MOD), liquid phase deposition (LPD), spray pyrolysis and thermal evaporator under vacuum. A lot of researchers are competing in producing thin films with a simple technique, large surface area, inexpensive and non-pollution for industrial user. Dip coating with sol-gel process have been widely used to prepared thin films and ceramic powder. This type of method has an capability to control the stoichiometric literally at the molecular level.

ABO_3 family is known as cations elements for A and B and anion element for O or oxygen. Recently a lot of ABO_3 family for examples barium titanate, barium strontium titanate and strontium titanate have been attracted due to their ferroelectric and electro-optic properties (Soledade *et al*., 2002 and Goa *et al*., 2002). Strontium titanate is a paraelectric material with cubic perovskite structure (Zanetti *et al*., 1997 and Benthem *et al.*, 2001). Theoretically, strontium titanate material is known to has properties such as high dielectric constant, good thermal stability, second order phase transformation and stress induce phase transition photo-activity (Kim *et al*., 2007). These advantages makes strontium titanate as the best material and widely used for application in memory cell capacitors for non-volatile memories or dynamic random access application (DRAM), microelectronic, solar and sensor technology in recent years usually in bulk material or thin films technology development (Brankovic *et al*., 2004).

1.2 Problem Statement

Nowadays, strontium titanate has attracted many researchers because of its wide application and favorable performance in industry. With this purpose, numerous of work have been done in different environment and condition to develop a good quality of strontium titanate thin films with a simple step, low cost and environmental friendly.

In recent years, works on sol-gel preparation with dip coating technique to deposit strontium titanate thin films have been actively considered. Even though there are several report on strontium titanate thin films, there is no clear-cut understanding on the relation between numbers of coating layer thin films and annealing temperatures with several characterization. Thus, this experiment will be done by various deposition parameters such as number of coating layer on corning glass substrate and at different annealed temperatures. By changing the parameters in strontium titanate thin films, one can expect to obtain new characterization result and may give better understanding on structural and electrical conductivity. Thus, the change in behavior of these films can be used in specific applications and development.

1.3 Research Objectives

Research objective of this study are:

i. To prepare strontium titanate thin films by using sol-gel dip coating method at different numbers of coating layer and annealed temperatures.
ii. To characterize the structural behavior of strontium titanate thin films in coating layer and at annealing temperatures by using X-ray diffraction

(XRD) analysis, atomic force microscopy (AFM), Fourier Transformation Infrared Spectroscopy (FT-IR) and photoluminescence spectrometer (PL).

iii. To investigate the electrical conductivity of coating layer thin films by using van der Pauw (VDP) technique.

1.4 Scope of Studies

The structural and chemical bonding of strontium titanate was characterized by using x-ray diffraction (XRD) analysis while infrared spectroscopy (FT-IR) was used to confirm the existence of strontium titanate crystallization. Atomic force microscopy (AFM) was used to characterize the morphology of the films. Meanwhile, emission and electrical conductivity behavior of the films were investigated by using photoluminescence spectroscopy (PL) and Van der Pauw (VDP), respectively.

This thesis has covered five chapter. Chapter 1 includes background, problem statement, objective and scope of studies. Chapter 2 discussed about literature review regarding the physical properties of strontium titanate, thin films methodology in previous work and properties of strontium titanate thin films. This covers theory of sample characterization of strontium titanate thin films, on the structural and electrical conductivity properties. The methodology and instrumentation in chapter 3 covered all the experimental and characterizations process. Next, chapter 4 discussed the results of experimental conducted in the research. Lastly, chapter 5 summarizes the studies and some suggestion are presented for future works.

REFERENCES

Baba, S., Numata, K., and Miyake, S. (2000). Characteristics of Post-annealed $SrTiO_3$ Thin Films Prepared by Mirror-confinement-type ECR Plasma Sputtering. *Science and Technology of Advanced Materials*. 1, 211-217.

Bae, D. S., Kim, E. J., Park, S. W. and Han, K. S. (2006). Fabrication and Microstructure of the Composite Membranes by Sol-Gel Process. *Journal Metal*. 41, 6162-6164.

Benthem, K., Elsasser, C., and French, R. H. (2001). Bulk Electronic Structure of $SrTiO_3$: Experiment and Theory. *Journal of Applied Physics*. 90(12), 6156-6164.

Brankovic, G., Brankovic, Z., Varela, J. A., and Longo, E. (2004). Strontium Titanate Films Prepared by Spray Pyrolysis. *Journal of the European Ceramic Society*. 24, 989-991.

Brankovic, G., Brankovic, Z., Goes, M. S., Santos, C. O. P., Cilense, M., Varela, J. A., and Longo, E. (2005). Barium Strontium Titanate Powders Prepared by Spray Pyrolysis. *Materials Science and Engineering*. B122, 140-144.

Cai, Q. J., Gan, Y., Park, M. B. C., Yang, H. B., Lu, Z. S., Li, C. M., Guo, J., and Dong, Z. L. (2009). Solution- Processable Barium Titanate and Strontium Titanate Nanoparticles Dielectric for Low-Voltage Organic Thin-Film transistors. *Chemistry Materials Article*. 21, 3135-3161.

Cheng, Z. Y., Wang, H. F., Quan, Z. W., Lin, C. K., Lin, J., and Han, Y. C. (2005). Layered Organic-Inorganic Perovskite-Type Hybrid Materials Fabrication by Spray Pyrolysis Route. *Journal of Crystal Growth*. 285, 352-357.

Dantus, C., Rusu, R. S., and Rusu, G. I. (2011). On the Mechanism of Electronic transport in Polycrystalline CdO Thin Films. *Superlattices and Microstructures*. 50, 303-310.

Deraman, K., Sakrani, S., Ismail, B.B., Wahab, Y., and Gould, R. D. (1994). Electrical Conductivity Measurements in Evaporated Tin Sulphide Thin Films. *Journal Electronics*. 76(5), 917-922.

Desai, J. D., Min, S. K., Jung, K. D., and Joo, O. S. (2006). Spray Pyrolysis Synthesis of Large Area NiO_x Thin Films from Aqueous Nickel Acetate Solution. *Applied Surface Science*. 253, 1781-1786.

Djermouni, M., Zaoui, A., Kacimi, S., and Bouhafs, B. (2010). Vacancy defects in Strontium Titanate: Ab Initio Calculation. *Computational Materials Science.* 49, 904-909.

Gao, Y., Masuda, Y., Yonezawa, T., and Koumoto, K. (2002). Site-Selective Deposition and Micropatterning of $SrTiO_3$ Thin Film on Self-Assembled Monolayers by tge Liquid Phase Deposition Method. *Chemistry Materials*. 14, (12), 5006-5014.

Gao, Y., Masuda, Y., Yonezawa, T., and Koumoto, K. (2003). Preparation of $SrTiO_3$ Thin Films by the Liquid Phase Deposition Method. *Materials Science & Engineering*. B99, 290-293.

Han, J., Wan, F., Zhu, Z., and Zhang, W. (2007). Dielectric Response of Soft

Mode in Ferroelectric $SrTiO_3$ .Applide Physics Latters. 90: 1-3.

Hod, I., Shalom, M., Tachan, Z., Ruhle, S., and Zaban, A. (2010). $SrTiO_3$ Recombination-Inhibiting Barrier Layer for Type II Dye-Sensitized Solar Cells. *Journal Physics Chemistry*, 114, 10015-10018.

Hyun, S., and Char, K. (2001). Effect of Strain on the Dielectric Properties of Tunable Dielectric SrTiO3 Thin Films. *Applied Physics Letters.* 79(2), 254 – 256.

Iwatsuki, S., Kera, M., Nakashima, K., Fujii, I., Takei, T., Kumada, N., and Wada, S. (2011). Preparation of Strontium Titanate Nanocubes Using Titanium Alkoxide and Their Accumulations by Capillary Force. *Materials Sciences and Engineering*. 18, 1-4.

Josef, G., and Hans, Meixner. (1990). Electrical Conductivity of Sputtered Films of Strontium Titanate. *Journal Applied Physics*. 67(12) 7453 – 7459.

Kamalasanan, M. N., Kumar, N. D., and Chandra, S. (1996). Fourier Transform-Infrared and Optical Studies on Sol-Gel Synthesized $SrTiO_3$ Precursor Films. *Journal of materials Science*. 31, 2741-2745.

Kang, Y. C., Seo, D. J., Park, S. B., and Park., H. D. (2002). Direct Synthesis of Strontium Titanate Phosphor Particles with High Luminescence by Flame Spray Pyrolysis. *Materials Research Bulletin*. 37, 263-269.

Kao, C. F., and Yang, W. D. (1999). Preparation of Barium Strontium Titanate Powder from Citrate Precursors. *Applied Organometallic Chemistry.* 13, (383-397)

Kim, K. H., Park, J. K., Kim, C. H., Park, H. D., Chang, H., and Choi, S. Y. (2002). Synthesis of $SrTiO_3$:Pr, Al by Ultrasonic Spray Pyrolysis. *Ceramic*

International. 28, 29-36.

Kim, K. J., Kim, J. H., Park, M. S., Kwon, H. K., Kim, H., and Kim, Y. J. (2012). Enhancement of electrochemical and Thermal Properties of Polycrystalene Separators Coated with Polyvinylidene Fluoride-Hexafluoropropylene Co-Polymer for Li-Ion Batteries. *Journal of Power Sources*. 198, 298-302.

Kim, K. J., Suzuki, M., Yoshikawa, A., Fukuda, T., Auh, K. H., and Shin, K. C. (2007). Films Synthesis of $SrTiO_3$ by the Spray-ICP Technique. *Journal of Alloys and Compounds*. 440, 216-219.

Kirk, K. J, Elgoyhen, J., Hood, J. P., and Hutson, D. (2011). Use of Mass Loading to Operate a Thin Film Ultrasonic Transducer in the 300 kHz-10 MHz Frequency Range. *Journal Electroceram*. 27, 29-32.

Krzysztof, S., Jan, L., Cieslinski., and Kamil, L. (2012). Van der Pauw Method on a Sample with an Isolated Hole. *Physics Letters A*.

Leite, E. R., Mastlaro, V. R., Zanetti, S. M., and Longo, E. (1999) Crystallization Study of $SrTiO_3$ Thin Films Prepared by Dip Coating. *Materials Research*. 2(2), 93-97.

Longo, V. M., Figueiredo. A. T., Lazaro. S., Gulgel. M. F., Costa. M. G. S., Paiva-Santos. C. O., and Franco. R. W. A. (2008) Structural Condition That Leads to Photoluminescence Emission in : An Experimental and Theoretical Approach. *Journal of Applied Physics*. 104, 023515.

Mar, M. N., Ratner, B. D., and Yee, S. S. (1999). An Intrinsically Protein-Resistant Surface Plasmon Resonance Biosensor Based Upon a RF-Plasma-Deposited Thin Film. *Sensor and Actuators B Chemical*. 54, 125-131.

Marques, M., Teles, L. K., Anjos, V., Scolfaro, L. M. R., Leite, J. R., Freire, V. N., Farias, G. A., and Silva, E. F. (2003). Full-Relativitic Calculation of the $SrTiO_3$ Carrier Effective Masses and Complex Dielectric Function. *Applied Physics Letters*. 82(18), 3074-3076.

Mironov, V. L., (2004). *Fundamentals of Scanning Probe Mictoscopy.* The Russian Academy Sciences Institute of Physics of Microstructures.

Moos, R., and Hardtl, K. H. (1997). Defect Chemistry of Donor-Doped and Undoped Strontium Titanate Ceramics Between 1000° and 1400 °C . *Journal of the American Ceramic Society*. 80(10), 2549-2562.

Ohly, C., Eifert, S. H., Guo, X., Schubert, J., and Waser, R. (2006). Electrical Conductivity of Epitaxial $SrTiO_3$ Thin Films as a Function of Oxygen Partial Pressure and Temperature. *Journal of the American Ceramic Society*. 89(9), 2845-2852.

Paik, K. W., Hyun, J. G., Lee, S., and Jang, K. W. (2006). Epoxy/$BaTiO_3$ ($SrTiO_3$) Composite Films and Pastes for High Dielectric Constant and Low Tolerance Embedded Capacitors in Organic Substrates. *Electronic System integration Technology Conference*. Dresden, Germany: IEEE, 794 - 801.

Patidar, D., Rathore, K. S., Saxena, N. S., and Sharma, T. P. (2008). Energy Band Gap and Conductivity Measurement of CdSe.Thin Films. *Chalcogenide Letters*. 5(2), 21-25.

Pontes, F. M., Lee, E. J. H., Leite, E. R., and Longo E. (2000) High Dielectric Constant of $SrTiO_3$ Thin Films Prepared by Chemical Process. *Journal of Materials Science*. 38, 4783-4787.

Pontes, F. M., Leite, E. R., Lee, E. J. H., Longo, E., and Varela, J. A. (2001). Preparation Microstructural and Electrical Characterization of $SrTiO_3$ thin

Films Prepared by Chemical Route. *Journal of the European Ceramic Society*. 21, 419-426.

Pookmanee, P., and Phanicphant, S. (2009). Titanium Dioxide Powder Prepared by a Sol-Gel Method. *Journal of Ceramic Processing Research*. 10(2), 167-170.

Raut, N. C., Mathews, T., Chandramohan, P., Srinivasan, M. P., Dash, S., and Tyagi, A. K. (2011). Effect of Temperature on the Growth of TiO_2 Thin Films Synthesized by Spray Pyrolysis: Structural Compositional and Optical Properties. *Materials Research Bulletin*. 46, 2057-2063.

Ren, Y., Zhao, G., and Chen, Y. (2011). Fabrication of Textured SnO_2 : F Thin Films by Spray Pyrolysis. *Applied Surface Science*. 258, 914-918.

Rho, J., Jang, S., Ko, Y. D., Kang, S., Kim, D., Chung, J. S., Kim, M., Han, M., and Choi, E. (2009). Photoluminescence Induce bt Thermal Annealing in $SrTiO_3$ Thin Film. *Applied Physics Letters*. 95, 241906.

Romero, R., Martin, F., Ramos-Barrado, J. R., and Leinen, D. (2010). Synthesis and Characterization of Nanostructured Nickel Oxide Thin Films Prepared with Chemical Spray Pyrolysis. *Thin Solid Films*. 518, 4499-4502.

Samsudi Sakrani. (2002). *Kuliah: Teknologi Saput Tipis.* Universiti Teknologi Malaysia, Skudai, Johor.

Sansonetti, J. E., and Martin W. C., (2011). *Gaithersburg Patent No. MD 20899*. Retrieved on 16 August, 2013, from http://www.nist.gov.

Schmidt, S., Lu, J., Keane, S. P., Bregante, L. D., Klenov, D. O., and Stemmer, S. (2005). Microstructure and Dielectric Properties of Texture $SrTiO_3$ Thin Films. *Journal of the American Ceramic Society*. 88(4), 789-801.

Soledade, L. E. B., Lomgo, E., Leite, E. R., Pontes, F. M., Lanciotti, Jr., Campos, C. E. M., Pizani, P. S., and Varela, J. A. (2002). Room-temperature photoluminescence in amorphous $SrTiO_3$ – the influence of acceptor-type dopants. *Applied Physics Materials Science & Processing*. 75, 629 – 632.

Sur, S., Ozturk, Z., Oztas, M., Bedir, M., and Ozdemir, Y. (2011). Studies on Structural and Electrical Properties of MnO Films Prepared by the Spray Pyrolysis Method. *Physica Scripta*. 84, 1-4.

Suriani, A.B. (2005). *The Structural And Optical Properties of Hydrogenerated Amorphous Carbon (a-C:H), Thin Films Deposited Using A DC-PECVD Technique.* Degree of Master of Science (Physics). Universiti Teknologi Malaysia.

Sravani Gullapalli and Andrew R. Barron (2010). Physical Methods in Chemistry and Nano Science. *Creative Commons Attribution License (cc-By3.0)*. 0500.

Swanson, H., and Fuyat. Nalt. Bur. (1954). Stand. (U.S), Circ. 539 (3), 44.

Tumarkin, A. V., Gaidukov, M. M., Gagarin, A. G., Samoilova, T. B. and Kozyrev, A. B. (2012). Ferroelectric Strontium Titanate Thin Films for Microwave Applications. *Taylor and Francis*. 439, 49-55.

Wang, J., Yao, X., and Zhang, L. (2004). Preparation and Dielectric Properties of Barium Strontium Titanate Glass-Ceramics Sintered from Sol-Gel Derived Powers. *Ceramic International*. 30, 1749-1752.

Xu, C. Huang, J., Tan, X., Yu, T., Cui, Z., and Zhao, Lin. (2010). Preparation, Characteristics, and Photochatalytic Tests of Fe-Doped TiO 2 Films Prepared by a Sol-Gel Drain Coating via Homemade Devices. *Journal of*

Dispersion Science and Technology. 31, 1732-1739.

Xie, J., Ji, T., Xihui, O. Y., Xiao, Z., and Shi, H. (2008). Preparation of $SrTiO_3$ nanomaterial from Layered Titanate Nanotubes or Nanowires. *Solid State Communication.* 147, 226-229.

Yan, H., and Okuzaki, H. (2011). $SrTiO_3$ Insulator for Low-voltage Organic Field-effect Transistors. *Synthetic Metals*. 161, 1781-1786.

Zanetti, S. M., Longo, E., Varela, J. A., and Leite, E. R. (1997). Microstructure and Phase Evolution of $SrTiO_3$ Thin Films on Si Prepared by the use of Polymeric Precursor. *Materials Letters*. 31, 173-178.

Zanetti, S. M., Leite, E. R., Longo, E., and Varela, J. A. (1999). Crack Developed During $SrTiO_3$ Thin-Film Preparation from Polymeric Precursors. *Applied Organometallic Chemistry*. 13, 373-382.

Zanetti, S. M., Leite, E. R., Longo. E., and Varela. J. A. (1999). $SrBi_2Nb_2O_9$ Thin Films Deposited by Dip Coating Using Aqueous Solution. *Journal of the European Ceramic Society*. 19, 1409-1412.

Zhou, Y. X., Bhuiyan, S., Scruggs, S., Fang, H., Mironova, M., and Salama, K. (2003). Strontium titanate Buffer Layers Deposited on Rolled Ni Substrates with metal organic Deposited. *Superconductor Science and Technology*. 16, 901-906.

Zhou, X. Y., Miao, J. Y., Dai, Chan, H. L. W., Choy, C. L., Wang, Y., and Li, Q. (2007). Epitaxial Growth of $SrTiO_3$ Thin Film on Si by Laser Molecular Beam Epitaxy. *Applied Physics Letters*. 90, 012902.