10th Eco-Energy and Materials Science and Engineering Symposium


On December 5-8, 2012
Sunee grand hotel,
Ubon-ratchathani

Organized by

Co-organized by
PREFACE:
Message from the President of
Rajamangala University of Technology Thanyaburi

Rajamangala University of Technology Thanyaburi (RMUTT), in conjunction with Kyoto University, is pleased to host the 10th Eco-Energy and Materials Science and Engineering Symposium (10th EMSES). This international conference is not only giving an opportunity for Thai and foreign researchers to present and discuss their research works and update their expertise but also to initially stimulate the development of research works on eco-energy and materials science and engineering. Our program consists of six research tasks: (1) Energy Technology, (2) Environmental and Social Impact, (3) Nanotechnology and Materials Science, (4) Energy Economics and Management, (5) New Energy technology and (6) Nuclear Technology.

I would like to take this opportunity to express our sincere gratitude to our two distinguished Plenary Speakers for kindly accepting our invitation. I deeply appreciate of the very strong support given by Kyoto University. Thanks to the tireless works of the Organizing Committee, the Technical Program Committee, the invited speakers and paper and poster contributors, and excellent program been assembled to cover a broad spectrum of interesting topic.

We warmly welcome you to the 10th EMSES on December 5-8, 2012, Ubon Ratchathani, Thailand.

Numyoot SONGTHANAPITAK, Ph.D.
President of Rajamangala University of Technology Thanyaburi
and Conference Chairman of 10th EMSES 2012
PREFACE:
Message from the Director of
Institute of Advanced Energy, Kyoto University

It is my great pleasure to have the 10th Eco-Energy and Materials Science and Engineering Symposium (EMSES) with Rajamangala University of Technology Thanyaburi (RMUTT) under the long-term collaboration between RMUTT and Kyoto University. The 1st EMSES was held in 2001 in Thailand and the symposium has been expanded in its scientific contents as well as the academic network. I believe that the 10th EMSES gives a good opportunity to all participants to exchange their knowledge and idea to realize eco-friendly energy system in society. I would like to express my welcome to all participants and sincere thanks to the 10th EMSES organizing committee and all supporting organizations to make us having this symposium. I hope that the symposium will be successful and lead to further progress in energy science and technology and also in friendships of participants.

Professor Yukio Ogata, Ph.D.
Director of Institute of Advanced Energy, Kyoto University
PREFACE:
Message from the Former Dean of
Graduate School of Energy Science, Kyoto University
Program Leader,
Global COE “Energy Science in the Age of Global Warming”

I want to express my hearty welcome to all participants of Eco-Energy and Materials Science and Engineering Symposium (10th EMSES). This symposium is aiming the realization of importance of energy and materials technology through the academic, science and technology network among the world communities. The symposium gives an opportunity for researchers to discuss their research works and also to initially stimulate the development of research works on eco-energy and materials science and engineering. Once the cooperation among researchers has been created, the further cooperation work will be developed.

I would like also extend my sincere thanks to all who made the meeting possible, including the 10th EMSES organizers, the SEE forum committee members, and the Japanese Government, JSPS, for their kind support. I am looking forward to seeing you in Ubon Ratchathani, Thailand.

Professor Takeshi YAO, Ph.D.
Former Dean of Graduate School of Energy Science, Kyoto University
and Program Leader, Global COE “Energy Science in the Age of Global Warming”
Message from the Chairperson of 10th EMSES Organizing Committee

Rajamangala University of Technology Thanyaburi (RMUTT), in conjunction with Kyoto University, is pleased to host the 10th Eco-Energy and Materials Science and Engineering Symposium (10thEMSES).

RMUTT has a major mission on encouraging and supporting all areas of research. One of the key reasons is to assist in developing capability in science and technology in order to cope with recent rapid change in this field. We have jointly set up an academic symposium on the 10thEMSES with the perception on the significance of exchanging knowledge and research experiences between researcher in the field of energy, materials technology and environmental science. This symposium is not only giving an opportunity for Thai and foreign researcher to present and discussion their research works and update their expertise but also to initially stimulate the development of research works on eco-energy and materials science and engineering. Once the cooperation among researchers has been created, the closer future cooperation incorporate with joint-research works will be developed. Thus, to support the aforesaid role, the symposium working committee would like to invite you to participate in this academic symposium.

I would like to express our sincere thanks to the organizing committee, participants and contributors for your kind corporation to this symposium. I wish this symposium proceeding will be a useful reference for future scientific research development.

Sommai PIVSA-ART, Ph.D.
Dean of Faculty of Engineering, RMUTT
Director of CoE on Sustainable Energy System (Thai-Japan)
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30°C : 33.3%RH
40
### Conference Program of 10th Eco-Energy and Materials Science and Engineering

#### 5th December 2012

<table>
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<tr>
<th>Time</th>
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#### 6th December 2012

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<td>09:45-10:45 am</td>
<td>Keynote Speaker I: Japan Power Generation Mix and Energy Security after Fukushima Nuclear Accident, presented by Professor Dr. Keiichi N. Ishihara, Graduate School of Energy Science, Kobe University, Japan</td>
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<td>10:45-11:00 am</td>
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<td>11:00-12:00 am</td>
<td>Keynote Speaker II: Vertical Motions in Greater Bangkok Area after the 2004 Sumatra-Andaman Earthquake from GPS Observations and Its Prediction based on the Geophysical Modelling, presented by Professor Dr. Chalermmhon Saritrapop, Chulalongkorn University, Thailand</td>
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<td>Prof. Dr. Padungsak Ratthanacho</td>
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<td>Asst. Prof. Dr. Warunee Aniyawatwyanan</td>
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<td>Asst. Prof. Dr. Jakree Sritonchart</td>
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#### Poster Session

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<td>Dr. Sorapong Pavasupree and Dr. Sumonman Niamlang</td>
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## Conference Program of 10th Eco-Energy and Materials Science and Engineering

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<td>Prof. Dr. Takeshi Yao</td>
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<td>Dr. Leong Yew Wei</td>
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<td>Assoc. Prof. Dr. Kawee Srikulkit</td>
<td>Prof. Dr. Jun Li</td>
<td>Prof. Dr. Hiroyuki Hamada</td>
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<td>Asst. Prof. Dr. Boonrit Prasartkeaw</td>
<td>Assoc. Prof. Dr. Yuji Aso</td>
<td>Dr. Sarocha Charoenvai</td>
<td>Dr. Narongchai O-Charoen</td>
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<td>Nano&amp;Materials Technology 5</td>
<td>Environmental &amp; Social Impact 1</td>
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<td>Prof. Dr. Chul-Su Kim</td>
<td>Prof. Dr. Yuichi Anada</td>
<td>Prof. Dr. Keiji N. Ishihara</td>
<td>Assoc. Prof. Dr. Natha Kuptashien</td>
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<tr>
<td>Co-Chair</td>
<td>Dr. Winai Chanpeng</td>
<td>Assist. Prof. Dr. Kazushi Yamada</td>
<td>Asst. Prof. Dr. Sommai Pivsa-art</td>
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<td>03:15-04:00 pm</td>
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Structural Characteristics and Dielectric Properties of La$_{1-x}$Co$_x$FeO$_3$ and LaFe$_{1-x}$Co$_x$O$_3$ Synthesized via Metal Organic Complexes

Wankassama Haron$^1$, Thanmanoon Thaweecha$^1$, Worawat Wattanathan$^1$, Apirat Laobuthee$^3$, Hathalkarn Manaspiya$^3$, Chatchai Veranitsa$^4$ and Nattamon Koosnaeng$^*$

$^1$Department of Chemistry, Faculty of Science, Kasetsart University, Chatuchak, Bangkok, Thailand 10900
$^2$Department of Materials Engineering, Faculty of Engineering, Kasetsart University, Chatuchak, Bangkok, Thailand 10900
$^3$The Petroleum and Petrochemical College, Chulalongkorn University, Phayathai, Bangkok, Thailand 10330
$^4$Department of Material and Metallurgical Engineering, Faculty of Engineering, Rajamangala University of Technology Thanyaburi, Klong 6, Thanyaburi, Pathumthani 12110
E-mail: fscinmk@ku.ac.th*

Abstract—La$_{1-x}$Co$_x$FeO$_3$ and LaFe$_{1-x}$Co$_x$O$_3$ perovskite-type oxides with 0.1 ≤ x ≤ 0.3 are prepared by thermal decomposition of the metal organic complexes, using triethanolamine (N(CH$_2$CH$_2$OH)$_3$) as ligand and La(NO$_3$)$_3$6H$_2$O and Fe(NO$_3$)$_3$9H$_2$O as starting materials. CoCl$_2$6H$_2$O is used as the dopant. The obtained products calcined at 850°C for 2 h were characterized by XRD, FTIR, BET and SEM and their dielectric properties were investigated. It was found that all the as-prepared samples crystallized in orthorhombic structure of LaFeO$_3$ perovskite and exhibit conducting behavior. It suggests that the substituted Co(II) and oxygen deficiency play an important role in the ionic conductivity of these materials.

Keywords—Co(II)-doped LaFeO$_3$, dielectric property, LaFe$_{1-x}$Co$_x$O$_3$, metal-organic complexes

1. INTRODUCTION

Recently, substitution effects of various impurity ions into the A and B sites of perovskite oxide with chemical formula ABO$_3$ are scientifically attractive. Particularly, LaFeO$_3$-based oxides have been received much attention since they have potential as candidate materials for various applications in advanced technologies, such as, cathode materials in solid oxide fuel cells [1-3], catalysts [4], chemical sensors [5-8] and magnetic materials [9] etc. The preparation of LaFeO$_3$ and the related compounds have been achieved by many processes, including solid-solid reaction, co-precipitation, sol-gel, decomposition of cyanide and citrate methods [10-14].

In this work, La$_{1-x}$Co$_x$FeO$_3$ and LaFe$_{1-x}$Co$_x$O$_3$ with 0.1 ≤ x ≤ 0.3 are prepared by thermal decomposition of the metal organic complexes and the effects of partially metal ions doped to replace La(III) and Fe(III) at the A and B site of LaFeO$_3$ structure were characterized. Because dielectric properties of this type of compounds have rarely been studied so far [15], their dielectric properties are measured as a function of frequencies, at the ambient temperature. Dielectric constant and dielectric loss as the influence of Co(II) concentrations substituted at A or B site of LaFeO$_3$ based perovskite are also investigated.

2. EXPERIMENTAL

2.1. Materials

Lanthanum(III) nitrate hexahydrate (La(NO$_3$)$_3$6H$_2$O) was purchased from Fisher Scientific.

Iron(III) nitrate nonahydrate (Fe(NO$_3$)$_3$9H$_2$O), Cobalt(II) chloride (CoCl$_2$6H$_2$O), Triethanolamine (TEA, N(CH$_2$CH$_2$OH)$_3$) and Ethylene glycol (EG, HOCH$_2$CH$_2$OH) were purchased from Ajax Finechem. All reagents were used as received.

2.2. Methods

The synthesis process of LaFeO$_3$ and Co(II)-doped LaFeO$_3$ from the metal-organic complexes is illustrated in Figure 1.

![Fig. 1. Flowchart for Synthesis of LaFeO$_3$ and Co(II)-doped LaFeO$_3$ via Metal-Organic Complexes](image)

The precursor, metal-organic complexes of LaFeO$_3$ (LFO) was prepared by the chemical reaction of La(NO$_3$)$_3$6H$_2$O, Fe(NO$_3$)$_3$9H$_2$O and TEA with the 1 : 1 : 3 mole ratio of La(III) : Fe(III) : TEA in ethylene glycol (EG) solvent. The reaction mixture was distilled at 190°C for 6 h with continuous stirring. Distillation was carried
out until nearly the 2/3 of EG had been evaporated. The complex was separated by filtration, washed twice with ethanol and dried at 80 °C. The as-prepared metal-organic complex was characterized by TGA (761 Connecticut 06859 Perkin Elmer, heating rate of 10°C/min over 50°C to 1000°C temperature range).

Similarly, to obtain the Co(II) doped precursors of La₅₋ₓCoₓFe₀₅₋ₓO₇ (LFCO) and Feₓ₋₉La₉CoₓO₉ (LFCO) with x = 0.1, 0.2 and 0.3, the stoichiometric molar quantities of Co(II) : La(III) and Co(II) : Fe(III) as the ratio of 0.1 : 0.9, 0.2 : 0.8 and 0.3 : 0.7 were added.

All metal-organic complex precursors were converted to ceramic powder by calcination under static air at 850°C for 2 h. The powder products were characterized by XRD, using CuKα radiation (Rigaku Miniflex X-ray powder diffractometer, operated at 40 kV and scan rate was 2° min⁻¹ with step of 0.02°). FTIR spectra were obtained by a Perkin-Elmer 2000-FTIR. KBr was mixed with a solid sample by an agate mortar and pestle to prepare a pellet specimen for identifying the samples. The specific surface areas of powders were measured by Brunauer-Emmett-Teller (BET) nitrogen gas absorption method. The powder microstructures were identified by scanning electron microscope (SEM, 1450VP LEO).

The dried samples were ground, sieved at 45 microns and uniaxially pressed (~ 30 Mpa) into pellet with 13 mm diameter, 1.5 mm thickness and subsequently isostatically pressed (CIP) at ~200 MPa. The dense pellets were prepared by stepwise sintering in air, at 700°C, 2 h, and at 1100°C, 2 h and naturally cooled in the furnace. The Archimedes was used to determined bulk density and X-ray diffraction analysis was carried out on the polished sintered ceramic pellet samples. Gold electrodes were painted on both faces of the pellets using gold paste and then fired at 800°C for 2 h. The dielectric constants (κ) and dielectric loss factors (tan δ) of these pressed pellets were measured at room temperature between 1-1000 kHz using LCR meter (4194A, Hewlett Packard).

3. RESULTS AND DISCUSSION

3.1. Characterization of Metal-Organic Complex Precursors

Figure 2 comparatively shows the FTIR spectra of a free ligand, TEA and metal-organic complex precursor for preparing LaFeO₃ (LFO) ceramic. The broad band located at around 3382 cm⁻¹ was assigned for the stretching of O-H groups which is due to the moisture absorption and/or the TEA residue from the reaction. In Figure 2(a), the very weak band around 2950-2870 cm⁻¹ correlated with the absorption of C-H stretching vibration for CH₂ group and the peaks in the region of 1477-1325 cm⁻¹ were assigned to the C-H bending. The band at 1640 cm⁻¹ was attributed to O-H overtone. The small peaks at about 935 and 1074 cm⁻¹ were ascribed to the C-O and C-N stretching, respectively. FTIR spectrum of metal-TEA complex (Figure 2(b)) exhibited a significant peaks shifted from that of free TEA ligand. The strong bands at about 2882 cm⁻¹ and a new peak at 1152 appeared. In addition, the small absorption peak at 518 cm⁻¹ is assigned to M-O or M-N stretching of metal coordinated with TEA ligand. Consequently, observation of the C-O and C-N

stretching of coordinating ligand slightly shifted to lower frequencies, denoting the formation of metal-organic complex. FTIR spectra of the Co(II)-doped perovskite oxide precursors are similar to that of undoped LFO precursor.

Unfortunately, an attempt to recrystallize metal-organic complex precursors failed because of their high stability and undissolved in any solvent such as methanol, ethanol, acetone, hexane, acetonitrile, dichloromethane, ethyl acetate or chloroform. Thus, further characterizations and their structures could not be carried out.

To obtained ceramic powders, the prepared complexes were calcined to remove the organic contents. The calcination temperature and weight loss phenomena of complexes were determined by TGA. Figure 3 shows the TGA thermogram of undoped LFO precursor. There are three regions of weight loss. The first weight loss occurring below 200°C resulted from water evaporation and organic solvent decomposition. The second weight loss ranging from 200°C up to 500°C corresponded to oxidation of the organic contents, generating volatiles and char. Finally, the slight weight loss was found from 500°C to 700°C and it was ascribed to the burning of carbon-residue. Above 700°C, no weight loss was observed, showing that the appropriate temperature for calcining and converting the complexes to ceramic powders is started at 700°C.

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**Fig.2. FTIR Spectra of (a) Free Ligand, TEA and (b) Metal-organic Complexes**

**Fig.3. TGA Thermogram of Metal-organic Complex Precursor**
Based on TGA result, all complexes were calcined at 850°C for 2 h to ensure that all of organic contents were completely removed.

3.2. Characterization of Ceramic Powders

Figure 4 (A) and (B) shows XRD patterns of the as-prepared ceramic powders calcined at 850°C for 2 h, namely, LaFeO₃ (LFO), La₀.₅Co₀.₅FeO₃ (LCFO-1), La₀.₅Co₀.₅FeO₃ (LCFO-2), La₀.₅Co₀.₅FeO₃ (LCFO-3), LaFeO₃Co₀.₅O₃ (LFCO-1), LaFeO₃Co₀.₅O₃ (LFCO-2) and LaFeO₃Co₀.₅O₃ (LFCO-3). The XRD spectrum of each ceramic displayed only reflections corresponding to the orthorhombic structure of perovskite LaFeO₃ (ICPDS file no. 37-1493). No crystalline phase of other metal oxides was detected for all compositions and Co(II)-doped powders, suggesting that the A site, La(III) or the B site, Fe(III) of LaFeO₃ perovskite was partly substituted by Co(II) so that no phase change in XRD was observed. Consequently, the diffraction peaks of all Co(II)-doped powders are a bit broaden with no noticeable of peaks shift. The crystallite size calculated using the Scherrer equation was 0.26 Å for LaFeO₃, however, for La₀.₅Co₀.₅FeO₃ and LaFeO₃Co₀.₅O₃ the crystallite sizes were smaller and found in the range of 0.10-0.20 and 0.10-0.14 Å, respectively. This implied that the growth of crystallite size is prevented by Co(II) substitution in the lattice sites of LaFeO₃.

FTIR spectra show strong and sharp peak at 562-576 cm⁻¹ which is attributed to antisymmetric stretching vibration of Fe-O in BO₆ octahedral unit of perovskite oxide ABO₃ as shown in Figure 5. However, the weak band at ~1500 cm⁻¹ was observed. This ascribed to COO⁻ wagging vibration of CO₃²⁻, demonstrating that the sample contained certain amounts of impurity which occurred during thermal decomposition of metal-organic complex and could be destroyed if longer heat treatment is applied.

**Fig.5.** FTIR Spectra of LaFeO₃ and LaFe₀.₅Co₀.₅O₃ Calcined at 850°C for 2 h

Surface area and porosity characteristics of the powders are illustrated in Table 1. BET surface area of LFO was 10.06 m²/g which was higher than that prepared by other methods reported elsewhere [16-17]. The doped products, LCFO series illustrated relatively low specific areas of ~ 5 m²/g while that of LFCO series varied in the range of 9.40-25.88 m²/g.

**Table 1.** BET Surface Area, Porosity and Pore size of the powders calcined at 850°C for 2 h

<table>
<thead>
<tr>
<th>Sample</th>
<th>Notation</th>
<th>BET surface area (m²/g)</th>
<th>Pore volume (cm³/g)</th>
<th>Pore size (nm)</th>
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</thead>
<tbody>
<tr>
<td>LaFeO₃</td>
<td>LFO</td>
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<td>0.03</td>
<td>12.79</td>
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<td>La₀.₅Co₀.₅FeO₃</td>
<td>LCFO-1</td>
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<td>5.77</td>
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<td>La₀.₅Co₀.₅FeO₃</td>
<td>LCFO-2</td>
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<td>6.39</td>
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<td>La₀.₅Co₀.₅FeO₃</td>
<td>LCFO-3</td>
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<td>0.01</td>
<td>5.90</td>
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<td>8.05</td>
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<td>LFCO-2</td>
<td>19.34</td>
<td>0.02</td>
<td>4.85</td>
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<tr>
<td>LaFeO₃Co₀.₅O₃</td>
<td>LFCO-3</td>
<td>25.88</td>
<td>0.01</td>
<td>2.31</td>
</tr>
</tbody>
</table>

The SEM micrographs of some perovskite powders prepared are shown in Figure 6. The morphology of the LFO powder exhibited homogeneous and porous microstructure (Figure 6 (a)). Denser microstructure was observed in the LCFO-3 due to particle agglomerated (Figure 6 (b)), corresponding to lower specific areas of 5.25 m²/g. Agglomeration in LFCO-3 exhibited irregular shape of block-like particles with homogeneous particles distribution and various size of porosity (Figure 6 (c)). This might be responsible for the highest surface area of 25.88 m²/g found in LFCO-3.
3.3. Studied Dielectric Properties of Pellet Samples

3.3.1 Characterization of Pellets

Prior to dielectric measurement, density of pellet samples sintering at 1100°C for 2 h were determined. The density of all pellets was higher than 90% of theoretical density as presented in Table 2. The phase identification of pellet samples confirmed by XRD showed identical diffraction pattern as that of LaFeO$_3$ (Figure 7 (A) and (B)). It was found that diffraction peaks of each pellet became narrower and stronger, indicating a high degree of crystallinity.

Fig.6. SEM micrographs of ceramics powder calcined at 850°C for 2 h

![SEM micrograph](image)

Table 2. Density (% of the Theoretical Density) of Pellets Samples Sintering at 1100°C for 2 h

<table>
<thead>
<tr>
<th>Sample</th>
<th>Density (% theoretical)</th>
<th>Sample</th>
<th>Density (% theoretical)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LFCO-1</td>
<td>92</td>
<td>LFCO-1</td>
<td>98</td>
</tr>
<tr>
<td>LCFO-2</td>
<td>91</td>
<td>LFCO-2</td>
<td>97</td>
</tr>
<tr>
<td>LCFO-3</td>
<td>91</td>
<td>LFCO-3</td>
<td>91</td>
</tr>
</tbody>
</table>

![XRD Patterns](image)

Fig.7. XRD Patterns of the Sintering pellet at 1100°C for 2 h (A) La$_{1-x}$Co$_x$FeO$_3$ (LCFO) and (B) LaFe$_{1-x}$Co$_x$O$_3$ (LFCO)

3.3.2 Dielectric Behaviors of Co(II)-doped LaFeO$_3$ Pellets

Figure 9 and 10 demonstrate the variation of dielectric constant (K) and dielectric loss (tan δ) as a function of frequency measured at room temperature. With increasing frequency, all the pellets in LCFO and LFCO series exhibited dispersion and relaxation in dielectric constant and the dielectric constant found in LCFO series was much lower compared to that of LFCO series (Figure 9(A) and Figure 10(A)). In LCFO series, only dielectric constant of La$_{0.9}$Co$_{0.1}$FeO$_3$ (LCFO-1) was enhanced exhibiting dielectric constant of 150-10 between 1-1000 kHz, however, its dielectric loss was higher than 0.5 over the same range (Figure 9(B)) , suggesting that electrical behavior was dominated.

In LFCO series, the dielectric constants of all three compounds, LFCO-1, LFCO-2 and LFCO-3 were enhanced. As increasing the amount of Co(II) dopant, the dielectric constant decreased. The dielectric constant of LaFe$_{0.9}$Co$_{0.1}$O$_3$ (LFCO-1) is 750-13 and its dielectric loss is 12-0.8 over the frequency range of 1-1000 kHz (Figure 10(b)). Because of the high dielectric losses of all the pellet samples in LFCO series, it indicated electrical...
behavior in all range of frequency (Figure 10(B)). The highest dielectric constant found in both Co(II) doping series, LCFO-1 and LFCO-1 might be associated to the smallest grains sizes and grain boundary as presented in Figure 8.

This observation in electrical characteristic change proved that the La(III) and Fe(III) ion in LaFeO₃ perovskite structure are party substitute by the Co(II) ion, corresponding to no observation of phase changes in XRD result. When Co(II) occupies the sites of La(III) or Fe(III) in the crystal lattice, in the view of charge compensation, oxygen vacancies are produced to maintain a neutral charge, consequently, holes are generated, resulting in non-stoichiometric LaₓCoₓFeO₃₋ₓ and LaFeₓCoₓO₃₋ₓ compounds. As a result of holes producing in the structure of Co(II)-doping sample, the conductivity was enhanced resulting in high dielectric loss, showing low potential for use as dielectric materials. So that LaₓCoₓFeO₃ and LaFeₓCoₓO₃ are one group of the modification LaFeO₃ p-type semiconductors that may be useful for gas sensing application.

Fig.8. SEM micrograph of LCFO and LFCO pellet samples sintering at 1100°C for 2 h

Fig.9. Dielectric Constant, K (A) and Dielectric Loss Factor, tan δ (B) of LaCoₓFe₉₋ₓO₃ vs Frequency at Room Temperature: (a) LFO, (b) LCFO-1, (c) LCFO-2 and (d) LCFO-3

Fig.10. Dielectric Constant, K (A) and Dielectric Loss Factor, tan δ (B) of LaFeₓCoₓO₃ vs Frequency at Room Temperature: (a) LFO, (b) LCFO-1, (c) LCFO-2 and (d) LFCO-3

4. CONCLUSION
LaₓCoₓFeO₃ and LaFeₓCoₓO₃ (x = 0, 0.1, 0.2 and 0.3) powders were successfully prepared from metal-organic complex decomposition synthesized from the reaction of La(NO₃)₃·6H₂O, Fe(NO₃)₃·9H₂O, triethanolamine (N(CH₂CH₂OH)₃) and appropriate amount of cobalt(II) chloride (CoCl₂·6H₂O). XRD results showed that all the compounds were perovskite phase with orthorhombic structure and no other phases was observed. The specific surface areas of ceramics in LCFO series is ~ 5 m²/g while that of LFCO series increased when the amount of Co(II) dopants increases and found in the range of 9.40-25.88 m²/g. From the investigation of the dielectric constant and dielectric loss, we found that LaₓCoₓFeO₃ and LaFeₓCoₓO₃ showed p-type semiconducting properties. The dielectric loss of the LaFeO₃ increased with Co(II) doping, especially in LaFe₀ₓCo₀ₓO₃, corresponding to the increasing of electrical conductivity.
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REFERENCES


