Chapter 1

Introduction

1.1 Statement of the Problem

Nowadays, fossil fuel is consumed very rapidly and is likely to be exhausted in the near future which results in an increase in oil prices. Moreover, there is a growing concern regarding global warming and climate change. Therefore, several studies have been conducted to find an alternative energy source which is environmentally friendly. A fuel cell is a device used to produce alternative energy using hydrogen as a fuel. An fuel cell have received greater interest over recent decades because it generates electricity directly from fuel by way of an electrochemical reaction.

A fuel cell produces electricity from an external supply of fuel (on the anode side) and oxidant (on the cathode side). The basic physical structure of a fuel cell consists of an electrolyte layer in contact with a porous anode and cathode on either side. The components and characteristics of fuel cells are similar to a typical battery, but they are different in that the consuming reactant must be refilled in a fuel cell, while a battery stores electrical energy chemically in a closed system. In addition, the electrodes within a battery react and change as a battery is charged or discharged. Fuel cell electrodes are catalytic and relatively stable. Fuel cells can operate virtually continuously as long as the necessary flows of fuel and oxidants are maintained. A fuel cell is regarded as an energy generator while a battery is an energy storage.

Fuel cells are identified by the type of electrolyte used. There are five main types of fuel cells i.e. Proton Exchange Membrane Fuel cells (PEMFCs), Alkaline Fuel Cells (AFCs), Phosphoric Acid Fuel Cells (PAFCs), Molten Carbonate Fuel Cells (MCFCs), and Solid Oxide Fuel Cells (SOFCs). An SOFC has attracted considerable attention as an efficient power-generating system with very low greenhouse gas emissions and high fuel flexibility as compared with other fuel cell systems. Currently, the commonly used materials are yttria-stabilized zirconia (YSZ) as the electrolyte (Baur and Preis, 1937), Ni/YSZ as the anode, doped $LaMnO_3$ as the cathode (Minh, 1993; Minh and Takahashi, 1995). The advantages in using a ceramic electrolyte such as YSZ in SOFC are that the liquid electrolyte management problems and material corrosion are eliminated. But the conductivity requirement for solid electrolyte needs high operating temperature which causes disadvantages, such as short lifetime of the cell and high cost of materials. Therefore, the development of next generation SOFCs has been focusing on reducing the operating temperature to an intermediate temperature range at 600-700°C (Haile, 2003).

The operating temperature of SOFC is limited by the electrochemical reactions and thermally activated transport processes such as oxide ion conductivity of the ceramic electrolyte and the reaction mechanisms in the electrodes (anode and cathode). The developments of an SOFC from a high operating temperature to an intermediate temperature (IT-SOFC) requires many parameters such as production technology, system costs, and suitable materials as shown in Figure 1.1. The ionic conductivity improvement for electrolyte materials is one way of improvement for IT-SOFC in many reports.

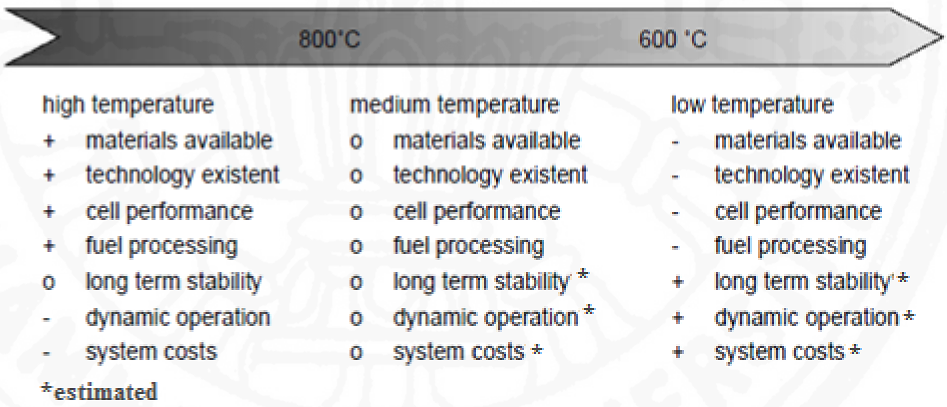

Figure 1.1 Advantages (+) and disadvantages (-) of SOFC for different operating temperature ranges, (o) designated states between (+) and (-) (Weber and Ivers-Tiffèe, 2004)

The operation of an SOFC is based on electrical condition in the ceramic components, especially an electrolyte in which an oxygen ion transfers from a cathode to an anode. The electrical conductivity in an electrolyte is greatly influenced by its microstructure such as grain size and grain boundary (Vest and Honing, 1974; Tuller, 1981). AC impedance spectroscopy is a valuable tool employed for characterizing the electrical behavior of both the bulk (grain interiors) and the grain boundaries of the electrolyte (Barsoukov and Macdonald, 2005).

1.2 Rationale of the Study

The ionic conductivity of electrolyte is decreased when an SOFC is operated at lower temperature. To operate an SOFC at lower temperature, the ionic conductivity must be improved. There are two approaches to enhance the ionic conductivity; the first one is to find a new electrolyte material which has higher oxygen ion conductivity than the commonly used YSZ electrolyte. Another approach is to reduce the thickness of the electrolyte to shorten the distance for oxygen ion transport.

Zirconia-based electrolyte such as yttria-stabilized zirconia (YSZ) and ceria-based electrolyte such as gadolinia-doped ceria (GDC) are employed as the electrolytes in this research. YSZ is currently the most widely employed material as an electrolyte. YSZ has good ionic conductivity and low electronic conductivity at high temperature (1000°C). It is chemically stable at the SOFC operating conditions. However, at lower temperatures, the ionic conductivity of YSZ is lower than that of GDC. Therefore, GDC is an interesting candidate for IT-SOFC. Besides, tetragonal zirconia polycrystals (TZP) has been proposed as an SOFC electrolyte material because of its high toughness and strength.

Per the previous rationale, in this work, the electrolyte for IT-SOFC was studied. This research takes advantage of YSZ, GDC and TZP properties to improve the overall electrolyte properties by blending the materials as composite electrolytes. Specifically, YSZ was mixed with TZP and GDC. To investigate the suitability of the materials used as electrolytes for SOFCs, YSZ, TZP and GDC as well as TZP/YSZ and GDC/YSZ composites were characterized to examine their electrical properties, microstructures, phase identifications, and mechanical properties.

1.3 Objectives of the Study

In this study, the electrical property, microstructure, phase identification, and mechanical property of the electrolyte for a solid oxide fuel cell was investigated.

An understanding of the factors which influence ionic conductivity can help in optimizing the operating conditions for further improvement of the electrolyte properties. The following objectives have been identified for this study:

1. To characterize electrical property of single material electrolytes, *i.e.*, YSZ, TZP and GDC for solid oxide fuel cell application using an AC-impedance spectroscopy technique.
2. To study the correlation between electrical properties and microstructure of single material electrolytes.
3. To study mechanical properties of single material electrolytes.
4. To identify a suitable sintering temperature and time which offer the optimum electrical property of single material electrolytes.
5. To characterize an electrical property of composite electrolytes (TZP/YSZ and GDC/YSZ) for solid oxide fuel cell using an AC-impedance spectroscopy technique.
6. To study the correlation between electrical properties and microstructures of composite electrolytes.
7. To study the mechanical properties of composite electrolytes in comparison with single material electrolytes.
8. To identify a suitable sintering temperature, sintering time and ratio of TZP/YSZ and GDC/YSZ composites which offer the optimum electrical properties.

1.4 Scope of the Study

The followings are the identified scope of the study:

1. The single material electrolytes and composite electrolytes were fabricated using a pressing and sintering method
2. The composite electrolytes were fabricated using various composition ratios.
3. Effects from sintering temperature and sintering time of all electrolytes were studied.
4. Electrical property of the electrolytes was characterized using an AC-impedance spectroscopy technique.
5. Microstructures of the electrolytes were characterized using a scanning electron microscopy technique.
6. Phase identification of the electrolytes was conducted using an X-ray diffraction technique.
7. Mechanical properties of composite electrolytes were studied using three-point bending tests to compare with those of the single material electrolytes.