CHAPTER 1
INTRODUCTION

1.1. Thesis rationale

Piezoelectricity describes either a variation of the dielectric displacement due to a stress (direct effect) or a deformation due to an electric field (converse effect). Today, piezoelectrics are widely used in actuators, sensors, transducers and transformers. At first, the piezoelectric effect was observed in single crystals only, since its discovery by J. and P. Curie in 1880 at the end of World War II. At that time, the discovering of ferroelectricity in barium titanate ($BaTiO_3$ or BT) [1] really triggered the wide application of piezoelectricity, as this ferroelectric character enabled the first implementation of poling [2] which permitted to obtain piezoelectric properties in a poly-crystalline material. The path was then wide open for chemical variations of barium titanate and synthesis of new materials. The search for new ferroelectric compositions yielded the most widely used piezoelectric material up to now: the lead zirconate titanate ($Pb(Zr,Ti)O_3$ or PZT) solid solution [3]. Based on this success, complex lead-based perovskite materials were then systematically investigated leading to the first observation of a relaxor behavior in lead magnesium niobate and lead zinc niobate compounds [4]. These new compounds were exhibiting very high values of the dielectric constant with a pronounced frequency dispersion. In parallel, doping lead zirconate titanate with acceptor or donor species was shown [23] to significantly improve its properties, leading to hard (high stability) and soft (high response) ferroelectrics. However, high doping levels compromise the chemical and crystalline stability of PZT. These concerns naturally lead to the introduction of compensated doping (i.e. simultaneous acceptor and donor doping) that is equivalent to the dissolution of relaxors in lead zirconate titanate. Thus, a flourishing variety of relaxor-ferroelectric-based compositions exhibited very useful properties in the mid 1960's. With Curie temperatures close to room temperature, they exhibited properties alike the donor-doped materials with even higher dielectric permittivities and piezoelectric modulus.

Piezoelectric transformers combine the role of actuator and transducer action. The input electrode area of the transformer converts the electrical energy into mechanical vibration. The output electrode area converts this transmitted mechanical vibration energy back into an electrical signal; i.e., high or low voltage (step-up or step-down transformer). For a piezoelectric material suitable for transformer action, it is essential to satisfy both the requirements for high power actuator and receiver. This implies that the material should have a large mechanical coupling factor (k) and a piezoelectric constant (d), as well as a high mechanical quality factor (Q_m). Further, a high dielectric constant is required in order to draw large power with low dielectric loss in order to suppress heat generation [5].

In this study, compositions in the PZN-PZT based systems will be developed based on the material engineering approach (processing vs electrical properties). This work involves the fabrication of high purity PZN-PZT based in both powder and ceramic forms, and a study of the correlation between their compositions, microstructures and electrical properties. In order to enhance the properties of PZN-PZT based system that are suitable for piezoelectric transformer applications, the effects of hard doping variables, i.e. Fe_2O_3 and MnO_2, on microstructure and electrical properties will then be quantitatively evaluated.

1.2. Purpose of the research

The main objective of this dissertation is to carry out the studies of electrical properties of PZN-PZT based ceramics and specifically to focus on the enhancemence in electrical properties through various additions such as Fe_2O_3 and MnO_2. Our focus has been a basic study to optimize PZN-PZT based compositions by which acceptor additions make oxygen vacancy and important changes in their electrical behavior. It is also our aim to develop the composition based suited for piezoelectric transformer applications through the structure-property relationships.

These goals will be accomplished by

1) Optimization of the powder and ceramic preparations to obtain the single phase of PZN-PZT-based composition.
2) Investigating the physical and electrical properties of these compositions in the bulk ceramic.
3) Examining the influences of composition variation and addition of Fe_2O_3 and MnO_2.

By achieving the above goals, the results would provide the fundamental understanding of the electrical behavior of PZN-PZT based systems, which have the potential in electronic devices such as piezoelectric based applications.

1.3. Organization of the thesis

This thesis is organized according to the sequence of objectives described above. It includes of 6 main chapters.

Chapter 2 provides the background needed for the research areas covered in the following chapters. Three major knowledge and literature reviews used in this thesis framework are presented in the following sequences; (1) ferroelectricity, (2) perovskite material, (3) figure of merit in piezoelectric, and (4) drive/control techniques. First part, ferroelectricity, guides the readers through the phenomenon of dielectric polarization, thereby introducing the concept of frequency dependences of the dielectric constant and loss or dielectric relaxation phenomena including normal and relaxor ferroelectrics. The next part is intended to study perovskite material which is aimed as a main material in this research. The next part is intended to study figure of merit in piezoelectric which is aimed as a main property in this research. The last part is the introduction of drive/control techniques by the relation property with drive/control techniques which is employed to select based composition for this research.

In Chapter 3, an overall description of specimen processing is described by dividing into 2 categories; the preparation of powders and ceramic processing. The processing parameters and the method of characterization are presented.

Chapter 4 is dedicated to the investigation of physical and electrical properties of PZN-PZT based composition. There are three part, (1) Synthesis, formation and characterization of PZN-PZT powder, (2) Effect of PZN content on properties of PZN-PZT ceramics, and (3) Effect of Zr/Ti ratio on properties of PZN-PZT ceramics.

The scope of measurement is defined and the results of dielectric, piezoelectric and ferroelectric properties are shown.

Chapter 5 is intended to investigate the effect of Fe_2O_3 and MnO_2 addition on physical and electrical properties of PZN-PZT based composition.

Finally, in Chapter 6, the overall conclusions of this study are drawn and the future extensions of this study are proposed.