CHAPTER 1

INTRODUCTION

1.1 Principles, rationale and hypothesis

Ferroelectric ceramics are materials which have spontaneous polarization with changing the direction of the spontaneous polarization between two or more orientations by applied field. The domains in ferroelectric ceramics can be reoriented by an electric field or by a mechanical stress loading of sufficient magnitude. The consequences of domain switching in ferroelectric materials are the occurrence of non-linear response [1]. Applying a large alternating electric field causes the polarization to reverse (switch), and this gives rise to the ferroelectric hysteresis loop, relating the polarization to the applied electric field. The hysteresis loop is the single most important measurement that can be made on a ferroelectric material when its electrical behavior is characterized. Hysteresis is a unique property of ferroelectric materials arising when ferroelectric materials are applied electric field and then domain switching following electric field direction is conducted. However, domains do not switch immediately following applied electric field, they gradually switch slower than frequency of applied electric field, occurring as the delayed phase of polarization apart from applied electric field, initiating the hysteresis loop. Hysteresis loops come in all sizes, shapes and similar to fingerprints identifying the materials in a very special way [2]. For this reason, hysteresis properties have to be considered when ferroelectric materials are applied in any devices. The observation of hysteresis loops is originally carried out with a conventional Sawyer-Tower circuit [3]. Normally, hysteresis studies are proceeded under frequency and electric field conditions [3].

Last few years, there have been reports on the scaling behavior of the dynamic hysteresis in ferromagnetic and ferroelectric materials because the dynamic hysteresis, i.e., hysteresis area $< A >$ as a function of the field amplitude E_0 and frequency f, has become important consideration in many applications, whose performance is related to the signal amplitude and frequency. However, some discrepancies between theoretical and experimental results still exist [4-13]. Many theoretical studies have been focused on the power-law scaling relation

$$< A > \propto f^{m} E_0^{n} \tag{1.1}$$

(where m and n are exponents that depend on the dimensionality and symmetry of the system) of hysteresis curves in spin and polarization systems [4-8]. Earlier investigations have reported the scaling relations in thin-films, bulk ceramics, and liquid crystal [4-5, 7, 13-22] of some ferroelectric materials, such as $Pb(Zr,Ti)O_3$ (or PZT), $Bi_4Ti_3O_{12}$, $SrBi_2Ta_2O_9$, PMN-PT film, soft and hard PZT bulk ceramics and the deformed helix ferroelectric liquid crystal (DHFLCs). It is interesting to observe that scaling behaviors of different materials derived from theoretical models, thin-film, and bulk ceramics are generally comparable (only slight difference in exponents m and n), suggesting that materials with similar domain structures should have very comparable dynamic hysteresis and scaling behaviors, as previously proposed in recent investigations [16, 18, 23-24]. It could be stated that the dynamic hysteresis (hence the scaling behavior) is mainly controlled by available domain states and polarization switching mechanism.

To support the hypothesis that materials with similar domain states should have very comparable dynamic hysteresis and scaling behaviors, the dynamic hysteresis of various ferroelectric materials are investigated and their scaling relations are established and compared.

1.2 Purpose of the research

The main objectives are as follows:

1. To investigate the dynamic hysteresis behaviors in some ferroelectric materials,
2. To demonstrate the scaling relations in form of hysteresis area $< A >$ as a function of field amplitude E_0 and frequency f in some ferroelectric materials,
3. To examine and understand the scaling behavior-domain state relation in some ferroelectric materials to support the hypothesis that materials with similar domain states should have very comparable dynamic hysteresis and scaling behaviors.

1.3 Material candidates for this study

To observe dynamic hysteresis and scaling behaviors dependent on domain structures, materials with several crystal structures providing various domain states are selected for measurements.

The simple and normal ferroelectric $BaTiO_3$ [BT] single crystal is chosen to determine dynamic hysteresis responses and scaling relations under influence of frequency and field amplitude at room temperature and compare to previous investigations, such as in soft and hard PZT ceramics [16-17]. Simultaneously, polycrystalline BT bulk ceramic is also observed to clarify the influence of domain homogeneity on dynamic hysteresis and scaling behaviors as compared to BT single crystal. The $0.7Pb(Mg_{1/3}Nb_{2/3})O_3$–$0.3PbTiO_3$ [0.7PMN–0.3PT] single crystal, a relaxor ferroelectric material, is investigated for dynamic hysteresis and scaling manners as compared to normal ferroelectric BT single crystal. Finally, $(1\text{-}x)Pb(Zr_{1/2}Ti_{1/2})O_3\text{-}(x)Pb(Zn_{1/3}Nb_{2/3})O_3$ [(1-x)PZT-(x)PZN], where x = 0.1, 0.2, 0.3, 0.4, and 0.5, ceramic systems with various compositions providing various crystal structures are investigated to determine the dependence of hysteresis behaviors and scaling conducts on domain structures.

Furthermore, the temperature dependence of dynamic hysteresis and scaling behaviors in BT single crystal and BT bulk ceramic are observed to confirm contribution of domain structure in controlling scaling and hysteresis properties.

Finally, the electric field–waveform dependence of hysteresis behaviors and scaling relations in 0.7PMN-0.3PT single crystal is determined to clarify the influence of different field-waveform applications.