CHAPTER 5

CONCLUSIONS

5.1 Conclusions

This research performed the Fourier analysis on the ferroelectric hysteresis (which as Ising ferroelectric hysteresis from mean field calculation and Monte Carlo simulation, and $BaTiO_3$ ferroelectric hysteresis from Sawyer-Tower experiment) behavior. The aim is to establish the relationship between hysteresis properties (i.e. hysteresis area A, remnant polarization P_r, and coercive field E_c) and external perturbations parameters (i.e. temperature T, amplitude E_0 and frequency f of electric field $E(t) = E_0 \sin(2\pi ft)$) via Fourier transformation. The polarization signal of the hysteresis was then transformed from time domain to frequency domain to extract the amplitude of Fourier harmonics. After that, the relationship between hysteresis properties and external perturbations parameters associated to the amplitude of each Fourier harmonics were investigated. It is found that the hysteresis properties can be modeled by considering harmonics of Fourier transformation as the following:

- Hysteresis area depends only on amplitude of the electric field and amplitude of the first harmonic of the real part.
- Remnant polarization depends on amplitude of all odd harmonics of real part.
- Coercive field depends on amplitude of the electric field and amplitude of the first harmonic of the real and imaginary parts.

In general, this Fourier technique can also be applied to various ferroelectric

hysteresis generated using different kind of waveforms e.g. triangular, trapezoidal, etc., but not for square waveforms. In addition, this Fourier technique can also be used to improve the hysteresis signal quality (e.g. eliminating electric noise, measured from poor experimental setup). As a result, in hysteresis properties modeling, it can be used to enhance the power law scaling technique dominant (e.g. some materials may not response well to the field in some conditions, allowing noise to become which can strongly reduce the quality of the scaling). This research therefore provides an alternative approach which can be used to predict and model the complex hysteresis behavior, which can be enhanced to gain further understanding of the ferroelectric materials.

5.2 Suggestions

Even with extensive results provided in this work, the Fourier benefits to hysteresis modeling is still for from completed. For instance, the relationship between external perturbations parameters and Fourier harmonics do require further investigate. To list a few, there are windows of opportunities in Fourier area as the following:

1. Apply this technique to investigate the different kind of electric field waveforms e.g. square, triangular, trapezoidal, etc.

2. Consider the defect ferroelectric materials using Fourier decomposition.

3. In the study of aging ferroelectric materials, the zero harmonic of Fourier transformation relate to aging term. This zero harmonic of time dependent will be used to consider the aging behavior.