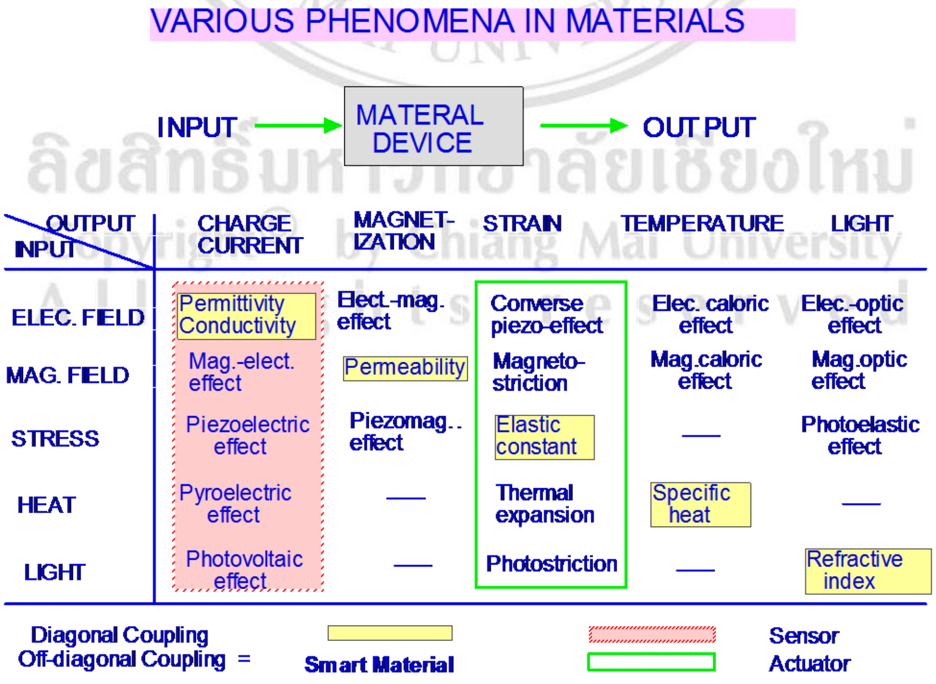
# CHAPTER 1

# Introduction

## 1.1 Introduction and overview

Nowadays, smart materials are the attractive and interesting materials. Their response to input, namely electric field, magnetic field, stress, heat and light, results to output as charge, magnetization, strain, temperature and light as shown in Table 1.1. It can be seen that the output from smart materials is various. The off-diagonal coupling in the table then generates output different from the character of input such as converse piezoelectric effect where the electric field generates the strain, and photovoltaic effect where the incident light generates electrical charge. Smart materials are recognized as their sensing ability and response in the materials [1].

Table 1.1 Various basic and cross-coupled properties of materials [1]



VARIOUS PHENOMENA IN MATERIALS

INPUT → MATERAL DEVICE → OUT PUT

| OUTPUT / INPUT | CHARGE CURRENT | MAGNET-IZATION | STRAIN | TEMPERATURE | LIGHT |
|---|---|---|---|---|---|
| ELEC. FIELD | Permittivity Conductivity | Elect.-mag. effect | Converse piezo-effect | Elec. caloric effect | Elec.-optic effect |
| MAG. FIELD | Mag.-elect. effect | Permeability | Magneto-striction | Mag.caloric effect | Mag.optic effect |
| STRESS | Piezoelectric effect | Piezomag.. effect | Elastic constant | — | Photoelastic effect |
| HEAT | Pyroelectric effect | — | Thermal expansion | Specific heat | — |
| LIGHT | Photovoltaic effect | — | Photostriction | — | Refractive index |

Diagonal Coupling 🟨
Off-diagonal Coupling = Smart Material
▨ Sensor
🟩 Actuator

To develop intelligent materials, the understanding of materials in terms of drive/control such as response to dangerous situation or environment destruction in real time information is required. So smart materials are defined as materials that can be altered or controlled by external or environment field to serve as useful detectors, and are classified into many categories [2]. They are used in many applications such as automation, process control systems, materials processing, aerospace, automotive, electronics, defenses and medical technologies and biotechnologies.

Ferroic and multiferroic materials are also the attractive smart materials. Ferroic crystals are the crystal having a phase or domain direction, according to spontaneous breaking symmetry of structure [3], which the domain pattern can reoriented by effective field such as electric field, magnetic field and stress so called ferroelectric, ferromagnetic and ferroelastic respectively, as shown in Table 1.2. Ferroic materials are related to many significant properties such as the domain structure response to hysteresis behavior, the area near ferroic phase transition which gives a high ferroic property, the phase transition and macroscopic properties changed with temperature dependence, and the strong coupling in their property. These make ferroic materials useful in many applications [2].

Multiferroic materials are the materials having two or more coupling properties of ferroic, such as ferroelectromagnetic multiferroics (FEM) the coupling between dielectric polarization and magnetization property which are affected by electric and magnetic fields. The magnetoelectric effect (ME) is the properties of ferroelectromagnetic multiferroics, the primary effect is the magnetized materials affected by electric field or dielectric polarized affected by magnetic field, and the secondary effect is response to change in permeability and permittivity. The magnetoelectric properties are used in many applications such as magnetic reading and writing, giant magneto resistance (GMR) reading/writing heads, multi-state memory element, magnetoelectric random access memories (MERAMs), and improved magnetic field sensors [5].

Table 1.2 Classification of primary and secondary ferroics [4]

| Ferroic class | Orientation state differ in | Switching force | Example |
|---|---|---|---|
| *Primary* | | | |
| Ferroelectric | Spontaneous polarization | Electric field | $BaTiO_3$ |
| Ferroelastic | Spontaneous strain | Mechanical stress | $CaAl_2Si_2O_8$ |
| Ferromagnetic | Spontaneous magnetization | Magnetic field | $Fe_3O_4$ |
| *Secondary* | | | |
| Ferrobielectric | Dielectric susceptibility | Electric field | $SrTiO_3$ |
| Ferrobimagnetic | Magnetic susceptibility | Magnetic field | NiO |
| Ferrobielastic | Elastic compliance | Mechanical stress | $SiO_2$ |
| Ferroelastoelectric | Piezoelectric coefficients | Electric field and mechanical stress | $NH_4Cl$ |
| Ferromagnetoelastic | Piezomagnetic coefficients | Magnetic field and mechanical stress | $FeCO_3$ |
| Ferromagnetoelectric | Magnetoelectric coefficients | Magnetic field and electric field | $Cr_2O_3$ |

Ferroelectric materials are the ferroic; the dielectric polarization or polarization domain is altered when the materials are subjected to electric field. First discovery of Rochelle salt (sodium potassium tartrate tetrahydrate) by Elie Seignette in La Rochelle, France in 1920, the material possesses spontaneous polarization inside and can be reversed by strong electrical field. The major turning points of ferroelectric were early in 1940s, the unusual dielectric properties were discovered in simple mixed oxides of perovskite like structure. The history of ferroelectricity has been described by many authors as L.E. Cross and R.E. Newnham, and G.H. Haertling and the important history was shown in Table 1.3 [6,7]. Many ferroelectric properties are useful and used in many application devices such as dielectric property of capacitors. Ferroelectric materials were fabricated to reduce Curie temperature ($T_c$) for the high dielectric permittivity near room temperature for application such as computer memories, the storage of digital information as nonvolatile embedded ferroelectric random-access memory (FRAM), piezoelectric/electrostriction. The most diverse application of ferroelectric materials covers sensors/actuators and acoustic wave component application, pyroelectric used in infrared detection application [7,8].

Table 1.3 Important events in ferroelectricity [6]

| | |
|---|---|
| 1920–1930 | Rochelle Salt period: discovery of ferroelectricity |
| 1930–1940 | KDP age: Thermodynamic and atomistic models of ferroelectricity |
| 1940–1950 | Early barium titanate era: High-K capacitors developed |
| 1950–1960 | Period of proliferation: Many new ferroelectrics discovered |
| 1960–1970 | Age of high science: Soft modes and order parameters |
| 1970–1980 | Age of diversification: Ferroics, electrooptics, thermistors |
| 1980–1990 | Age of integration: Packages, composites, and integrated optics |
| 1990–2000 | Age of miniaturization: Size effects, manipulated modes and dipoles |

The induced strain is one of the properties which is used to analyze the characteristic and select the suitable quality materials of ferroic, multiferroic and the subset ferroelectric for many application devices, such as sensors and actuators. In ferroelectric materials, the electric field induced strain is the important property which is used to explain the switching domain behavior of spontaneous polarization according to piezoelectric effect and electrostriction phenomena, for example in PMN compositions and PLZT ceramics which was used in actuator and electrooptic application respectively, which was developed to give the higher ferroelectric property by modification of the structure (perovskite type structure) in purpose to move the phase transition temperature $T_c/T_m$ closed to room temperature. And now the multifunctional materials are developed as smart materials whose responses to more than two fields, for example, the magnetoelectric effect which materials are affected by electric and magnetic field [1,6,7].

The electric field induced strain in ferroelectric material are very small in size and shape then high resolution measurement is required. In many of displacement measurements such as resistive displacement sensors, inductive displacement sensors, capacitive sensors, magnetic displacement sensors, Michelson interferometer technique is selected as it has been a long time well known for small displacement measurement. This technique is also simple, low cost, non-contact measurement and no need for calibration on the length scale, response to coherent monochromatic light of a wavelength stabilized Helium-Neon laser source with the uniphase wavelength ($\lambda$) of 632.8nm. The system can be easily modified and developed to observe electric field induced strain measurement with any affected fields [11-14].

In this research, the Michelson interferometer was set up on vibration freed optical table and connected with Sawyer-Tower circuit to measure electric field induced strain and dielectric polarization, respectively. In Michelson interferometer setup, the sample holder was modified in purpose to apply heat and magnetic field when electric field induced strain and polarization of ferroic sample was measured to observe and fully understand the induced strain behavior of ferroic materials at different temperature as a function of various electric/magnetic field strengths. In this research, it focuses on relaxor ferroelectric materials where the composition near morphotropic phase boundary (MPB) such as PLZT, PMN-PZT and PMN-PT ceramics. Temperature dependence behavior of electric field induced strain and polarization of PLZT, PMN-PZT and PMN-PT ceramics which was tailored to give highest the ferroelectric properties, when $T_c/T_m$ reduced to nearly room temperature, was investigated. Electric field induce strain and polarization at the temperature range of room temperature (30°C) to 70°C of PLZT, PMN-PZT and PMN-PT samples were measured. Magnetic field effect to electric field induced strain and polarization of PLZT, PMN-PZT and PMN-PT ceramics was also investigated. Magnetoelectric effect to relaxor ferroelectric composition near MPB, the PLZT, PMN-PZT and PMN-PT samples was studied by measuring electric field induce strain and polarization in the bias magnetic field condition at the range of 0 mT to 30 mT. Modified Michelson interferometer with an extra high tension (EHT) supply, Sawyer-Tower circuit, the temperature controlled chamber, an electro-magnetic field control system, and electronic components would be constructed. The ferroic material samples were studied at different conditions. All the controls and measurements were interfaced to a PC to record and the data were analyzed to obtain full understanding induced strain behavior of ferroic materials.

This thesis consists of five chapters to fulfill the understanding in development of Michelson interferometer for induced strain of ferroic materials. Chapter two involves theory background and literature review to explain ferroic, ferroelectric, magnetoelectric, induced strain as piezoelectric/electrostriction behavior, and how to analyze the intensity from Michelson interferometer. Chapter three concerns with experimental modified setup, including sample holder in the purpose to apply heat and magnetic field condition, and the electric field induced strain and polarization measurement in various parameters and conditions as frequency dependence, aging phenomena, temperature dependence and magnetic field effect. Chapter four consists of the results and data analysis from the electric field induced strain and polarization measurement in frequency dependence, aging phenomena, temperature dependence and magnetic field effect. Chapter five ends with the conclusions of the research.

## 1.2 Research objectives

1.2.1 To develop Michelson interferometer for induced strain measurement system

1.2.2 To investigate induced-strain characteristic relations with external fields (electric, magnetic and thermal) of ferroic materials

## 1.3 Usefulness of the research

1.3.1 The research will provide the understanding of induced strain characteristic relations with external fields (electric, magnetic and thermal) of ferroic materials by development of Michelson interferometer measurement system

1.3.2 The understanding of induced strain characteristic from this research can be applied in multifunctional-actuator based ferroic materials