

Faculty Mentor: Dr. Robert Ryan

Project Supervisor: Dr. George Youssef (gyoussef@csun.edu)

Project Title: Fabrication and characterization of thin-film PZT using sol-gel spin coating process

Available Positions: 4 positions are available, scheduled for a maximum of 15-20 hours per week. Contact the project supervisor for specific hours of employment. 10 Weeks Summer Research Internship

Expected Background: The work will take place in a laboratory environment. Students must be capable of working safely and responsibly. Safety training will be provided. No previous background in applied mechanics is required.

Project Description:

Electromagnetism is ubiquitous in many engineered systems and is the fundamental technology in computer memory devices, electromagnetic antenna systems, and electromagnetic motors. In the macro-scale, the concept of generating a magnetic field by passing a current through a wire (discovered in 1920s by Ampere) has proved to be the key to present day electromagnetic devices. This approach limits the further miniaturization of electronic devices because of the increase in energy losses due to the significant increase in resistive loads at the nanoscale. Thus, the major problem with scaling “conventional” electromagnetic components is that they become impractical as electronics are further miniaturized, representing a scientific barrier inhibiting further advancements toward electromagnetic miniaturization. An alternative solution is currently under investigation: coupling the conversion of electrical energy into mechanical energy (piezoelectric in ferroelectric materials) and conversion of magnetic energy into mechanical energy (magnetostriction in ferromagnetic materials) to create multiferroic composite materials. In multiferroic composite materials, indirect coupling between electric and magnetic energies is created through mechanical strain. An electric field is first applied to piezoelectric material, which are bonded onto magnetostrictive material. The generated strain due to the application of an electric field creates a magnetic field. Thus, voltage, rather than current, is used to switch the magnetic field ON/OFF, eliminating the reliance on current and removing the scientific barrier to further miniaturization of electronics.

In this research experience, students will fabricate and characterize thin PZT films using spin-coating technique. Piezoelectric materials are of the constituents of multiferroic composite materials. They will then characterize the films to measure electrical properties (synopsis included below) and mechanical behavior using photo-elasticity.

Piezoelectric material characterization: Piezoelectric materials have a coupling between their mechanical and electrical properties. Specifically, the application of an electrical field results in a mechanical strain, which is known as the direct piezoelectric effect. Inversely, a mechanical strain results in a change in the electric polarization of the material (i.e., the converse piezoelectric effect). The phenomenon is inherently nonlinear as such materials exhibit hysteresis; however, in typical applications, the operation of the material is suitably described by the linear constitutive equations (Eqn 1 and 2) since the range of operation is restricted between remanence and saturation (**Figure 1**):

$$\varepsilon_{ij} = s_{ijkl}\sigma_{kl} + d_{ijn}^*E_n \quad (1)$$

$$D_m = d_{klm}\sigma_{lm} + \epsilon_{mn}E_n \quad (2)$$

where ε_{ij} is the strain, s_{ijkl} is the elastic compliance, σ_{kl} is the stress, d_{ijn} is the piezoelectric coefficient, E_n is the electric field, D_m is the electric displacement, and ϵ_{mn} is the dielectric permittivity. In order to fully characterize the material, the piezoelectric coefficients and the elastic constants must be experimentally measured. **Figure 1** illustrates the experimental setup for piezoelectric material characterization as well as a schematic representation of the P-E hysteresis loop and electrical characteristics calculated from the loop.

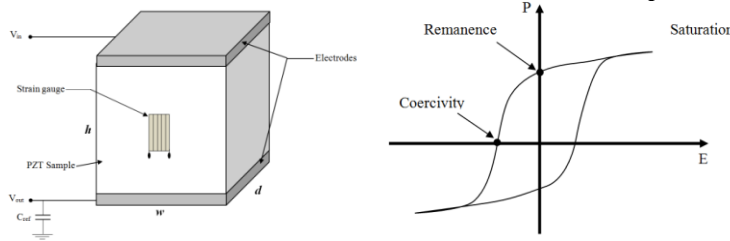


Figure 1: Setup for mechanical and electrical characterization and typical P-E hysteresis

The sample has a cubic geometry, which is polished to avoid premature failure due to surface cracks and cyclic loads. Two electrodes on the top and bottom surfaces perpendicular to the applied mechanical loads are deposited to assist in applying and measuring the electrical field.

The sample is first electrically loaded by applying a voltage across the top and bottom electrodes, then an axial compressive stress is applied to the specimen via a servo-hydraulic test frame (not shown in Figure 2) for mechanical characterization. The sample is isolated from the test frame via an insulating material such as alumina, where the choice of insulating material must have enough rigidity to avoid influencing the mechanical loading. Typical electrical loading of piezoelectric materials requires time-varying voltages (typically sinusoidal) on the order of several kilovolts which is done by connecting a function generator to a high voltage amplifier. Considering that the breakdown voltage of air is 3MV/m, it may be necessary to submerge the specimen in an oil bath, such as silicon oil, to prevent arcing. The strain is measured using two transverse strain gauges; one is applied to measure longitudinal strains while the other measures the strain in a perpendicular direction. Both gauges are attached on the same face and connected to a Wheatstone bridge. On the other hand, the charge on the specimen is measured using a Sawyer-

Tower circuit, a reference capacitor in series with the sample (**Figure 1**). The voltage across the reference capacitor is measured during testing and the reference state is reached in the non-polarized state where the capacitor is short circuited. Upon conclusion of this characterization, students will be familiarized with piezoelectric materials electrical and mechanical properties as well as the characterization techniques.