Piezoelectricity for Large Scale Power

Lindsay Herron

What is piezoelectricity?

- It is a dielectric material that can be polarized by an electric field or mechanical stress.
- Has No Center of Symmetry
- Examples of Different Types
  - High Power "Hard" Piezoelectric
    - Withstand high levels of electrical and mechanical stress
    - High Voltage and High Frequency Applications
  - High Sensitivity "Soft" Piezoelectric
    - High sensitivity and are donor-doped
    - Transducers, receivers, and generators

Center of Symmetry

- No Center of Symmetry required from a crystal to be capable of piezoelectricity.
- When unstressed and stressed the center of mass of the negative charges at the corners of the unit cell coincides with the positive charge at the center, showing no net polarization. [3]

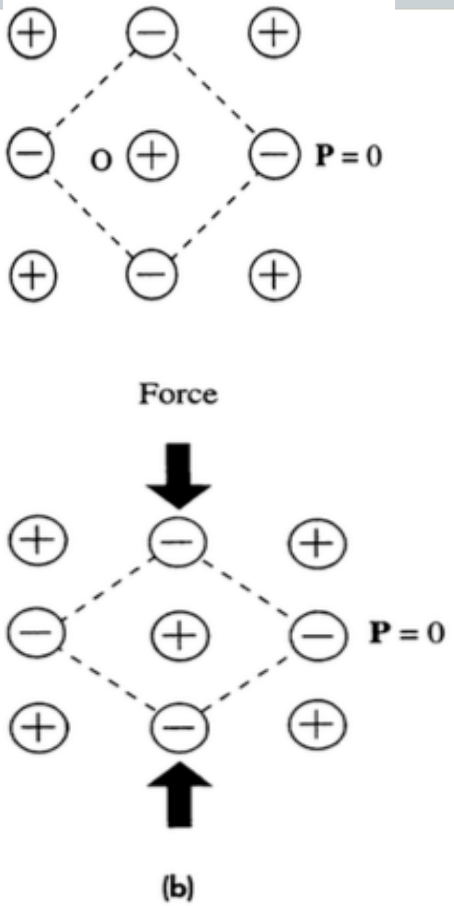

Figure 1. [3]

Causes of Strain on the Piezoelectric Material

- Normal Stress
  - Compression or tension (tensile stress) perpendicular to the surface.
- Shear Stress
- Vibrations
- Acoustic Noise at Resonance Frequency

Stress Example

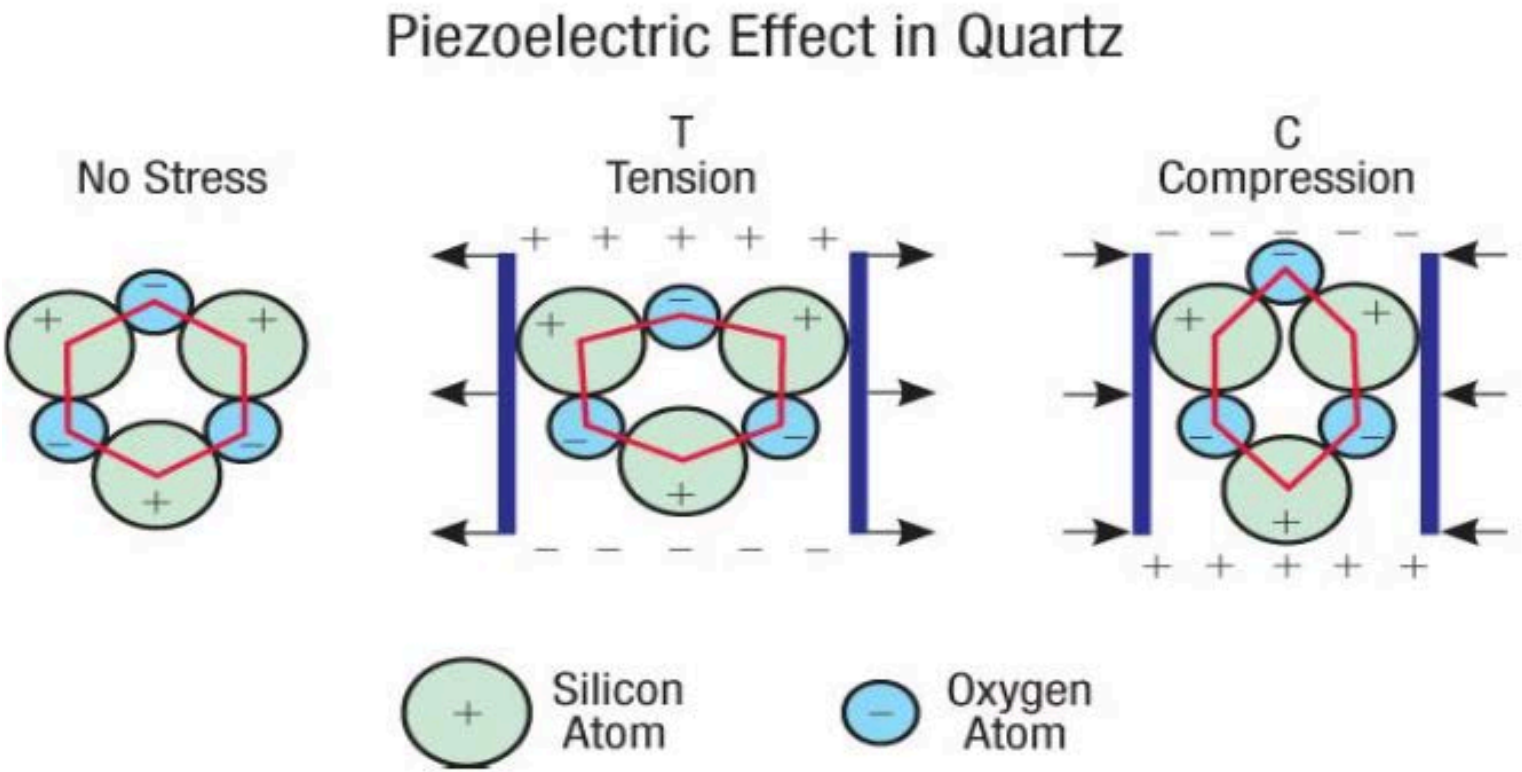

Figure 2. [5]

Manufacturing

- PZT ceramics widely used
  - Consists of lead zirconate titanate ($PbZrO_3$) and lead titanate ($PbTiO_3$)
    - Makes $PbTi_{(1-x)}Zr_xO_3$ where x is typically 0.5.
- Sintering process
  - PZT powders are placed in a mold and subjected to a pressure at high temperatures (below Curie Temperature).
  - Ceramic powders are fused through interdiffusion.

[3]

PZT Structure

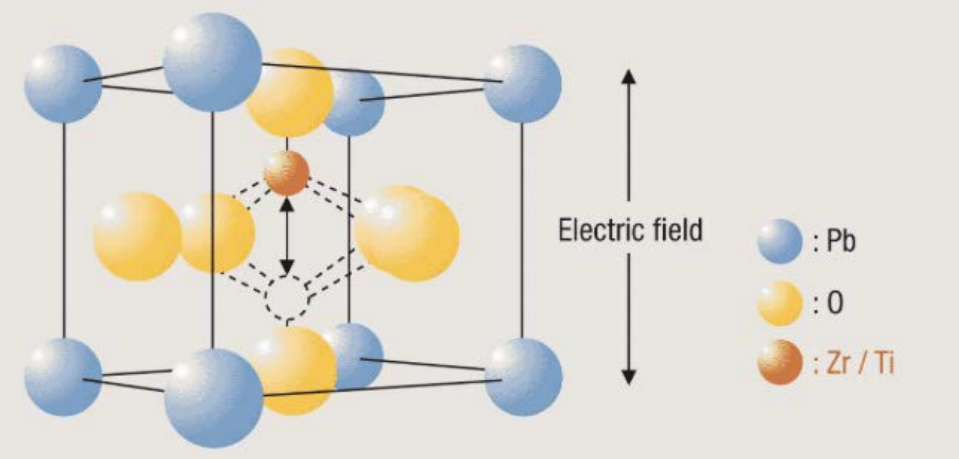

Figure 3. [2]

- There is extensive disorder in the magnitude and direction of the B-cation distortions within their oxygen octahedra and disorder in the magnitude and direction of the displacements of both the lead and oxygen ions away from their perfect perovskite positions. [8]

- This local disorder gives PZT its properties.

Performance of PZT

- Dependent on Grain Boundary
- Morphotrophic Phase Boundary (MPB)
  - Best performance occurs where tetragonal and rhombohedral phases meet.
  - Good-quality single crystals of PZT with compositions in the middle of the phase diagram are not available.

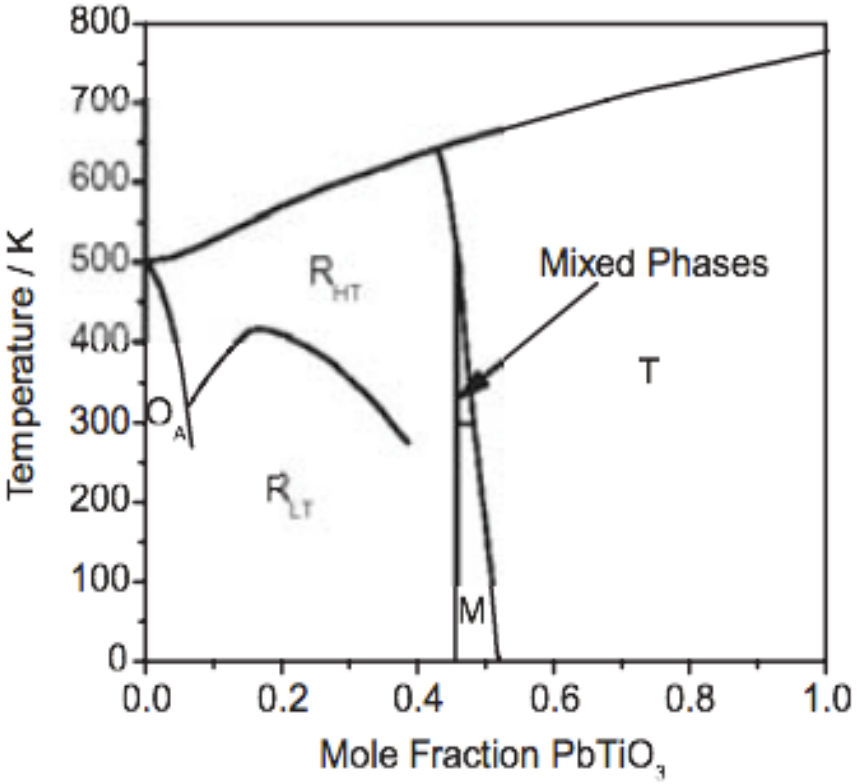

Figure 4. [1]

MPB

- At MPB, the free energy of the rhombohedral and tetragonal phases are equal.
- The electrical poling field may easily switch between tetragonal and rhombohedral domain states.
- Between the two there are effectively 14 available directions PZT may be reoriented by the poling field causing a high potential.

[7]

Poling

[3]

- Polling is done once electrodes are deposited onto the final ceramic component.
- Poling is the application of a temporary electric field, generally at an elevated temperature.
- Aligns the polarization of various grains and allows the crystal to develop piezoelectric behaviors.

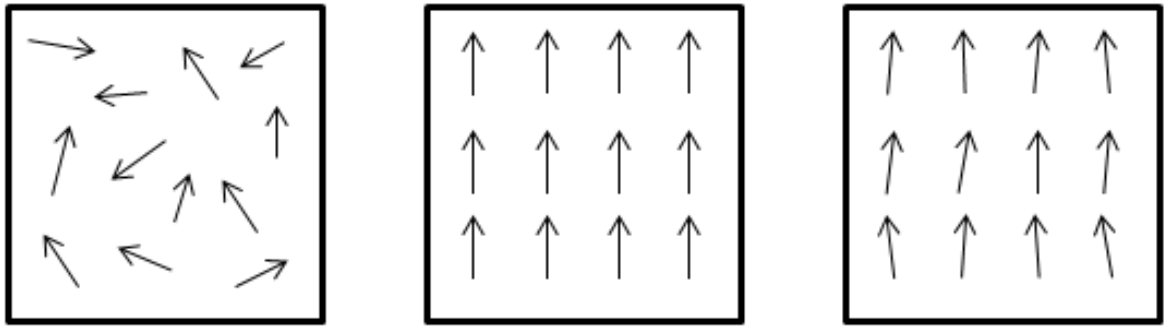

Figure 5. [9]

Smart Roads

- Expected energy is approximately 80 kilowatt-hours per kilometer of road during traffic hours.[4]
- More power generated during slower movement due to extended pressure time.[5]

Figure 6. [4]

Power Harvesting

- DC/DC converter allows a specific Voltage to be used.

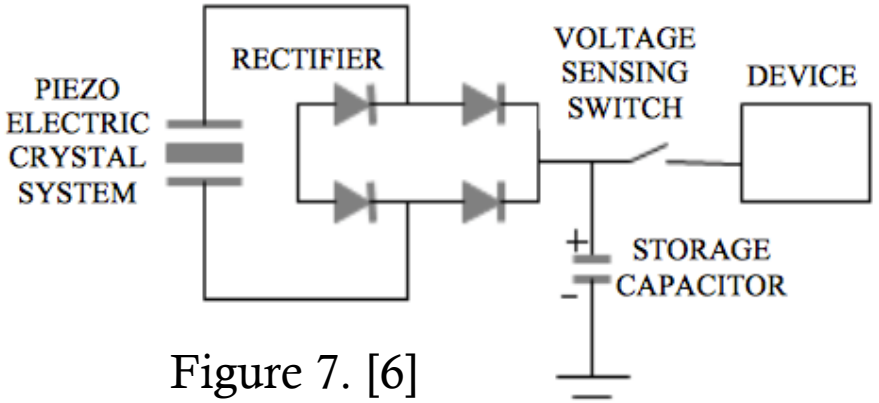

Figure 7. [6]

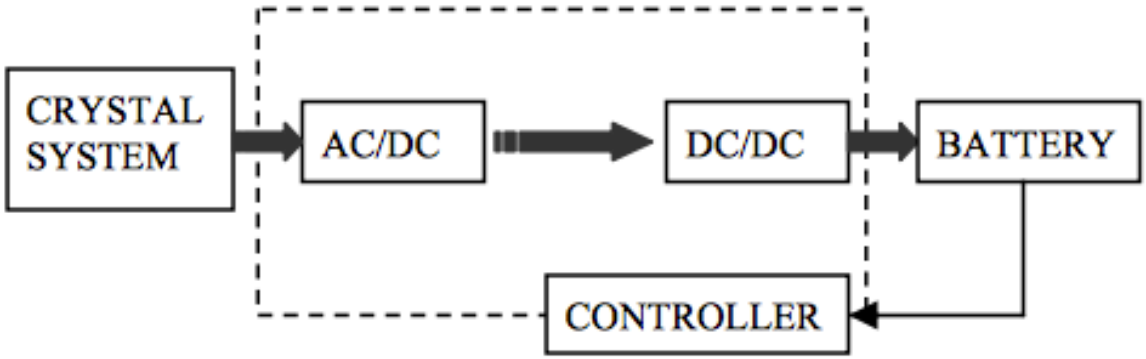

Figure 8. [6]

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