Piezoelectricity and Ultrasonic Devices - The Cornerstone of Modern Technology

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• Having an understanding of piezoelectric materials and devices is not common

• Benefit of this presentation to the consulting community to IEEE-CNSV members
Where are piezoelectric devices?

Medical

Consumer

Industrial

Military
• My background
• Definition of Piezoelectricity
• Question 1 – Converse Piezo Effect
  • 0.4mm, 40um, 4um, 0.4um
  • \( x = dE, \Delta L = dV \)
  • 0.4um = 400E-12m/V * 1E3V
• Question 2 – Direct Piezo Effect
  • 1000V, 100V, 10V, 1V
  • \( Q = dX, \text{ or } E = g X \)
  • \( V = \frac{gF}{A}L \)
  • 1800V = 30E-3[Vm/N] * 750 [N] * 0.004 [m] / 5E-5 [m^2]
  • 6.8E10N/m^2 / (750N / 5E-5m^2)
  • 0.5um
Piezo vs. Condenser Microphone

**Piezoelectric**

![Piezoelectric Microphone Diagram](image)

**Condenser Microphone**

![Condenser Microphone Diagram](image)
Piezoelectric materials have an internal polarization

That’s why they are piezoelectric
Origin of Piezoelectricity

NaCl

Pb(Ti,Zr)O3

Unit cell
Piezo Vs. Electromagnetic

Piezo

Electromagnetic
Piezoelectric materials provide a compact form factor

- Practical benefits of form factor
- Important to ultrasonic applications
## Assorted Applications

<table>
<thead>
<tr>
<th>Application</th>
<th>Aspect of Piezo Utilized</th>
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<tbody>
<tr>
<td>Non destructive testing (NDT)</td>
<td>High frequency ultrasound</td>
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<tr>
<td>Ultrasonic cleaner</td>
<td>Power ultrasound</td>
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<tr>
<td>Dental equipment</td>
<td>Ultrasonic mechanical resonance</td>
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<tr>
<td>Atomizer</td>
<td>Ultrasonic mechanical resonance, Ultrasound</td>
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<tr>
<td>Pressure sensor</td>
<td>Direct piezoelectric effect</td>
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<td>MEMS sensors</td>
<td>Clean room fab</td>
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<td>Inkjet printer</td>
<td>Fast mechanical response</td>
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<tr>
<td>Diesel fuel injector</td>
<td>Fast mechanical response with high force</td>
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<tr>
<td>Manufacturing (drilling, bonding, welding)</td>
<td>Ultrasonic mechanical resonance</td>
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<tr>
<td>Nano and Micro positioning</td>
<td>Converse piezo response, fine displacement</td>
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</tbody>
</table>


### 4 Quadrants of Force and Displacement

<table>
<thead>
<tr>
<th>High Displacement</th>
<th>Low Force</th>
<th>Low Displacement</th>
<th>Low Force</th>
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</thead>
<tbody>
<tr>
<td>• Bending actuators</td>
<td>• Multilayer actuators</td>
<td>• Not relevant</td>
<td>• Bare Piezo Crystals</td>
</tr>
<tr>
<td>• Compliant mechanism coupled</td>
<td>• Ultrasonic resonator</td>
<td></td>
<td></td>
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<tr>
<td>• Piezo polymer</td>
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- High Displacement: High Force
- Low Displacement: Low Force
Types of Ultrasonic Transducer Applications

• A: Devices in which the goal is ultrasound
  • Medical diagnostic
  • Ultrasonic welding
  • Phaco handpieces

• B: Devices in which the goal is not ultrasound
  • Ultrasonic motors
  • Piezoelectric transformers
Different Types of Piezoelectric Materials

- “Crystals”
- Ferroelectric ceramics
- Ferroelectric single crystals
- Polymer
- Composites

First piezoelectric applications used “crystals”
Lead Zirconate Titanate “PZT”

- Material used in majority of piezoelectric devices
- Ceramic (ionic compound)
  - Basic fabrication process
- Ferroelectric
- Properties can be tailored using defect chemistry
  - Link to Piezo Materials
Ferroelectricity

• Explicit definition
• What is practically means for us?
  • 1. Poling
  • 2. Large spontaneous polarization
  • 3. Ferroelectric domain walls
  • 4. Temperature sensitive

“Domains, we can’t live with them and we can’t live without them”

-A piezoelectric device engineer
• Piezoelectric Device Design
Ultrasonic resonance transducer
Oscilloscope Demonstration

Transducer – Mechanical Impulse

42 kHz resonance

Transducer – Electrical input
Piezoelectric Applications

• Ignitor
  • Charge = Force * d
  • Drop the capacitance of the piezo by making it thicker
• Q = CV
  • Large voltage
Bending Transducer

• Bond thin piezo layer to a passive layer
  • Piezo expands and device bends
  • Produces large displacement and low force
  • Slow response time

• Positioning applications, buzzers, atomic force microscopy, sensors, ultrasonic motors
Multilayer Piezoelectric Device

- Electric field drives piezoelectricity
  - Not voltage
- Make layers thinner
  - Producing larger electric field for same voltage
• Lead free piezoelectric materials

• More and more new inventions, some examples:
  • Ultrasonic knife for consumer use
  • Ultrasonic surgical for damaged tendon growth
  • Electronics cooling
  • Cell processing
About Ultrasonic Advisors

• Founded in 2019

• Expert advisory services to teams developing ultrasonic device products

• Past and active application areas
  • Atomizer, ultrasonic surgical transducers, ultrasonic motors, IOT sensors, various medical devices, portable ultrasonic devices

• Expertise in
  • Material selection, property characterization, mechanical design and analysis, electrical/circuit design and analysis, finite element simulations, device characterization, device optimization, and software and hardware development

• Best way to get in touch
  • Consultation call, email, email list

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