Piezo and pyroelectric properties of PZT thick films

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Dr Robert Dorey
Introduction

Why thick films?

Processing issues

Processing techniques

Properties

Applications
Why thick films?
### Introduction

<table>
<thead>
<tr>
<th><strong>Signal-to-noise ratio</strong></th>
<th><strong>SN</strong></th>
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<tbody>
<tr>
<td><strong>Sensitivity</strong></td>
<td><strong>S</strong></td>
</tr>
<tr>
<td><strong>Co-processing</strong></td>
<td><strong>CP</strong></td>
</tr>
</tbody>
</table>

1. Bulk processing  **SN**
2. Tape Cast         **SN / S**
3. Sol Gel           **S / CP**

**Alternatives?**
Processing issues
Processing Issues

Temperature

Reactions

Volatile compounds

Shrinkage
Processing Issues

Temperature

Reactions

Volatile compounds

Degradation of:

Substrates
Electrodes

Shrinkage
Processing Issues

Temperature

Reactions

Volatile compounds

Shrinkage

Reaction with:
Substrates
Electrodes

\[ Pb + Si = \text{Liquid} \ @ \ 714^\circ C \]
Processing Issues

Temperature

Reactions

Volatile compounds

Evaporation of Pb

Shrinkage
Processing Issues

Temperature

Reactions

Volatile compounds

Shrinkage

Shrinkage relative to substrate
Processing techniques
Processing techniques

Screen printing

Electrophoresis

Composite sol gel
Processing techniques

Screen printing

Electrophoresis

Composite sol gel
Processing techniques

Composite sol gel

PZT sol

Mix

Spinning of composite slurry

Dry

Pyrolyse

Sinter & Crystallise

PZT powder

Sol Infiltration & spinning

Mix

PZT powder

Sol Infiltration & spinning
Processing techniques

Composite sol gel film
Processing techniques

Sintering aid & Infiltration

(C+4S)₄

Sintering aid & Infiltration

(C+4S)₄

Infiltration
Processing techniques

Stepped composite sol gel film

Graded composite sol gel film
Processing techniques

Screen printed composite sol gel
Why thick films?
Processing issues

**Processing techniques**
Properties
Applications

Patterning
Wet Etching
Patterning

Powder Blasting
Properties
Properties

Difficult to compare films

Factors which can affect properties:

Composition
Film thickness
Grain size
Stress state
Crystal orientation
**Properties**

**Relative permittivity**

![Relative permittivity graph]

- Very similar results for hard and soft doped systems.
Piezoelectric Coefficient – $d_{33, f}$

![Graph showing the piezoelectric coefficient $d_{33, f}$ for Hard PZT and Soft PZT over different sol infiltration steps.](image-url)
Piezoelectric Coefficient – $e_{31, f}$

![Graph showing the piezoelectric coefficient $e_{31, f}$ for Hard PZT and Soft PZT over sol infiltration steps.](image-url)
Hysteresis

Bulk PZT (PZ26)  ComFi (PZ26)
Poling (X-ray Diffraction) - prediction

Before Poling  

During Poling  

After Poling
Properties

Poling (X-ray Diffraction)

Grain size broadening

- Normalised Intensity
- 0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0
- 42 43 44 45 46 47

- Bulk Composite
- Unpoled
- Poled

- Bulk PZ26
- Unpoled
- Poled
Poling (X-ray Diffraction)

Stress broadening
Properties

Pyroelectric

![Graph showing relative permittivity and loss vs. sol infiltration/pyrolysis stages](graph.png)

- Relative Permittivity
- Loss (%)

Sol infiltration/pyrolysis stages
Pyroelectric

![Graph showing the pyroelectric coefficient (C m⁻² K⁻¹) for different sol infiltration treatments. The coefficient increases with the number of treatments.](image-url)
Properties

Pyroelectric

Figure of merit

\[ F_v = \frac{P}{\varepsilon' (\varepsilon_r \tan \delta)^{\sqrt{2}}} \]

\[ F_d = \frac{P}{\varepsilon' \varepsilon_r} \]

Sol infiltration treatments

Screen printed material sintered at 1100 °C
## Properties

### Pyroelectric

<table>
<thead>
<tr>
<th></th>
<th>T max</th>
<th>$\varepsilon$</th>
<th>Loss (%)</th>
<th>$p$ \text{(x10}^{-4}\text{ Cm}^{-2}\text{K}^{-1})}</th>
<th>$F_V$ \text{(x 10}^{-2}\text{ m}^2\text{C}^{-1})</th>
<th>$F_D$ \text{(x 10}^{-5}\text{ Pa}^{-1/2})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PMNZT U</strong></td>
<td>1200 - 1300ºC</td>
<td>207</td>
<td>0.4</td>
<td>3</td>
<td>6.6</td>
<td>4.7</td>
</tr>
<tr>
<td>Tape cast</td>
<td>1250ºC</td>
<td>220</td>
<td>1.8</td>
<td>2.8</td>
<td>5.2</td>
<td>3.1</td>
</tr>
<tr>
<td><strong>PMNZT U</strong></td>
<td>1250ºC</td>
<td>220</td>
<td>1.8</td>
<td>2.8</td>
<td>5.2</td>
<td>3.1</td>
</tr>
<tr>
<td><strong>Screen</strong></td>
<td>1100ºC</td>
<td>220</td>
<td>1.7</td>
<td>1.2-1.5</td>
<td>2.7-3.9</td>
<td>0.8-1.1</td>
</tr>
<tr>
<td><strong>ComFi</strong></td>
<td>700ºC</td>
<td>350</td>
<td>3.0</td>
<td>2.74</td>
<td>3.45</td>
<td>0.94</td>
</tr>
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</table>
Examples of applications
Applications

200 MHz Ultrasonic transducer
Applications

Unimorph structures

Multi-arm actuator prototype

Diaphragm prototype structure
(image courtesy of EPFL- Parmenide project)
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