Acoustic Characterization of Materials

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Acoustic Characterization of Materials

**Current Projects - B. Tittmann:**

1. “Ultrasonic transducer irradiation test” ATR-NSUF
2. “Ultrasonic Flaw Detection” Bechtel Bettis
3. “High Temperature Transducers” with C. Lissenden, NEUP - DOE
4. “Characterization of Plant Cell Walls” with D. Cosgrove. EFRC-DOE
5. “Post irradiation test support” NEET-DOE

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Students – B. Tittmann:

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Yanran Wang

Visiting Scholars: M. Foutuhi; M. Schraff

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Ultrasonic Transducer Irradiation

ATR-NSUF-DOE
(A dvanced Test Reactor - National Scientific User Facility, Department of Energy)

B. Reinhardt and B. Tittmann
Acoustic Characterization of Materials

OUTLINE

1. Needs of the nuclear industry
2. Utility of ultrasound
3. Limitations of ultrasonic transducers
4. Dave Parks Thesis
5. Purpose of Experimentation
   • Demonstrate feasibility at high exposure
   • Magnetostrictive, Piezoelectric
   • Study sensor material evolution for future measurements
6. Significance
   Characterization is easily implemented once feasibility is demonstrated.
Purpose and Impact of Project

ATR-NSUF Transducer Irradiation

Dr. Bernhard Tittmann, Brian Reinhardt
Detailed Outline

• Needs of the nuclear industry
• Utility of ultrasound
• Limitations of ultrasonic transducers
• Dave Parks Thesis
• Purpose of Experimentation
  – Demonstrate feasibility at high exposure (magnetostrictive, piezoelectric)
  – Study sensor material evolution for future measurements
• Significance
  – Characterization is easily implemented once feasibility is demonstrated.
Increase safety and improve performance

- Enhanced accident tolerance
- Higher performance (increased burn rates)
- More accurate theoretical models
- In-situ monitoring

Current Monitoring Methods

• Temperature
  – Melt Wires (post examination required)
  – Thermocouples (Drift due to neutron exposure)

• Gamma Heating
  – Degradation of thermocouples (single measurement)

• Density/Fission Gas
  – LVDT
  – Diameter Gauge

• Young's Modulus
  – Loaded creep specimen (No practical for in-situ monitoring)

• Crack growth
  – Must be done out of pile
Paradigm shift from cook and look

Extreme CAUTION and COST for FEW data points
Current Relevant Ultrasonic Applications

• The following applications are well established:
  – Condition monitoring of check valves in nuclear power plants (J. Lee, M. Lee, Kim, Luk, & Jung, 2006)
  – Ultrasonic thermometers (Rempe 2011a)

• The following applications are currently under concerted development:
  – Ultrasonic fission gas release monitor (Villard & Schyns, 2009)
  – Under sodium viewing transducer (Kažys, Voleišis, & Voleišienė, 2008)
  – Fuel porosity measurements (Phani et al., 2007)
Typical Piezoelectric Response

Barium Titanate

PZT

Fig. 3. The different radiation damage rates in BaTiO₃ crystals which were in the poled and unpoled state during irradiation result in different magnitude of degradation in $P_r$ for identical exposures. The dashed line represents data from the first loop after irradiation of unpoled samples, while the data for the solid line are from the first loop from crystals which were in the poled state during irradiation. The $P_{r0}$ represents the unirradiated value for the remanent polarization.

Glower et. al, JAP 36,7 1965
Prior Research

PC
LabView

Pulser/
Receiver

Network
Analyzer

RG 213 U
cable 62’

rad hard
cable 4’

Aluminum
Alumina
Alumina
Aluminum
C-C
AIN
Aluminum

Penn State Radiation Science
and Engineering Center
Basic Results of Radiation Hardness of AlN

- Pulse Echo Amplitude with Reactor Turned off

- Observed a minor amplitude increase
- Data collected over 3 months
Gamma Heating Measurement

• Isotope generation adds 20° C to calculated temperature

• Isotope generation causes remnant heating after long irradiation 4° C
AlN Radiation Hardness Conclusion

- The AlN transducer is unaffected by:

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>fast neutrons</td>
<td>$1.85 \times 10^{18}$ n/cm²</td>
</tr>
<tr>
<td>thermal neutrons</td>
<td>$5.8 \times 10^{18}$ n/cm²</td>
</tr>
<tr>
<td>Gamma dose</td>
<td>26.8 MGy</td>
</tr>
<tr>
<td>Thermal cycles to 100 C</td>
<td>~200</td>
</tr>
</tbody>
</table>

- Post irradiation testing is simplified due to lack of activity >1μRad/hr at 10 cm

- Post irradiation testing revealed $d_{33}$ as 5.5 pC/N
  - (upper end of literature values for pristine samples)

- Not only does the transducer survive but it measures:
  - Temperature during irradiations
  - Time of flight throughout exposure
Magnetostrictive Transducers

• Certain Magnetostrictive Transducers have high Curie temperatures and are therefore candidates for insertion into a reactor.
Project Objectives

It is the objective of this project to subject three piezoelectric and three magnetostrictive transducers to in-pile conditions at the MITR up to at least \(10^{21}\) n/cm\(^2\) to evaluate their performance and life span in such an environment.
Significance

- In-Pile Instrumentation
- Material Properties
- Prognosis
- Non Destructive Evaluation
- Structural Health Monitoring