Mirror Technology Days

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Advanced Ultrasound NDE for SiC Optics Using Single Crystal Composite Transducers

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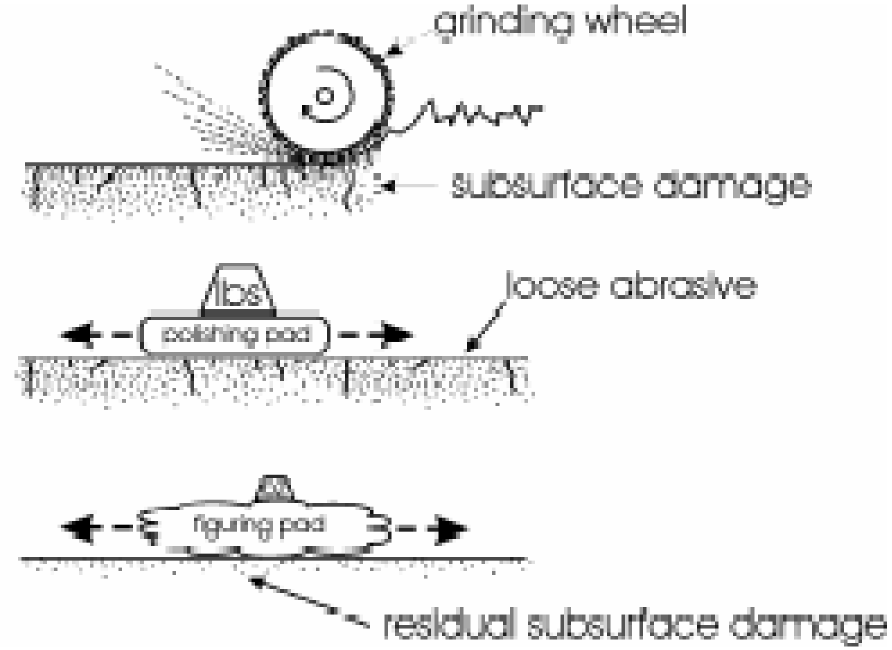
Outline

- **Background:**
  - **--** Ultrasound NDE
  - -- High Frequency Ultrasound
- **Single Crystal Piezoelectric Composite Ultrasound**
  - **--** Single crystal piezoelectrics
  - -- Piezoelectric composites
  - -- Composite transducers
- **C-Scan experiments**
- **Summary**

NDE for Ceramics

Ceramic Defects: crack, void, delamination, residue stress, inclusion, etc.

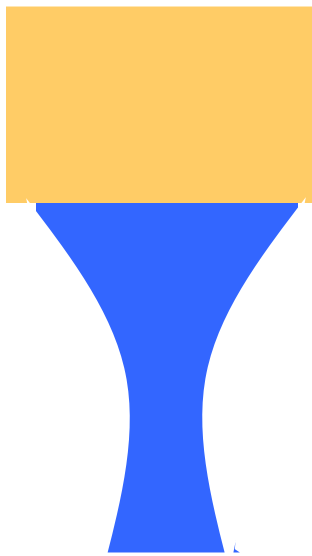


-- RAPT Industries, "Rapid Fabrication of Lightweight SiC Mirrors Using RAPTM Processing", Mirror Tech Days'06, Albuquerque, AL, 2006.

- Optical metrology: surface damage (SD).
- X-ray: can not distinguish damage at various depths and has limited resolution.
- Acoustic NDE: lack of high frequency phased array for in-situ real time imaging of large volume slices and acceptable spatial resolution.

Ultrasound NDE

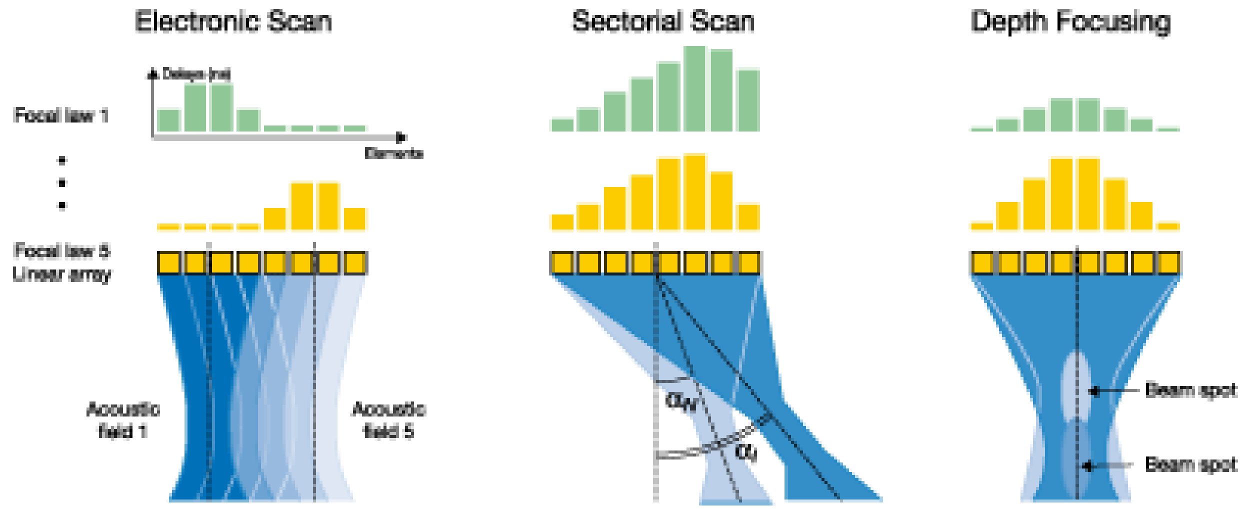
Single Element



•Frequency, F#: high resolution at both axial and lateral, limited penetration depth

•Mechanical scanning

Phased Array



•Frequency, element numbers: high resolution in axial, lateral and sectoral direction, high penetration depth;

•Electronic scanning

--*M. Moles, "Ultrasonic Phased Array", http://www.olympusndt.com/en/ultrasonic-phased-array/.*

High Frequency Ultrasound

- **Currently available HF transducers**

-- Piezoelectric Materials: ZnO, $LiNbO_3$, PVDF, and PZT—low piezoelectric response

-- Thickness mode: kt < 0.5

-- Array: frequency < 20 MHz, limited in fabrication of fine pitches

- **TRS Approach: PC-MUT**

-- Material: single crystal piezoelectric 1-3 composite—high piezoelectric response

-- Effective k33 mode: kt > 0.7 (@ 40 MHz)

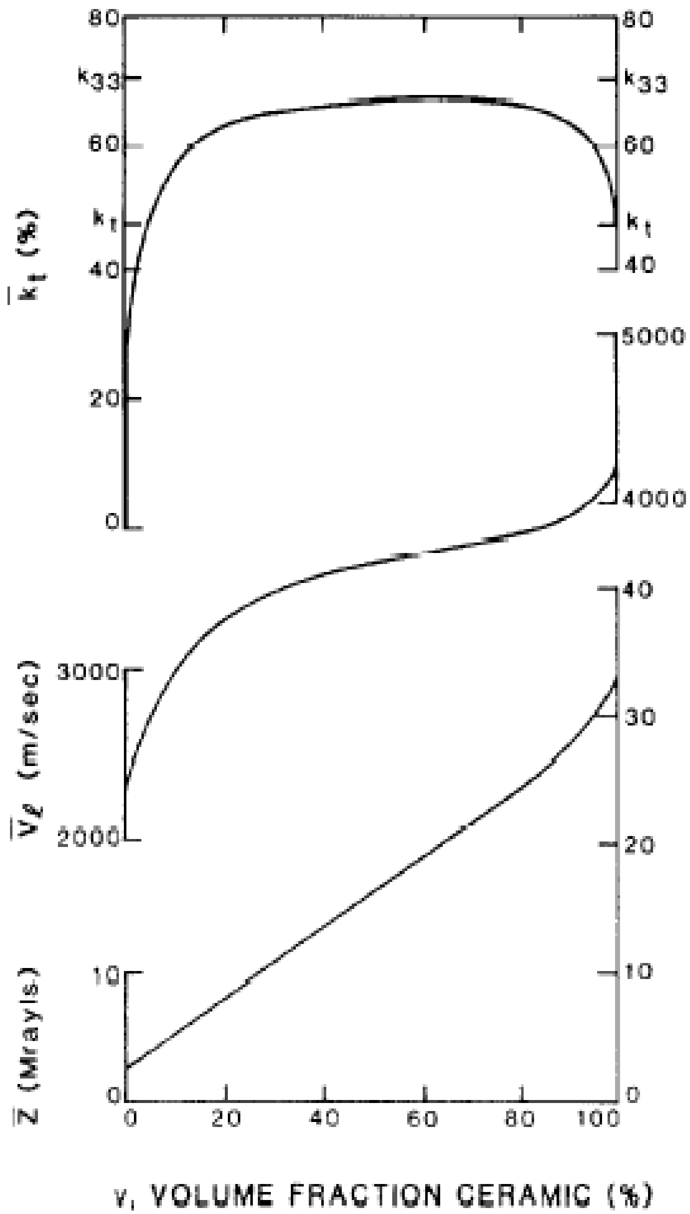
-- Array: fine pitches can be fabricated using photolithography based deep reactive ion etching process

Single Crystal Piezoelectrics vs. PZT

Property	Type II PZT (TRS200)	Type III PZT (TRS300)	Type VI PZT (TRS610)	PZN-4.5%PT Crystal	PMN-33%PT Crystal
Dielectric Constant	2050	1000	3900	5200	8000
Dielectric Loss	0.018	0.003	0.025	0.008	0.008
Curie Temperature	340°C	300°C	210°C	155°C	166°C
Piezo. Coeff. d_{33} (pC/N)	400	225	690	2000	2250
Coupling Constant k_{33}	0.73	0.64	0.79	0.91	0.91
Young's Mod. (GPa)	59	74	47	8.3	12
Mech. Quality Factor, Q_m	77	800	46	40	~50
Uses	Accelerometers, Actuators, Flow Meters, Hydrophones	Sonar Projectors, Cleaners, Therapeutic Ultrasound	Ultrasound Imaging Transducers, Actuators, Hydrophones	Ultrasound Imaging, Actuators, Sonar, Accelerometers	Ultrasound Imaging, Actuators, Sonar, Accelerometers

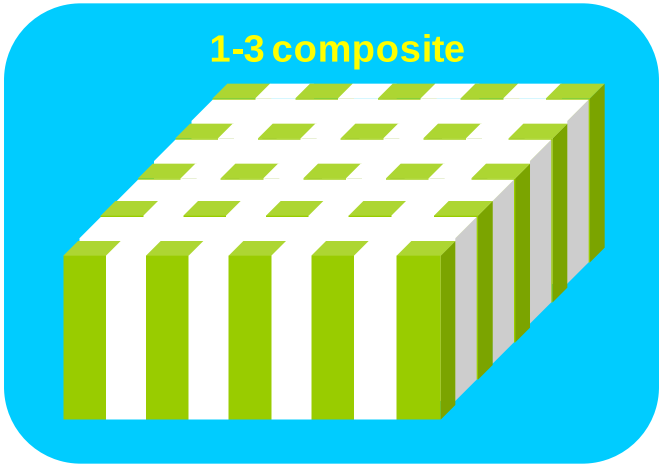
Introduction

Piezoelectric Composites



Piezoelectric composites for Ultrasound Transducer

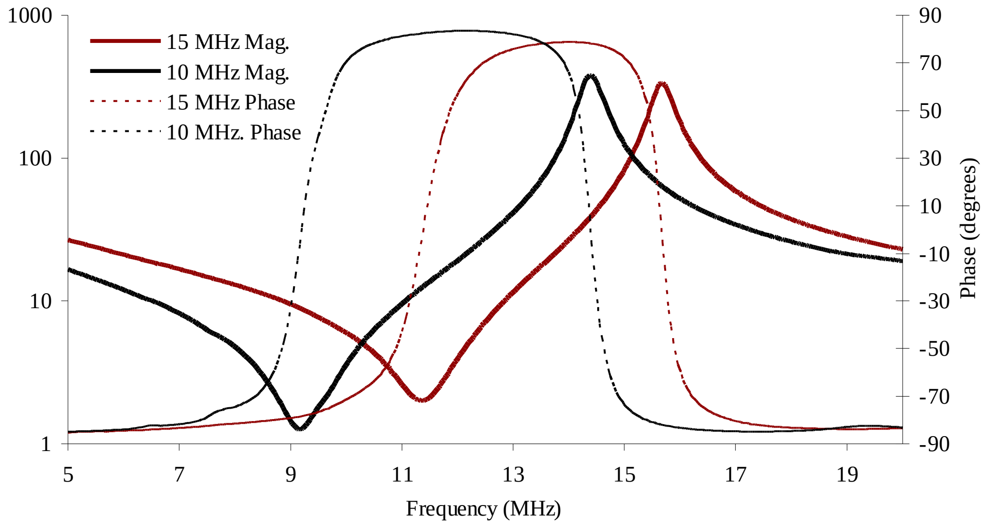
1) High electromechanical coupling;
2) Weak sidelobes;
3) High resolution because of the low-Q induced short pulse;
4) Wide bandwidth;
5) Low acoustic impedance for better acoustic matching.

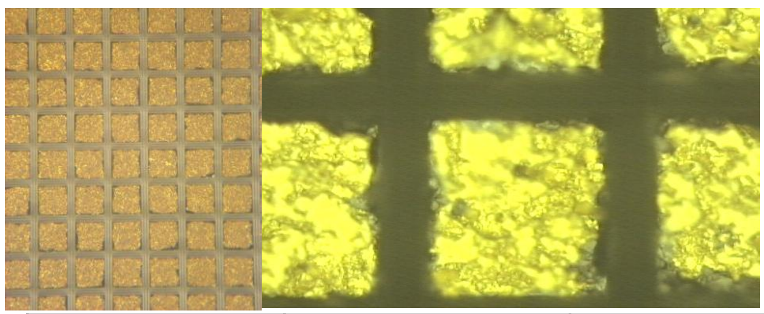


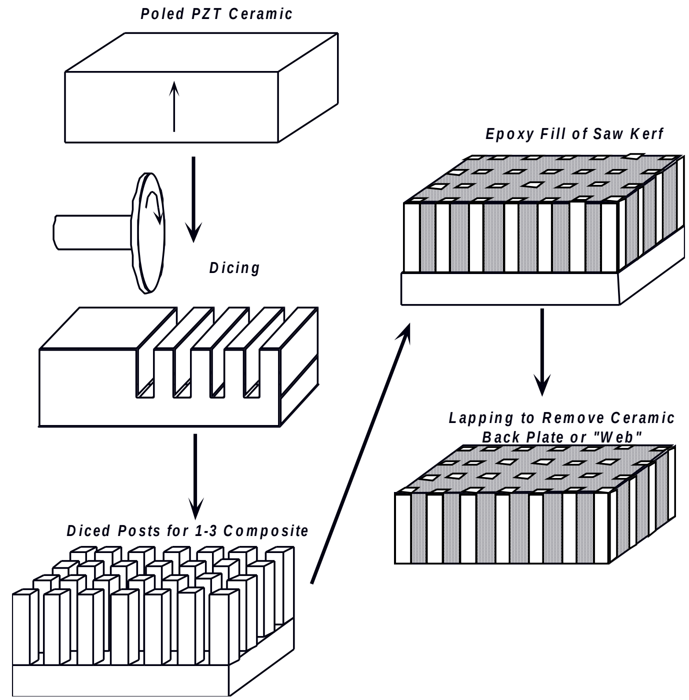
-- W.A. Smith and B.A. Auld, IEEE Trans. UFFC, pp.40-47, 1991.

Single Crystal Piezoelectric Composites

Fabrication





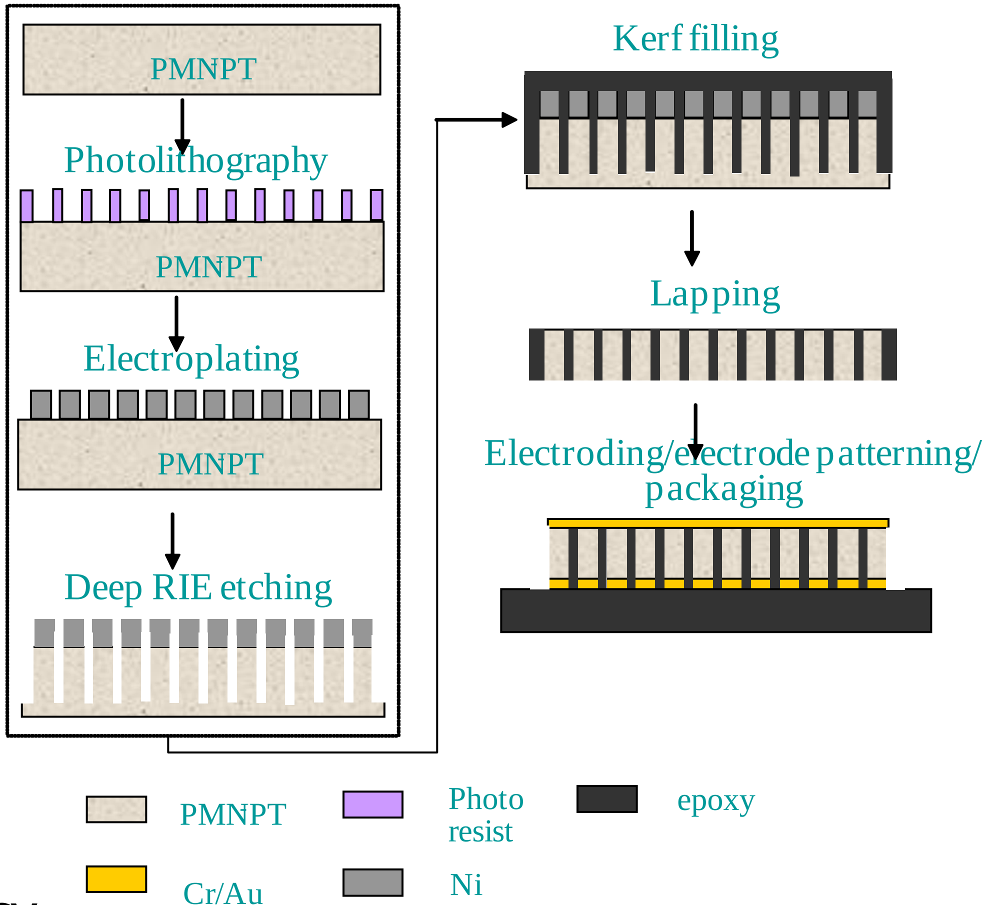


Frequency	Dielectric constant (K^T)	Dielectric constant (K^S)	Dielectric loss	Coupling coefficient
10 MHz	2135	527	0.016	0.79
15 MHz	1503	383	0.012	0.76

High Frequency Composite Fabrication

PC-MUT

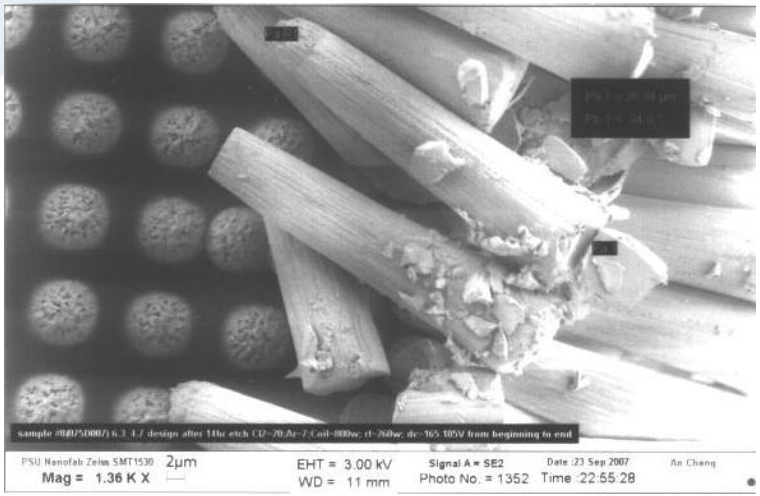
- Use Photolithography & Plasma Etching
- Form Fine Features in High Performance Single Crystal
- High Frequency, High Performance Composite
- Very High Resolution, Broad Bandwidth Single Elements
- Basis for Very High Frequency Integrated Array Transducers

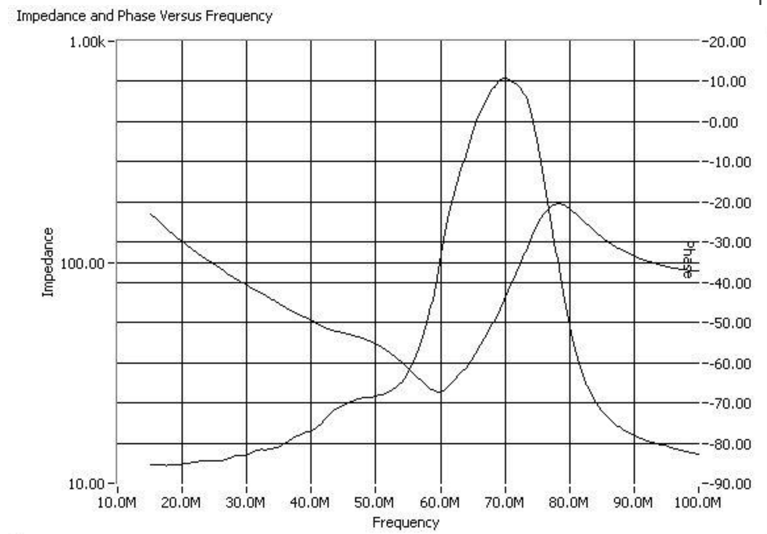


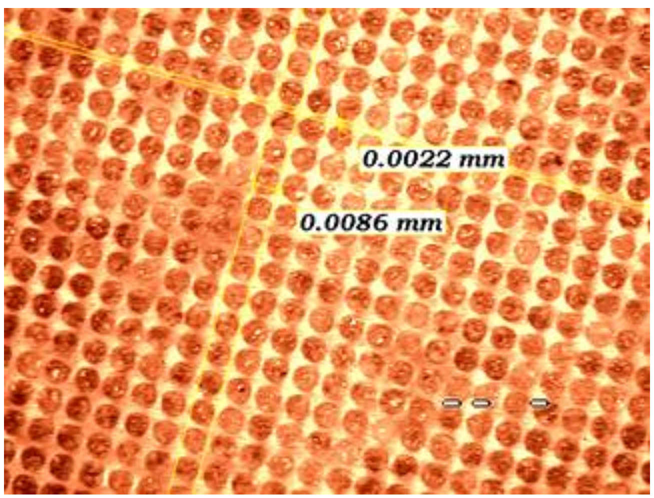
TRS Technologies

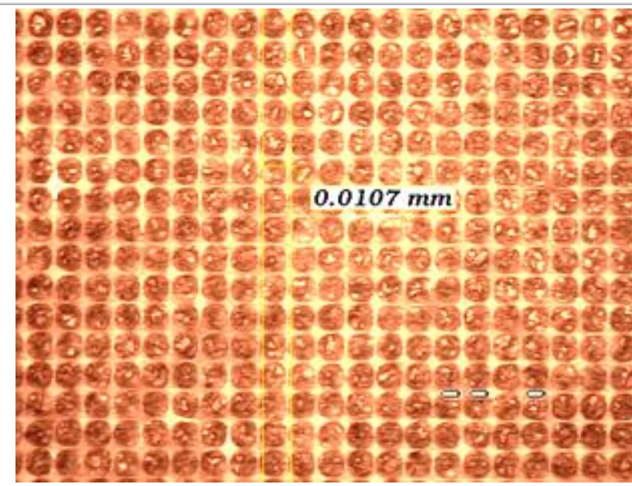
Microfabrication and Composite Characterization

PC-MUT



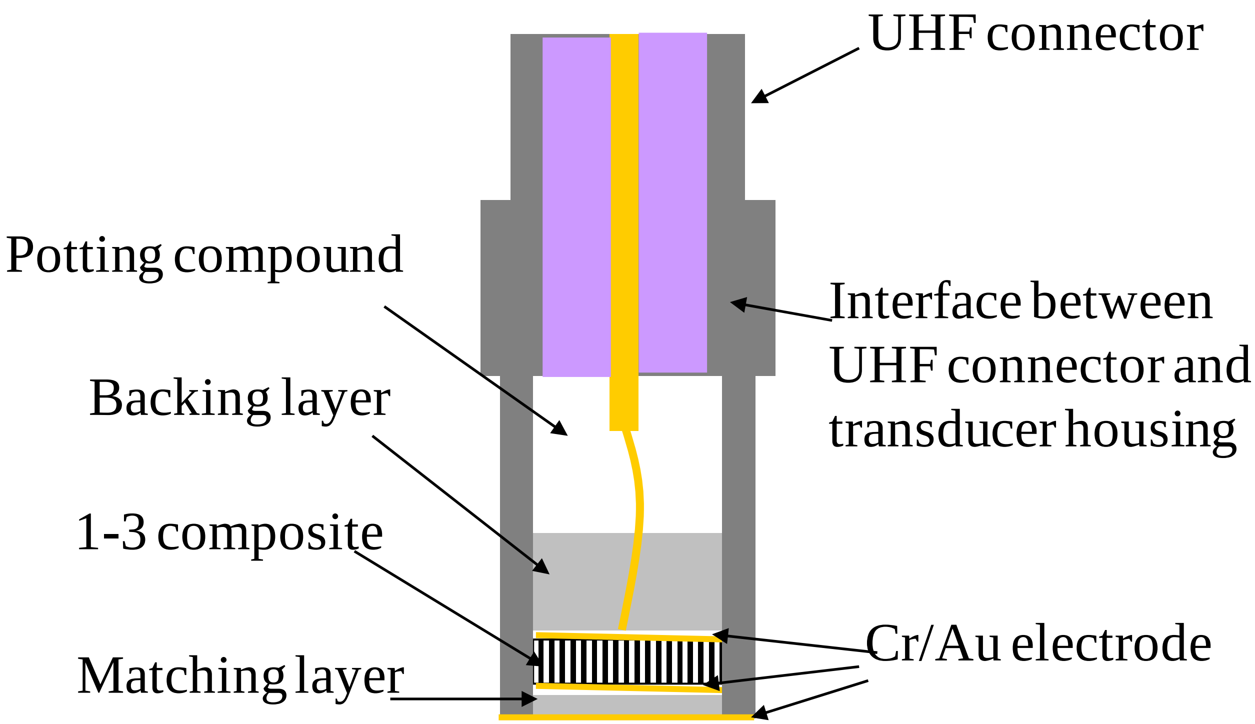




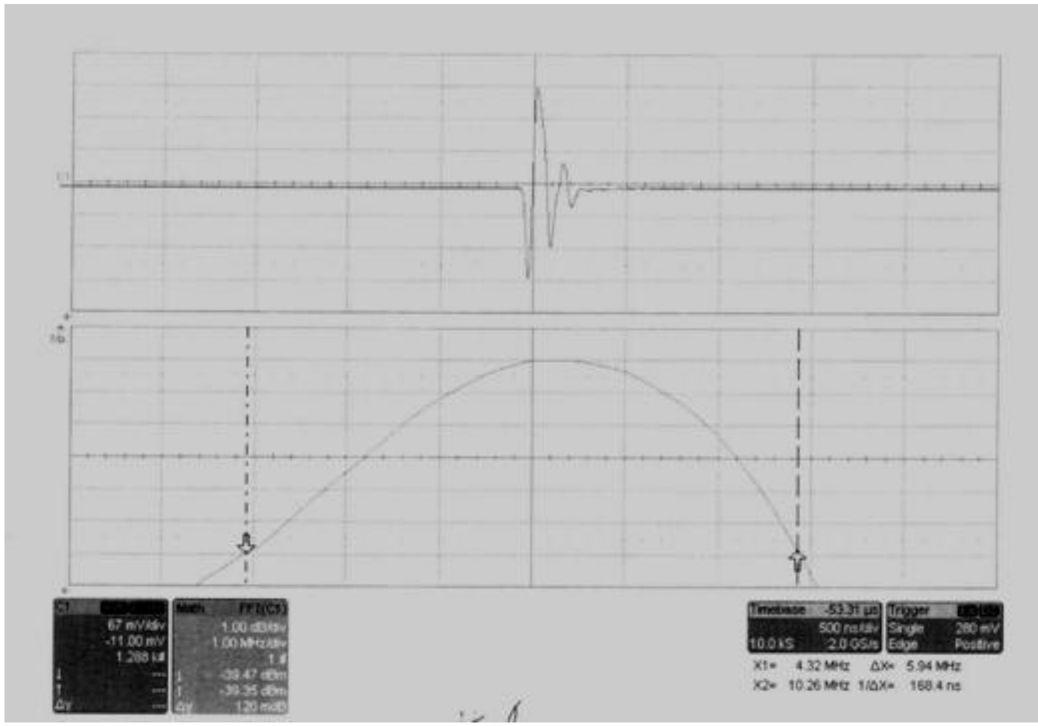


Samples	f_r (MHz)	f_a (MHz)	k_{eff}	Kerf (μm)	Thickness (μm)	Dielectric loss
75 MHz sample	60.1	78.1	0.67	< 3	~ 20	0.06

Piezoelectric Composite Transducers



Pulse-Echo Tests (10 MHz)

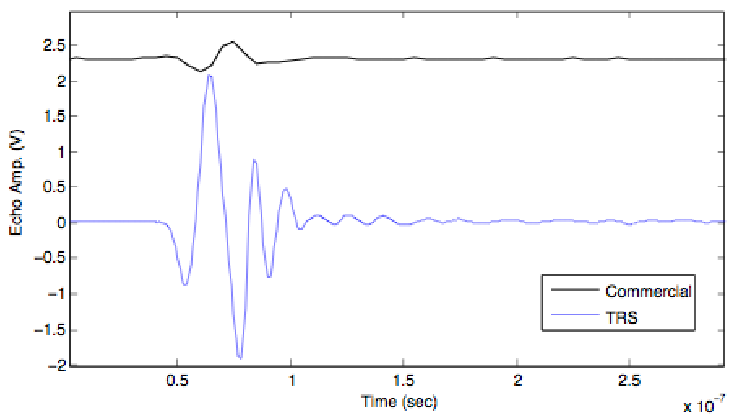


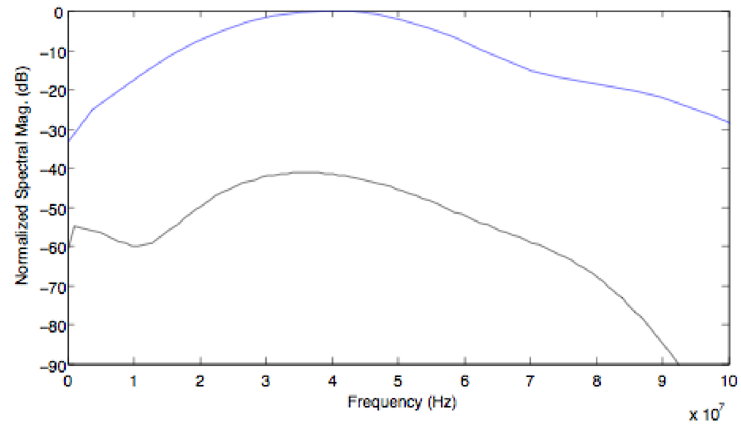
-6 dB bandwidth: ~ 90%

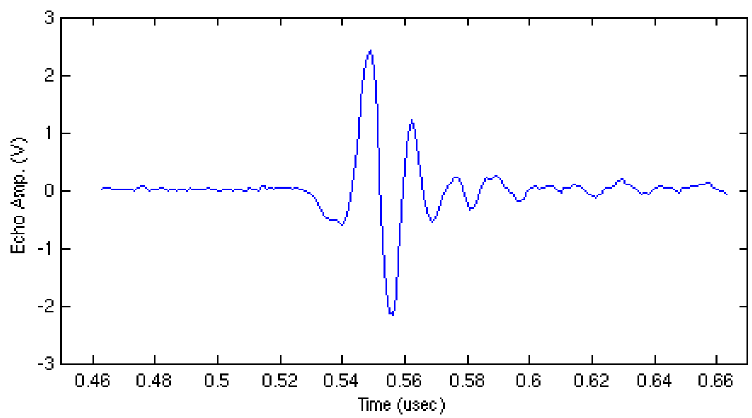
Loop sensitivity: -28 dB

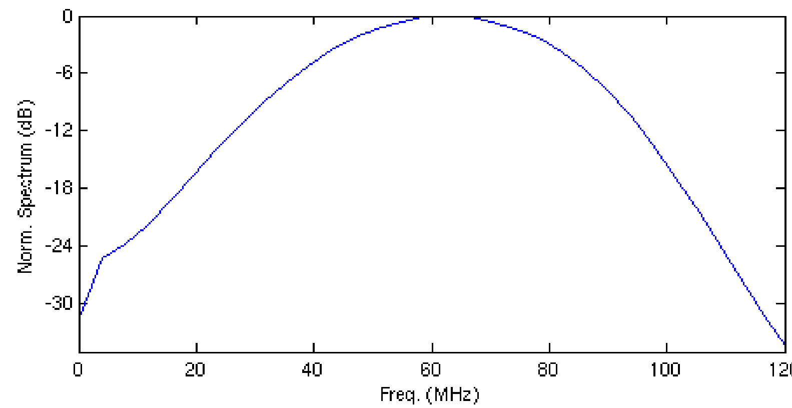
-20 dB pulse width: 0.28 us

Pulse-Echo Tests (75 MHz)





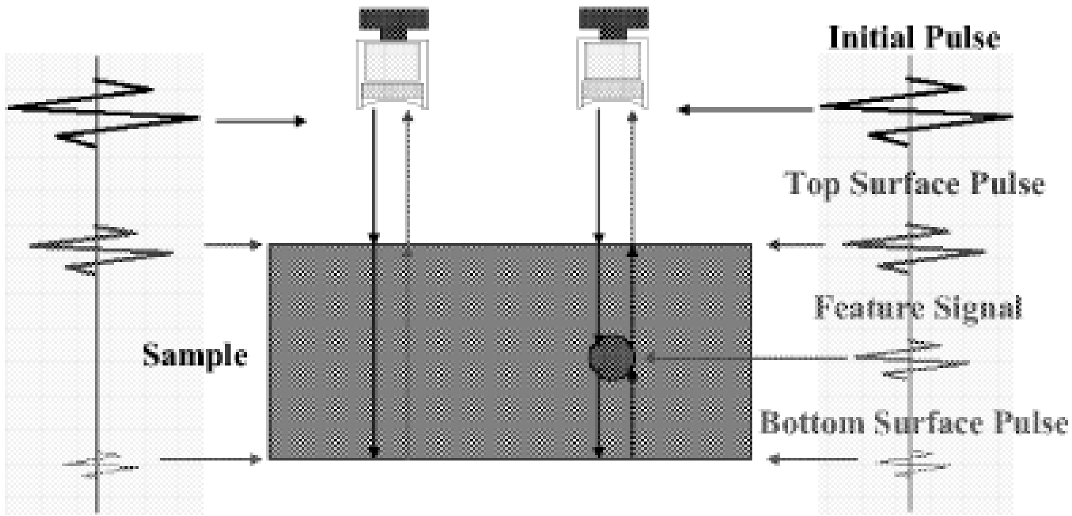




-6 dB bandwidth: ~ 80-90%

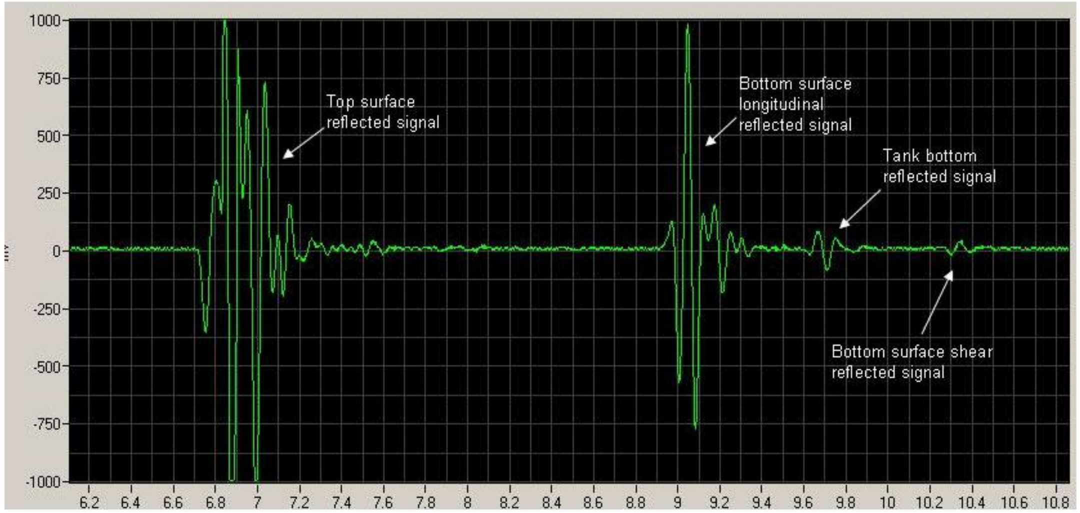
-20 dB pulse width: 0.03-0.06 us

C-Scan Experiments



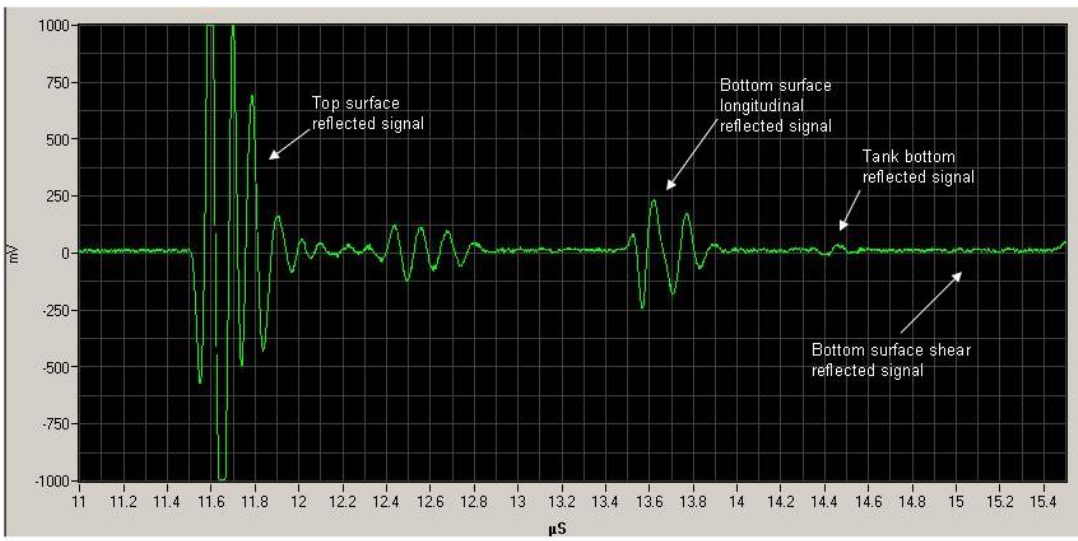
- Parameters to be measured: reflected pulse amplitude (top and bottom), time-of-flight (TOF) from bottom to top
- Mechanical scanning

Pulse-Echo Response



TRS 10 MHz (Receiver gain: -5 dB)

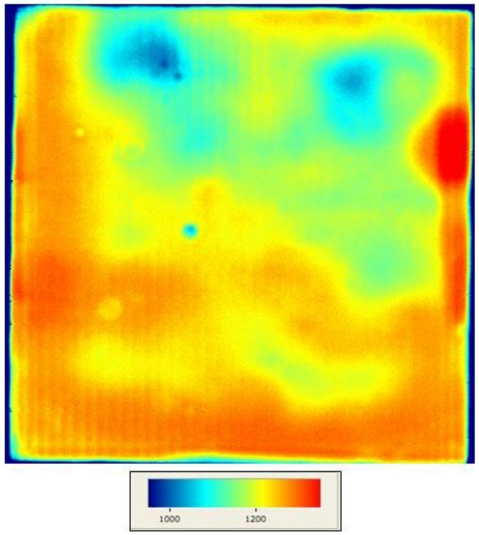
13 mm thick SiC tile



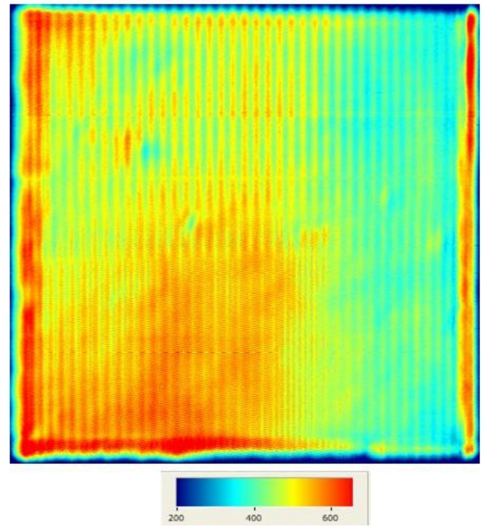
Commercial 10 MHz (Receiver gain: 20dB)

10 MHz C-Scan Experiments

13 mm sintered SiC

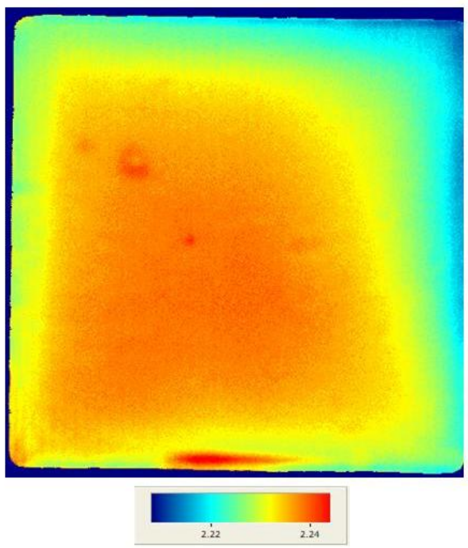


TRS 10 MHz

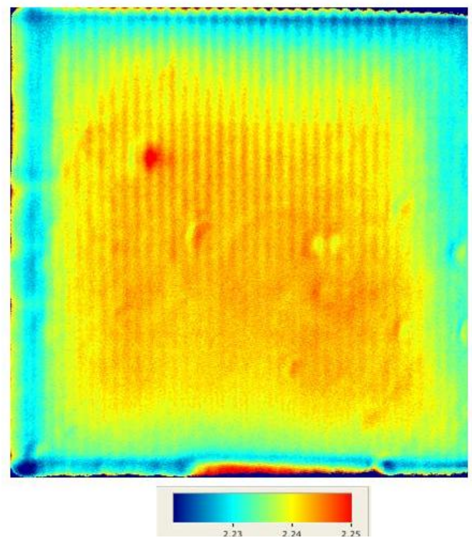


Commercial 10 MHz

Bottom Reflected amplitude



TRS 10 MHz

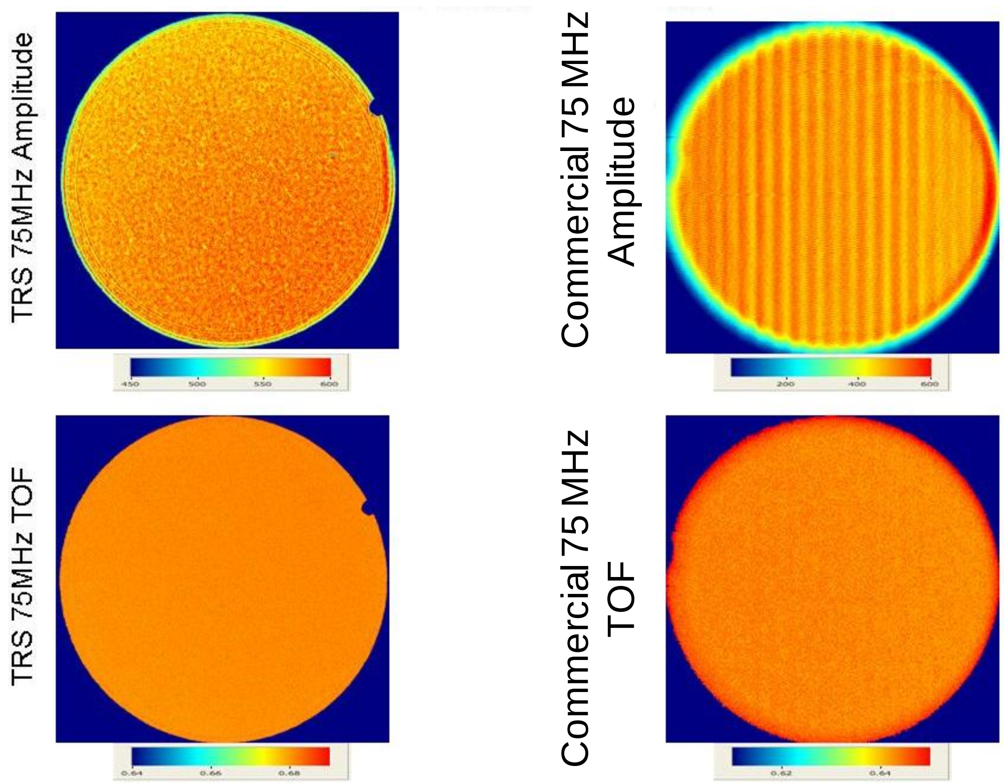


Commercial 10 MHz

Bottom to top TOF

75 MHz C-Scan Experiments

4 mm CVD SiC



Bottom Reflected amplitude

Bottom to top TOF

Summary and Future Work

- PMN-PT single crystal/epoxy 1-3 composites with frequency of 10 MHz, 15 MHz, and 75 MHz were successfully fabricated using the dice-and-fill and PC-MUT techniques.
- PMN-PT single crystal composites showed electromechanical coupling coefficients of ~0.67-0.79, and the loss remains low (< 0.06).
- The prototyped composite transducers exhibited high sensitivity and broad bandwidth, which was confirmed by C-Scan imaging experiments.

Future Work: High frequency PC-MUT phased array for NDE.

Acknowledgement

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- Authors would like to acknowledge the transducers fabrication and characterization assistance from Hua Lei, Chad Sunderland, and Brad Dunkin at TRS, helpful discussions from Dr. Larry Kessler at Sonoscan.
- Chris Duston and Michael Ngo from POCO are also greatly acknowledged for providing SiC samples.
- Micromachining processes were conducted at Penn State NanoFab (NSF).