Ultra Precision Grinding Demonstrated in the Fabrication of High Frequency Piezoelectric Ultrasonic Transducers

Speaker
Dr. Jean-François Saillant

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S. Cochran, J.F. Saillant

University of Paisley, Paisley, UK

D. MacLennan

Medical Devices Doctoral Training Centre, University of Strathclyde, Glasgow, UK

T.W. Button, H. Hughes

Applied Functional Materials Ltd, Edgbaston, Birmingham, UK

M. Ponting, J. Sweet

Loadpoint Ltd, Chelworth Industrial Estate, Cricklade, Swindon, Wilts., UK

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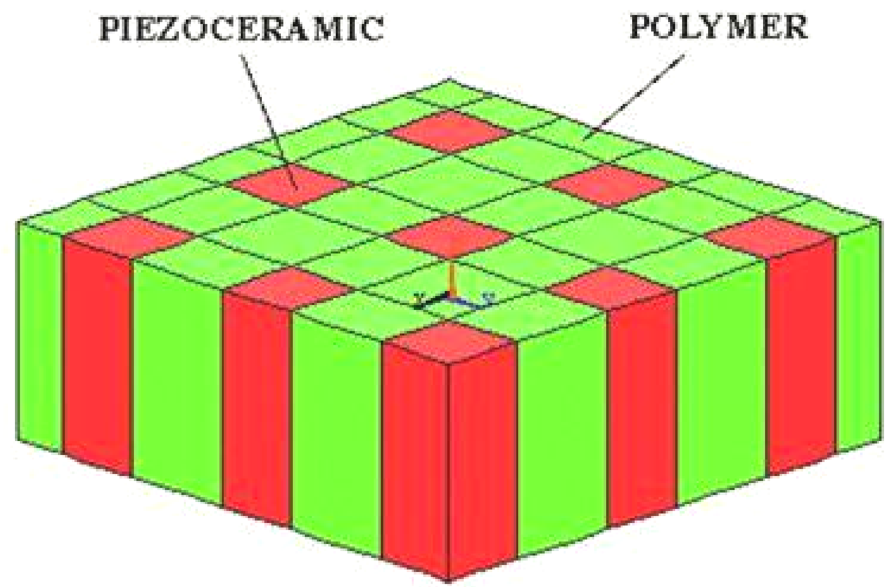
Outline

- Context
- Ultra precision grinding
- Results
  - Surface morphology of piezoceramic, polymer and piezocomposite
- Summary and conclusions

Context

Piezocomposite material

- Ubiquitous in ultrasound transducers for several applications
- Advantages:
  - high electro- -mechanical coupling
  - low acoustic impedance
  - low extraneous modes



- Material of choice for ultrasound at lower frequencies
- Production of active layers for high-frequency ultrasound remains a challenge.

Context

Ultra precision grinding

Results

Summary

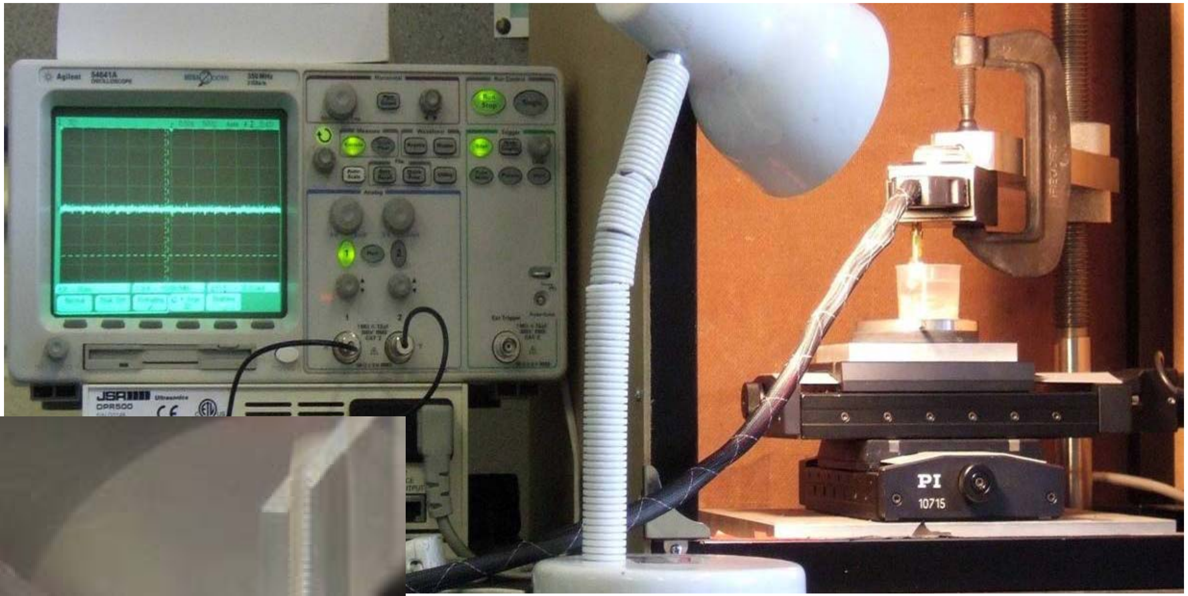
High Frequency Ultrasound

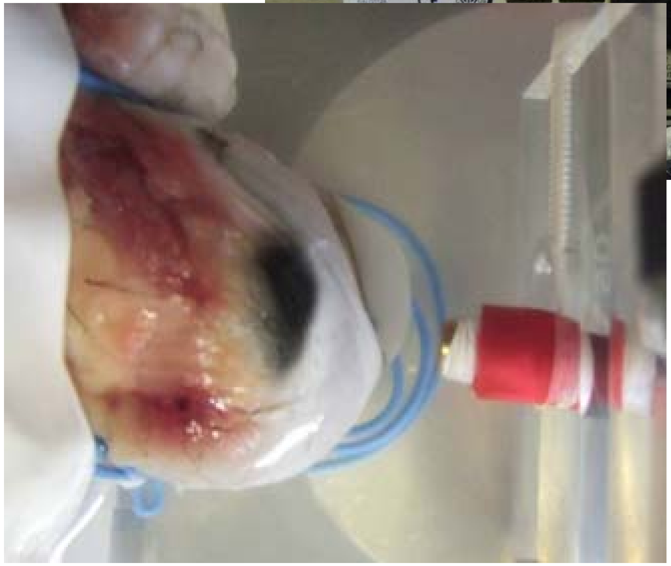
- High-frequency ultrasound has applications in both medical diagnostics and non-destructive testing, where high resolution imaging is required.

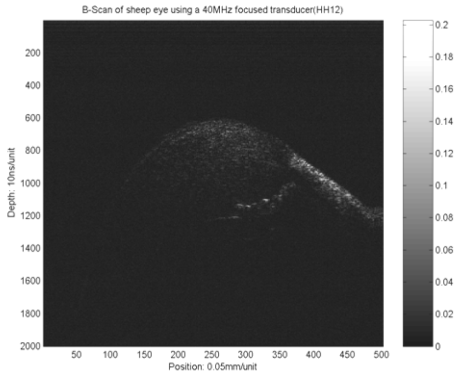
- AFM Ltd have produced piezocomposite transducers operating at 40 MHz capable of resolving 10 µm wire structures and details of a sheep's eye.

High Frequency Ultrasound

B-Scan Setup: Sheep's eye imaging

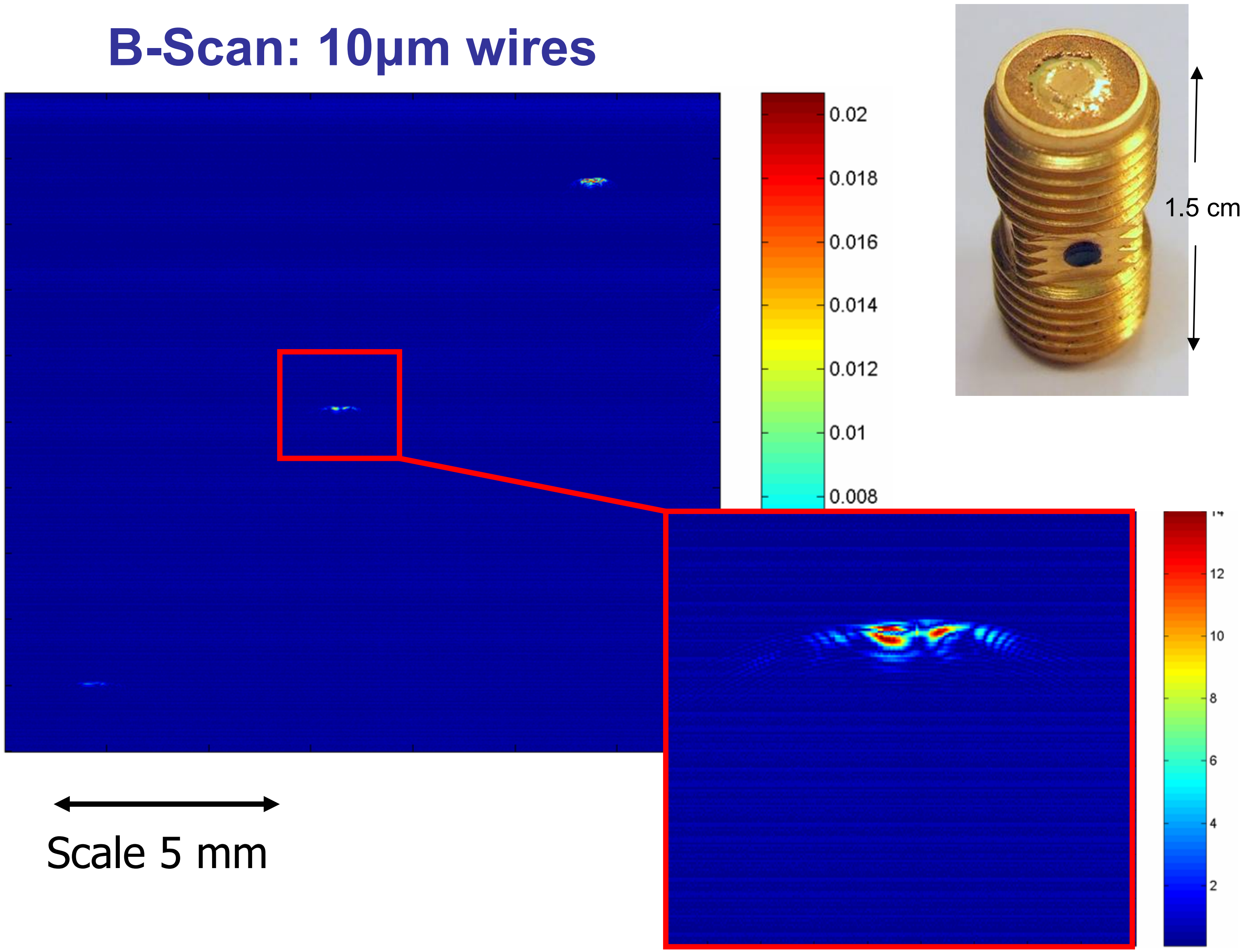






High Frequency Ultrasound

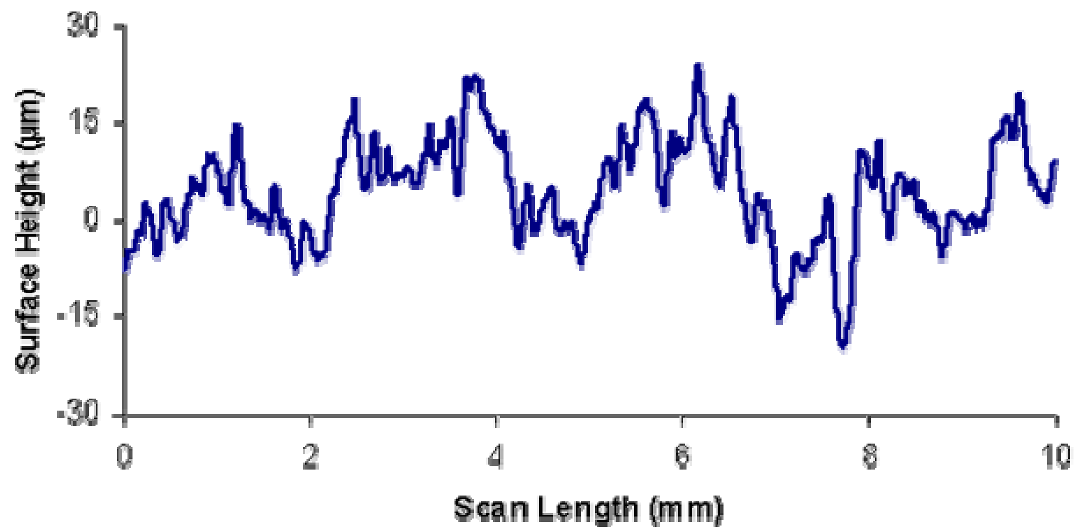
B-Scan: 10µm wires



Ultra precision grinding

Surface Flatness

- Conventional grinding techniques do not always achieve sufficiently uniform flatness across the piezocomposite layer surface.



- The surface profile of a composite shows over ±15 µm roughness
  - Nearly 80% of the active layer thickness of 35-45µm required in high frequency transducers

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Surface Flatness

- Precision lapping can be used, but is slow, particularly for uniformity across two-phase materials.
- Process uses:
  - Flat abrasive wheel
  - Abrasive slurry with particles of calibrated dimensions e.g. calcined Al_2O_3
  - Movable vacuum chuck for holding the sample
  - Flatness monitor

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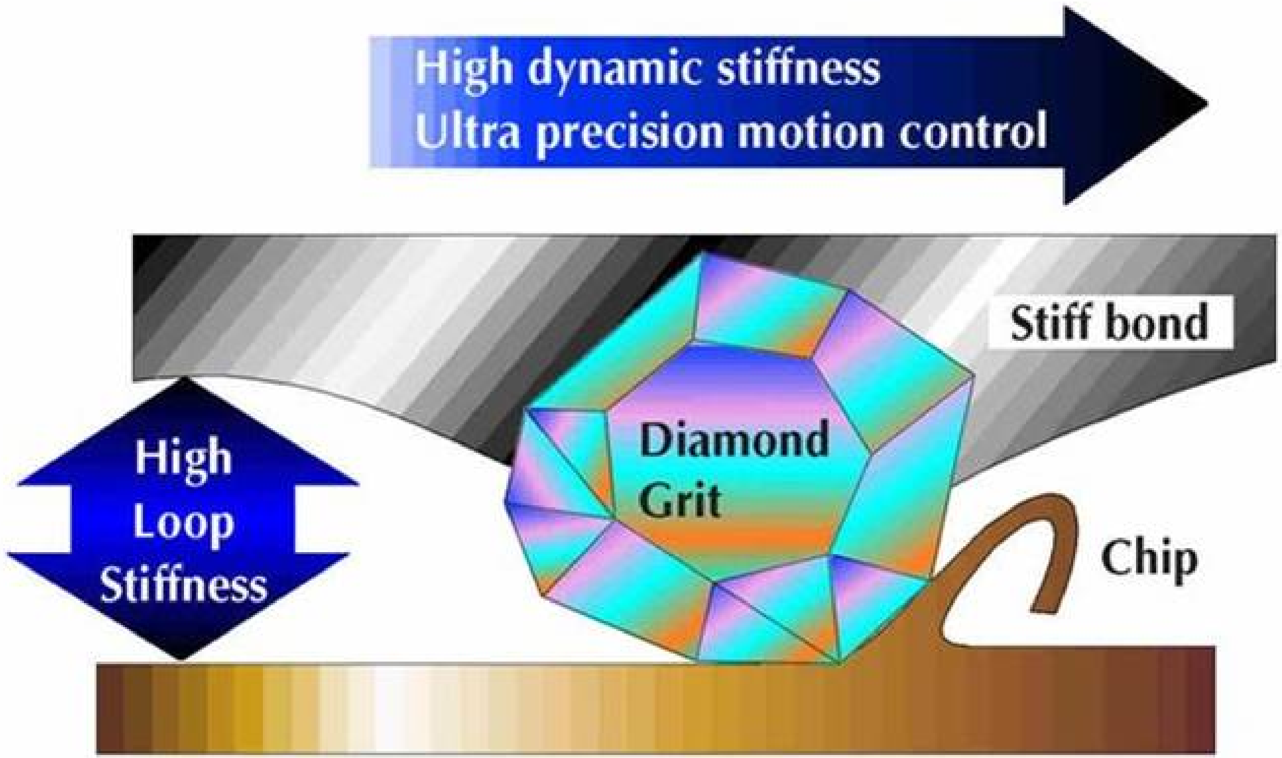
Ultra Precision Grinding

- Alternative process is ultra precision grinding
  - Loadpoint PicoAce NanoGrinder
  - Optical quality finishes and low levels of sub-surface damage on a range of material
  - Traverse grinding of flat or convex surfaces up to 305 mm in diameter
  - Plunge grinding to a maximum diameter of 200 mm

Ultra Precision Grinding

Mechanism of 'Ductile' or 'Shear Mode' CNC Grinding of Brittle Metals

This demands high precision, high stiffness machine tools and achieves very high surface smoothness with virtually no sub-surface cracks



- No micro cracks
- Very low depth of dislocation strain damage

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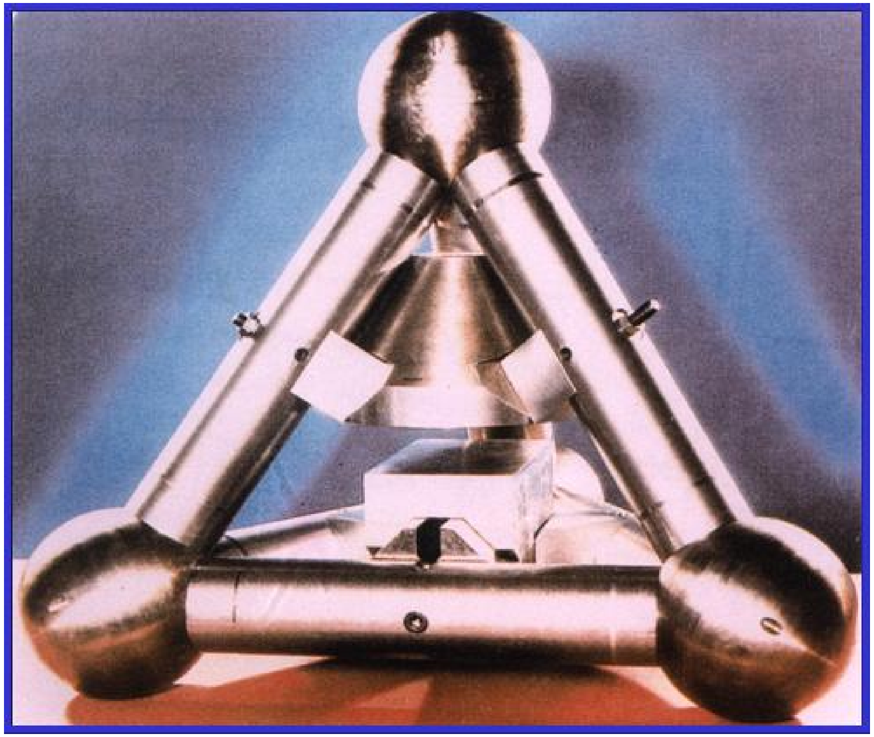
- The PicoAce's main pyramidal space frame structure is extremely stiff [1] and all key elements are designed to maximise damping.

- The resonant frequency is very high, ultra high stiffness hydrostatic oil bearings are used on all axes and an air bearing is used for the grinding spindle.



Loadpoint PicoAce NanoGrinder

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- *In process grinding wheel conditioning PicoAce ®© principles have been proved on Tetraform C machine that has ground 6 Å Ra surfaces on quartz and 1.06 nm Ra surfaces on glass [2].*

Loadpoint PicoAce NanoGrinder

- The general arrangement of PicoAce includes:
  - cup wheel grinding spindle
  - rotary work table
  - X and Z slideways mounted in a closed loop structure.
- The cup wheel spindle has a vertical axis and slides up and down in a cylindrical Z slideway positioned centrally over the base, with the rotary table mounted on the X slideway beneath.

Loadpoint PicoAce NanoGrinder

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Results

Methodology

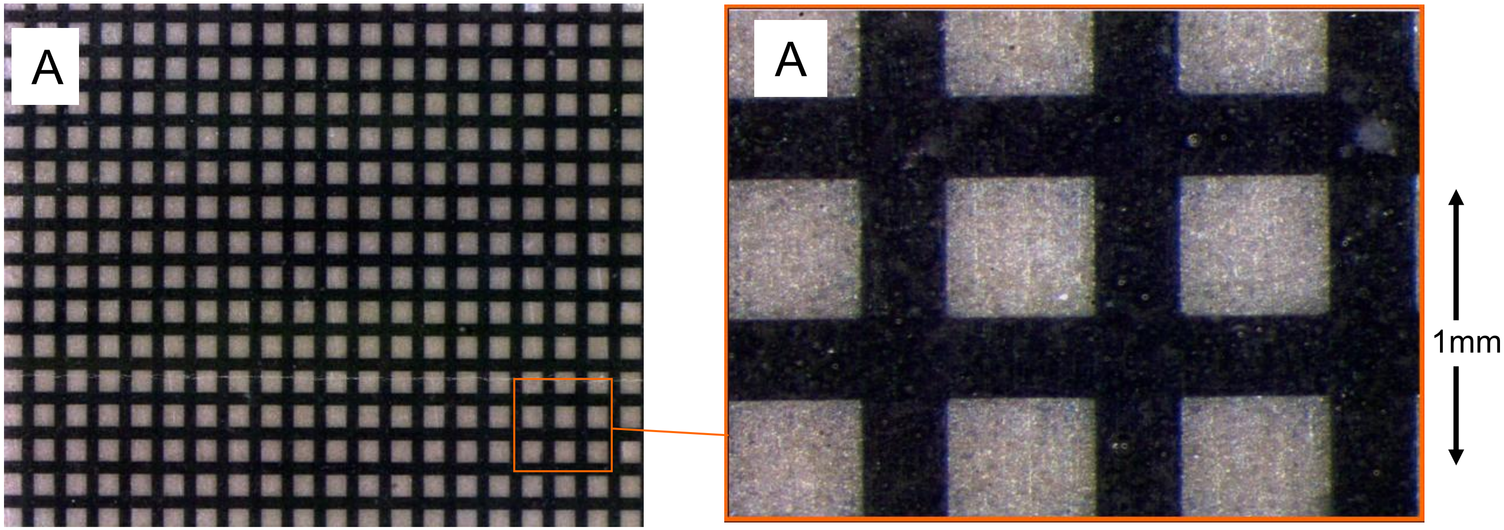
In the work reported here, ultra precision grinding was carried out on three separate composite configurations:

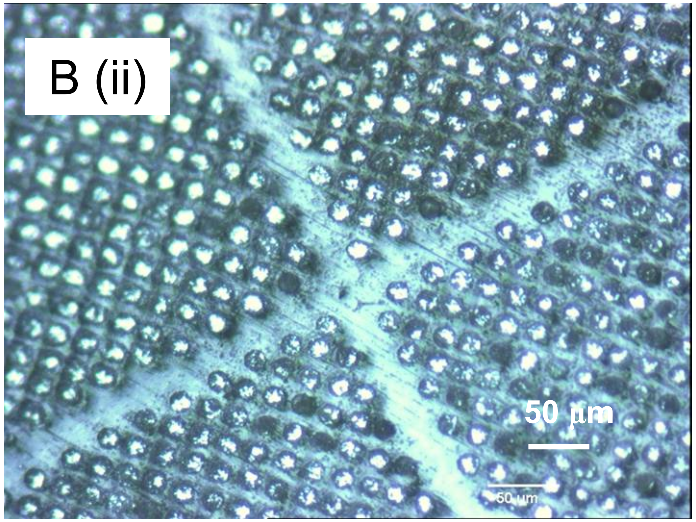
- ***Sample A*: PZT-4 piezocomposite made by standard dice and fill methods, ground by ultra precision grinding.**

- ***Sample B(i)*: High frequency composite made from Viscous Polymer Processing (VPP) ceramic using Mechanical Pattern Transfer (MPT), ground by precision lapping.**

- ***Sample B(ii)***: High frequency composite made from Viscous Polymer Processing (VPP) ceramic using Mechanical Pattern Transfer (MPT), ground by ultra precision grinding.

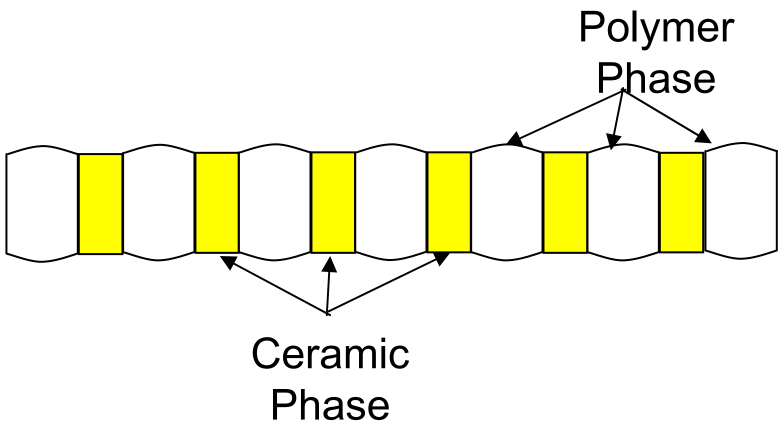
Results: Optical Microscopy

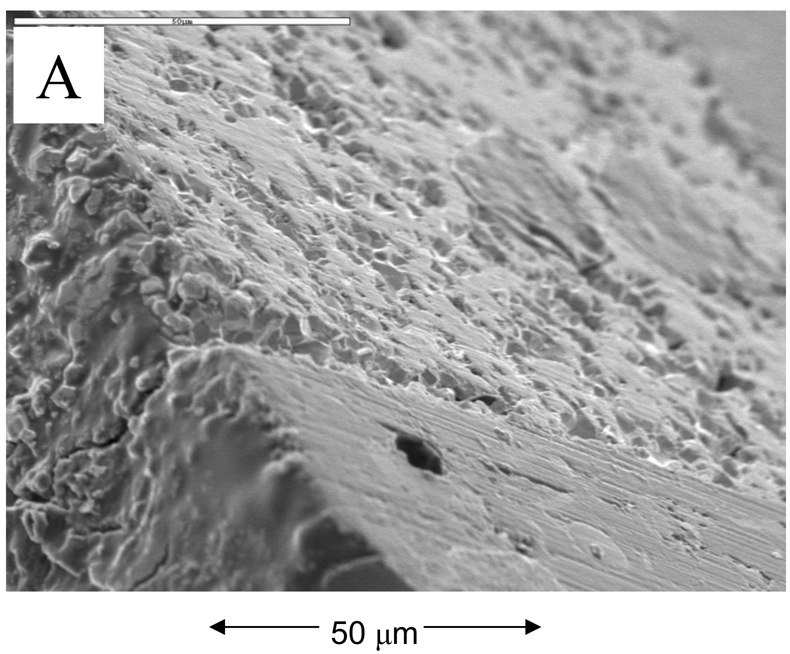




Microscope pictures of *Sample A* and Sample B(ii) after grinding by PicoAce.

Results: SEM Images of Composite



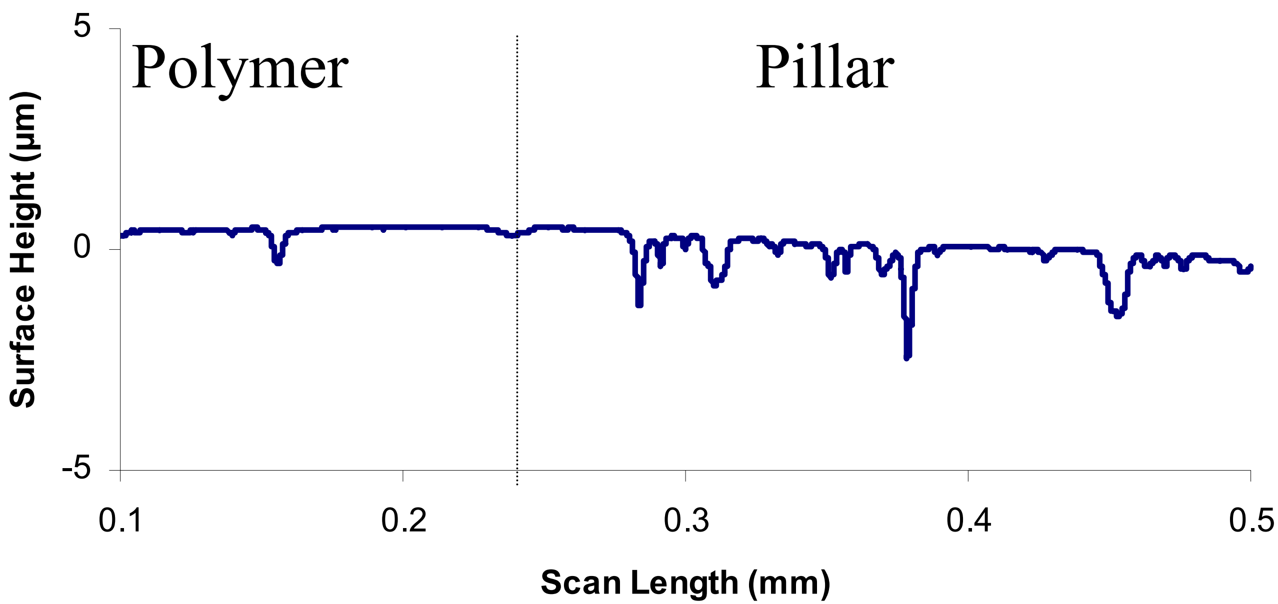


Active materials and binding polymer have different mechanical properties and hardness, commonly causing unevenness at the boundaries between the two materials after grinding of composites.

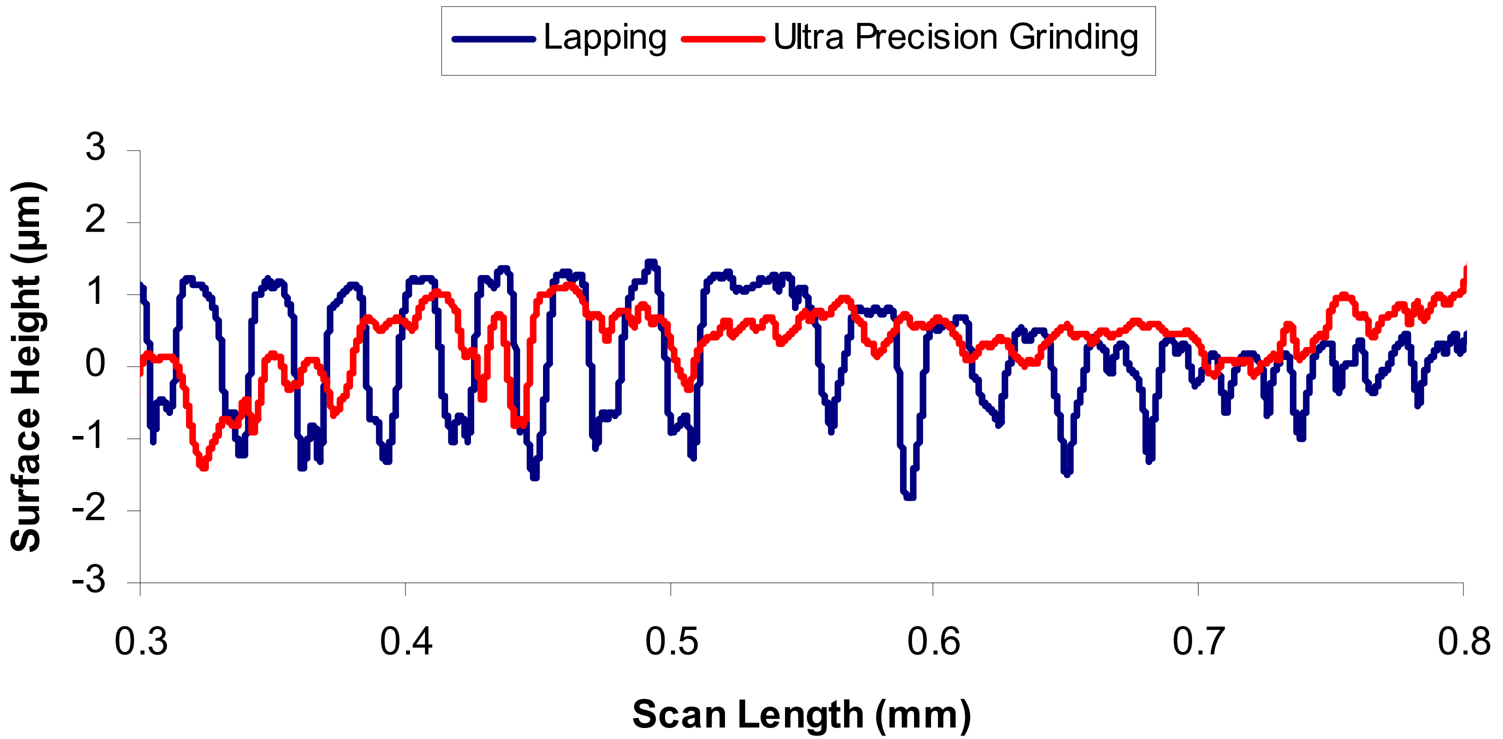
SEM picture of *Sample A* after ultra precision grinding with the PicoAce.

The boundary appears to be flat across the ceramic-polymer interface.

Results: Surface Profile Readings



- A surface profile reading of a pillar-polymer boundary in piezocomposite *Sample A* after ultra precision grinding by the PicoAce.
- The height difference between pillar and polymer are small enough to be suitable for high frequency devices.



Context

Ultra precision grinding

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- Surface profile readings from Sample B(i) after lapping (blue line) and Sample B(ii) after ultra precision grinding (red line).
- Ultra precision grinding produces an improved surface finish compared to lapping.

Context

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&
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Summary

- Cost-effective fabrication of transducers with frequencies above 20 MHz, needed for high spatial resolution measurements, is challenging because of the need for a thin layer of active material.

- Piezocomposites are the material of choice in high performance transducers at lower frequencies, but their thickness must be in the range 35 – 45 μm for a frequency of 50 MHz.

Summary

- Conventional grinding used in commercial piezocomposite fabrication is insufficiently precise for high frequency operation and is subject to undesirable intra-process variation.
- The most widely used alternative is precision lapping and polishing, but this is slow and therefore expensive.
- Here, results were reported from an alternative process of ultra precision grinding of piezocomposite material.

Conclusions

The PicoAce has shown promise for grinding piezocomposites.

- Combined removal of bulk material and surface finishing is particularly appropriate for high volume production.
- Composite material has been produced with ±1µm roughness, good enough for high frequency devices.
- Further investigation is underway, e.g. on bulk PZT for use in many different applications.

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Ra data was provided by John Corbett.

References

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2. Nix EL, Corbett J, Sweet JH, Ponting M (2005) *Dicing and Grinding of Electroceramics*. CARTS Europe, Prague, October 2005.