Progress in high resolution ultrasound towards in vivo pathology

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Introduction

Real time high resolution ultrasound systems have great potential in oncology and gastroenterology where there is a challenge in accurate diagnostic characterisation of some tissue regions due to limited access. A resolution of less than 0.3mm is needed for imaging tissue structures such as the lymph nodes.

High Frequency ultrasound (HFUS) systems are being developed for improved resolution, but image quality has so far been limited by using single element transducers. Miniature HFUS arrays, with sub-millimeter scale, are required to provide significantly improved image quality. Although the small scale makes fabrication difficult, the authors have show that it is feasible to fabricate HFUS arrays. These miniature arrays can be integrated into interventional tools such as biopsy needles, leading to *in vivo* pathology.

The next challenges to overcome are the design of an array suitable for *in vivo* pathology in specific clinical applications, and solutions for incorporating the transducer within an interventional tool. Design guidelines for miniature transducer arrays are presented. Preliminary designs for an array suitable for placing within a 2 mm diameter biopsy needle are presented.

Transducer design parameters

An imaging transducer linear array will desirably have at least 64 active elements. Table 1 below compares two transducer design parameters operating at different frequencies.
Arrays enable higher image frame rates compared to single element transducers and also permit blood flow imaging

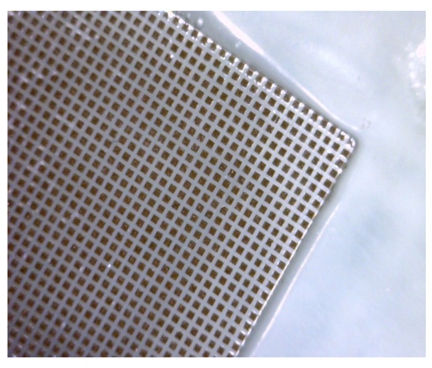
Table 1: Comparison of transducers parameters with different frequencies

Frequency	Pitch	Total array length	Image resolution	Image depth
5 MHz	300 µm	19 mm	600 - 1500 µm	200 mm
15 MHz	100 µm	6.4 mm	200-600 µm	60 mm
50 MHz	30 µm	1.9 mm	60 -150 µm	10 mm

Fabrication Process

1. Diced Piezoelectric Composite

A composite of a polymer and lead zirconate titanate (PZT), a polycrystalline ceramic, is made to improve the overall properties



Diced ceramic pillars with epoxy: pitch 150 µm, square pillars of 100 µm

2. Advanced Surface Finishing

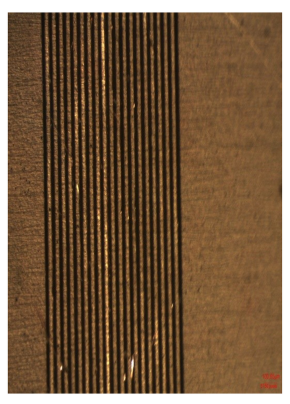
Surface finishing involves lapping and polishing. This leaves a flat and smooth surface that is needed for electrode patterning.

3. Array Definition

Lift-off photolithography has been used by the authors to pattern electrodes for arrays. Solvent resistance epoxy is need for filling the composite. Other methods like dicing are currently being investigated

4.Interconnect

Flip-chip bonding is being investigated for bonding flexi-circuits to the composite.



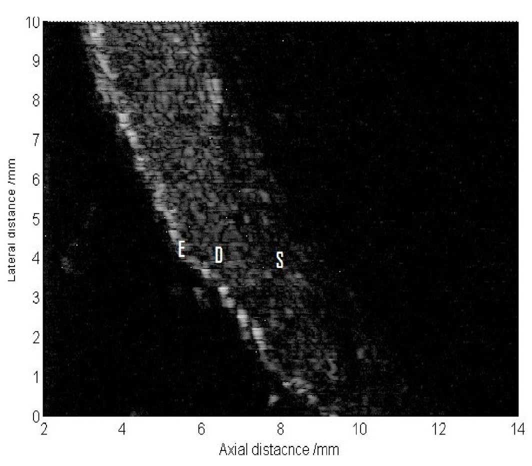
30 µm copper tracks with a pitch of 60 µm on a flex circuit

Single element prototype

These have a fixed geometric focus and are mechanically moved to form an image.
A 36 MHz transducer was fabricated using a composite made by a micromoulding technique [1], and used to scan skin layers shown below

Single element transducers [1]

Good resolution was obtained with the skin images as shown below.

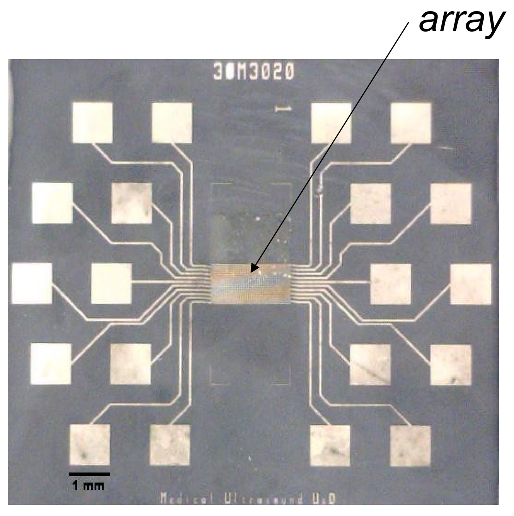


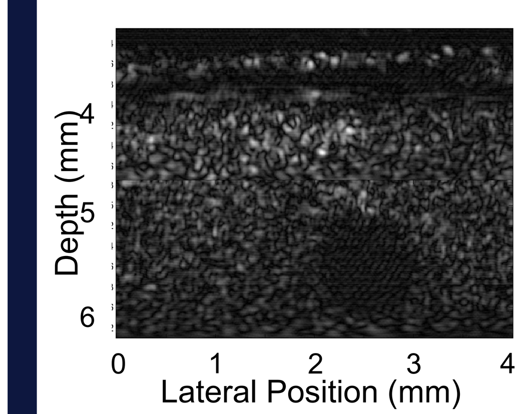
Skin layers with a single element 36 MHz transducer. The epidermis (E), Dermis (D) and subcutaneous (S) layers are clear.

Linear Array prototype

A 30 MHz array with 20 active elements was successfully fabricated with 30 µm pillars and kerfs of 20 µm.
The dimensions demonstrate the feasibility of making small arrays.

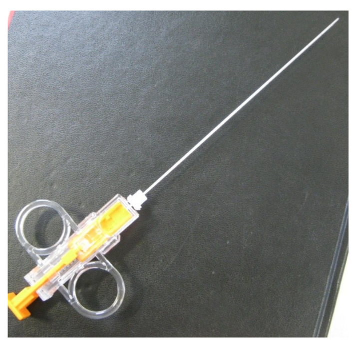
Array substrate with photolithography patterned electrodes defining elements. The large pads are where the electrical interconnects will be attached [1]





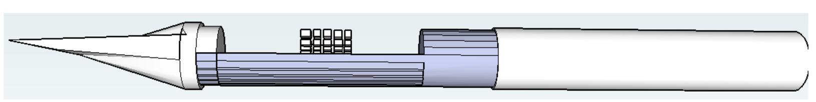
Synthetic aperture Image of 1 mm cylindrical cyst phantom in scattering background produced by the array.
Synthesised aperture: 4 mm, pitch: 10 µm [1]

15 MHz Linear Array in a needle biopsy



A standard 2 mm biopsy needle

The preliminary prototype of an array integrated with an interventional tool will be a 15 MHz transducer in a biopsy needle. An ultrasound array in the tip of a biopsy needle will offer the potential for improved diagnosis



Drawing of a needle with an array of ultrasound elements near the tip of the transducer

The designs incorporate a 64 element array, a pitch of 100 µm with total length of 6.4 mm to fit in a needle with a diameter of 2 mm.

The interconnects will be through a specially designed flex circuit connected to micro-coaxial cables within the needle for connecting to the imaging system.

Summary and Future work

- Recent advances in ultrasound imaging systems, and the development of needle-based probes are significant steps toward the development of *in vivo* pathology diagnostic systems.
- Continuing work includes optimising piezoelectric composite and array designs for high frequency transducers used in interventional tools.
- Fabrication of a prototype array in a biopsy needle is in progress
- Transducers made with single crystal piezoelectric materials are being investigated; these are more efficient, but are more difficult to work with.

[1]: *CEM Démoré, AL Bernassau, NL Bush, F Dauchy, L Garcia-Gancedo, D Hutson, C Meggs, JC Bamber, TW Button, Cochran S* Development of fine-scale arrays for high resolution ultrasound imaging. EUROSON2009, Edinburgh, 6-8 December 2009

Acknowledgments: AFM Ltd. (Birmingham, UK), Loadpoint Ltd. (Swindon, UK), Logitech Ltd. (Glasgow, UK), MIcroSystems Engineering Centre (Heriot-Watt University, Edinburgh, UK),