Published in final edited form as:

Nucl Instrum Methods Phys Res A. 2011 August 21; 648(Suppl 1): S135–S138. doi:10.1016/j.nima.2010.12.067.

Large Area MEMS Based Ultrasound Device for Cancer Detection

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Abstract

We present image results obtained using a prototype ultrasound array which demonstrates the fundamental architecture for a large area MEMS based ultrasound device for detection of breast cancer. The prototype array consists of a tiling of capacitive Micro-Machined Ultrasound Transducers (cMUTs) which have been flip-chip attached to a rigid organic substrate. The pitch on the cMUT elements is 185 μm and the operating frequency is nominally 9 MHz. The spatial resolution of the new probe is comparable to production PZT probes, however the sensitivity is reduced by conditions that should be correctable. Simulated opposed-view image registration and Speed of Sound volume reconstruction results for ultrasound in the mammographic geometry are also presented.

Keywords

cMUT; MEMS; Ultrasound; Large Area Array; Interposer; Breast Cancer

1. Introduction

Ultrasound is an important imaging modality for diagnosis and, in some countries, detection of breast cancer, particularly in women with dense breasts. In conjunction with the standard of care (digital x-ray mammography), full field 3D imaging of the breast with ultrasound could add sensitivity and specificity to screening in most clinical practices. Here we propose an architecture for a novel system using large scale 2D ultrasound transducer arrays yielding

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opposed view imaging of the compressed breast which could potentially address this unmet need in screening for breast cancer.

As illustrated in Fig. 1a, such a system has the advantage of being able to image in B-mode using pulse/echo ultrasound from both sides of the compressed breast thereby reducing signal loss due to round trip attenuation. In addition, such a system also has the capability (Fig. 1b) to implement Speed of Sound (SOS) volume reconstruction by through-transmission imaging of the compressed breast over a range of viewing angles. We have been developing novel transducers, fully tileable supporting substrate module assemblies and reconfigurable array electronics to address the challenges of yielding large 2D arrays. In parallel, we have been developing imaging algorithms and methods to take advantage of the opposed, 2D transducer arrays.

2. Development

One of the main challenges with a full field breast compression array is the large number of ultrasound transducer array elements that would be required to be interconnected to form the array. We have been developing a new array architecture based on reconfigurable arrays [1,2], fully 2D tileable substrate module assemblies [3], and Capacitive Micromachined Ultrasound Transducers (cMUTs) [4] in order to address this challenge. We have previously described the main design goals in the development of what we call Reconfigurable Arrays [1]. It is anticipated that such large area arrays offer superior imaging capability and greater flexibility than conventional approaches. As illustrated in Fig. 2, the full field array would be composed of a series of tileable modules comprising the cMUT transducer devices as well as co-integrated High Voltage capable reconfigurable array ASIC electronics. The modules would be built up using an advanced organic semiconductor interposer having 11-layers with a total cross-sectional thickness of only 0.5mm. We previously reported on a prototype using state-of-the-art flip-chip assembly methods for mounting both the top-side MEMS transducers and the integrated interface electronics ASICs on the backside of the interposer [3,5]. Reconfigurable array elements will allow imaging with modest numbers of signal acquisition channels and cMUTs are proposed in order to reduce cost and simplify assembly [4].

Imaging algorithm development for the dual-sided breast imaging system includes automated registration and fusion of images acquired using the two opposed arrays and novel Speed of Sound (SOS) volume reconstruction using a Simultaneous Algebraic Reconstruction Technique (SART) algorithm [6]. A special dual-sided breast mimicking phantom was also developed in order to allow for evaluation of the image registration and SOS algorithms [7]. Additional data for the algorithm development was gathered from patient studies using existing equipment.

3. Results

A novel interposer-based transducer test module configured to simulate a GE M12L PZT type linear multi-row probe was designed and fabricated using flip-chip cMUT dies [8, 3].

The goal of this design was to address issues related to assembly of the cMUTs to the interposer substrate and demonstrate feasibility of the tileable module assembly.

Imaging using the completed cMUT and interposer array module was done using a Precision Small Parts Gray Scale Phantom (GAMMEX 404GS LE, Gammex, Middleton, WI). Images were acquired at 50V bias which falls short of the 80V design. Shorting in the elements in these early prototypes prevented imaging at higher bias voltages. This results in a substantially undersampled aperture and the appropriate electromechanical coupling coefficient could not be achieved [9].

The probe was acoustically coupled to the phantom using perfluorocarbon liquid FC-84 (3M, St. Paul, MN) which also acted to electrically isolate the front face of the cMUTs and prevent further shorting. Both the cMUT probe and the production PZT probe were tested with the results being shown in Fig. 3. The center frequency for imaging was approximately 9 MHz, and the receive focus was set at or near the depth of the wire targets being imaged in both cases. As can be seen by comparison of the two images in Fig. 3, the spatial resolution of the two probes is similar. The results show comparable image resolution to the product probe but reduced sensitivity due to shorted cMUT elements resulting in a smaller active aperture. Shorting on the functional cMUT devices between signal electrodes and the common bias terminal remains an issue that must be resolved for full implementation of a reconfigurable array. The reverberations seen in Fig. 3a are likely due to the use of FC-84 for coupling and the reduced number of active elements. These effects were not seen in earlier clinical images using cMUTs [10].

Based on these promising results with the interposer test module, a fully integrated cMUT Acoustic Test Module incorporating an 8×14 array of 256 element cMUT chips and 6 reconfigurable array ASICs was designed. The total aperture of the prototype tileable module is 24 mm $\times$ 42 mm. As a first step in the fabrication of the fully tileable module, an Assembly Evaluation prototype was built using 112 dummy mechanical cMUT chips fully tiling the top surface of the transducer module (Fig. 4). This evaluation prototype demonstrates full brick-wall tiling of the array with minimal gaps (Fig. 5). Simulations have shown that the 100 μ m die-to-die spacing of the fabricated module reduces the side lobes due to gaps between tiles as required for excellent image quality.

For evaluation of the novel dual-sided imaging algorithms, existing probes and electronics were used. Good accuracy was achieved in automated recognition of shadowed image regions on decompressed ultrasound data obtained from the dual-sided phantom, allowing registration and then fusion of the warped bottom image volume to the registered top one. Fig. 6 shows scans of the dual-sided breast phantom as viewed from the top (left) and bottom (center) and the fused image (right) of cancer-like double cones overlying a small simulated cancer (left side of image) and a small simulated cyst (right). At 10 MHz, cancers, cyst and background have, respectively: speed of sound- 1472 m/s and attenuation coefficient- 15.6, 5.2 and 4.3 dB/cm.

First order image statistics of overlying image pixels were sufficient features for our two machine learning algorithms, support vector machines and artificial neural networks, both of

which achieved similar classification accuracies of 97%. We also achieved in-vivo accuracy of more than 90% for artifact, shadow and enhancement recognition, on 12 cancer and 10 cyst cases. Simulations of SOS imaging in the mammographic geometry show point spread functions similar to those of previously reported results for tomosynthesis [11], as expected given their similar angular range of viewing. The left image in Fig. 7 shows a simulated (red) 2 cm cancer with 5% contrast. The transmitter (blue) and receiver arrays (green) are on the left and right to model transmission imaging of the compressed breast. The SART reconstructed image is displayed, center, on the same scale as the left image and, right, as a strip on the simulated pulse echo image.

4. Conclusions

Initial imaging results using a preliminary array that integrates the transducers and the substrate show that the new integrated cMUT and substrate module has the potential to yield a fully tileable building block to create the large scale 2D transducer arrays. Simulated and experimental results on a new Speed of Sound through-transmission method for detection of breast cancer and opposed-view image registration are also promising.

Acknowledgements

We acknowledge the help of Barry Bonitz at Endicott Interconnect Technologies.

The project described was supported by Grant Number 1R01CA1152677 from the National Cancer Institute. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the National Cancer Institute or NIH.

Some of the technology described was derived from work originally supported by Grant Number R01 EB002485 from NIBIB. Contents of this publication are solely the responsibility of the authors and do not necessarily represent the official views of NIH.

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1a

1b

Fig. 1.
a: Opposed View B-Mode Transmit/Receive
b: SOS Imaging by Through Transmission

Fig. 2.
Tileable Module Assembly

3a

3b

Fig 3.
a: cMUT-Based Probe
b: Production PZT Probe

Fig 4.
Mockup Assembly

Fig. 5.
cMUT tiling with reduced gaps

Fig. 6.
Opposed-view image registration using standard ultrasound probe

Fig. 7.
SOS image results for simulated data (left) and with special-purpose phantom (right) using standard probe