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Multi-Row Linear cMUT Array Using cMUTs and Multiplexing Electronics

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***Abstract*—A large area reconfigurable imaging array for research purposes is being developed with co-integrated cMUTs and control electronics. The goal is a 2.5cm 2D tileable module with >16,000 transducer sub-elements spaced at a pitch of 185um in X and Y dimensions. As a prototype demonstration of some of the goals of this effort, a multi-row linear array using cMUTs and external multiplexing electronics was designed and fabricated. In this paper the challenges of trenched cMUT attach to a laminate interposer as part of a tileable module will be discussed. The architecture of the tileable module build-up for manufacturability, reliability, acoustic planarity, and reduced spacing between tiles and cMUT chips will also be addressed. Finally, a first prototype will be shown and experimental acoustic results with the new cMUT-based probe will be presented.**

Keywords-cMUT, Ultrasound, Module, ASIC, Reconfigurable Arrays, Tileable

I. INTRODUCTION

A major challenge in future ultrasound imaging systems is the large number of interconnects that exist between the signal processing electronics and the transducer array. As systems move to larger and larger two-dimensional arrays at finer pitches, existing technologies for interconnect are increasingly inadequate.

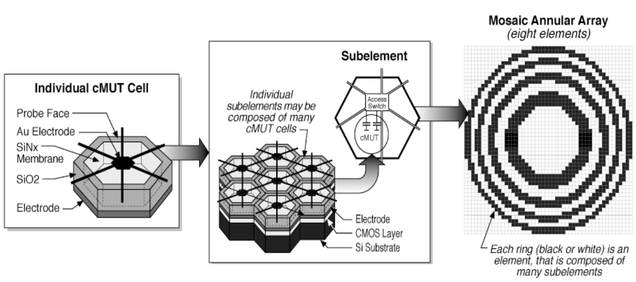

Figure 1: Mosaic Annular Reconfigureable Array Architecture. Individual subelements are connected together using switching electronics that are integrated immediately behind the active acoustic array.

A number of specific applications exist in which large area 'patch' type ultrasound transducer arrays can be used. These include cancer screening and continuous non-invasive blood pressure monitoring. Depending on the application, the element count for the large area transducer will range from 10,000 to >1,000,000. Given the large number of transducer elements, each with it's own respective signal processing circuitry, significant power, cost, and area penalties exist.

One attractive way to reduce the number of signal processing channels for such a large area array is through the use of a Mosaic Annular Reconfigurable Array [1]. Ultrasound systems, which use reconfigurable array architectures, can benefit from good image quality with a significant reduction in the number of system channels.

Additionally, Capacitive Micromachined Ultrasonic Transducers (cMUTs) are Micro-Electro-Mechanical Systems (MEMS) structures that are an attractive alternative to traditional PZT-based ultrasound transducers [2]. In particular, the semiconductor fabrication processes used to create these devices allow them to be processed in a similar way to the ASICs for the electronics which makes them more amenable to standard packaging flows.

As illustrated in Figure 1, the Mosaic Array architecture groups a number of 'Subelements' together along iso-phase lines to form larger transducer elements which are then each connected to a single system channel. In this way, an array that has 10's of thousands of active acoustic subelements can be reduced to a much smaller number of system processing channels (e.g. 20-100). This greatly reduces the requirements on the system and makes possible low power and low complexity electronics systems for large area arrays.

In order to realize such an array architecture, it is necessary to integrate switching electronics immediately behind the acoustic array. This is also illustrated in Figure 1. These switching circuits, which are realized using dedicated ASICs, connect directly to each respective subelement and can be programmed to short these elements to one another in a reconfigurable manner.

One of the main challenges which exists with such a system is how to interconnect the large number of transducers with a respective switching circuit on the adjacent ASICs. A number of potential solutions have been proposed, including the use of direct flip-chip attach [3,4] as well as integration of the cMUTs directly on top of the ASICs themselves [5].

In the current work, we use an interposer substrate which supports both the ASICs and the cMUTs by flip-chip attach. The advantages of such an architecture include the flexibility of attaching components separately thereby allowing for screening of known good devices, as well as relieving the routing bottleneck from the surface of the ASICs.

In the current paper, we describe promising initial efforts usuing functioanl cMUTs and dummy ASIC devices to create a module that can be tiled to yield a large area array based on the interposer architecture.

II. TRENCHED CMUT DEVICE

A photograph of a trenched cMUT device attached to the topside of a laminate interposer is shown in Figure 2. From this figure, the top portion of the pillar is attached to an active area of the Si device, which is only about 22um in thickness. A trenched cMUT device having a 85um square pillar that is 250um long is attached to a Teflon-based organic interposer using flip chip attach. The cMUT pillars are bumped with eutectic Sn-Pb solder. Figure 3 shows a SEM image of a solder bumped trenched cMUT device. A unique feature of this type of device is that an under bump metallurgy (UBM) structure is deposited on the pillar and then bumped with solder. This bumped trenched device is then flip chip solder attached to the topside of the laminate interposer. When these bumped trenched devices are attached to the interposer, the cMUT devices remain flat, and are spaced 100um apart. On the backside of the interposer a dummy ASIC chip with a 150um pitch and >4000 I/Os was flip-chip attached and underfilled. Also, ball grid array (BGA) spheres are attached on the backside. The BGA balls are used to attach the module to a board.

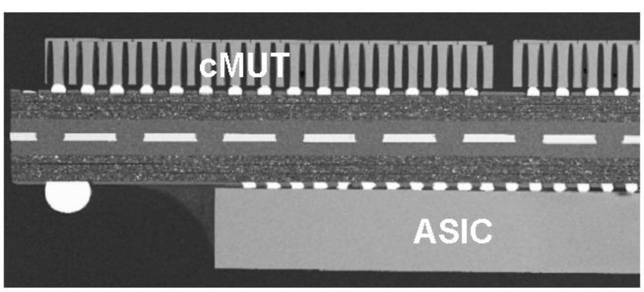

Figure 2: Photograph of cMUT devices flip chip attached to the topside of a laminate interposer

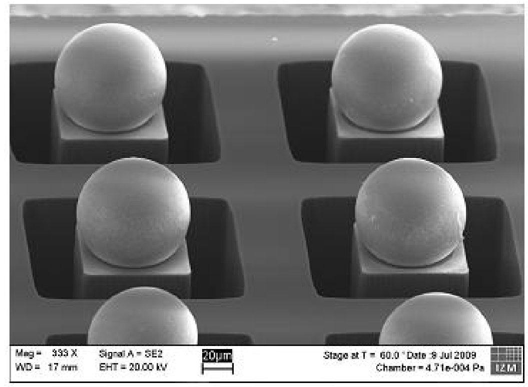

Figure 3: SEM image of a solder bumped trenched cMUT device.

The under cut at the base of the pillar in the trench has been shown to make the pillar very susceptible to failure, especially during handling. The UBM structure and the solder bump have been optimized to create a solder joint strength of about 23gm. However, shear and pull tests have shown that the solder attached pillar can withstand only a force of about 3.5gm. This lower pillar strength is due in part to the under cut region, shown in Figure 4, which reduces the strength of the pillar. Future work is underway to assess the reliability of the trenched cMUTs attached to the interposer having the under cut at the pillar base.

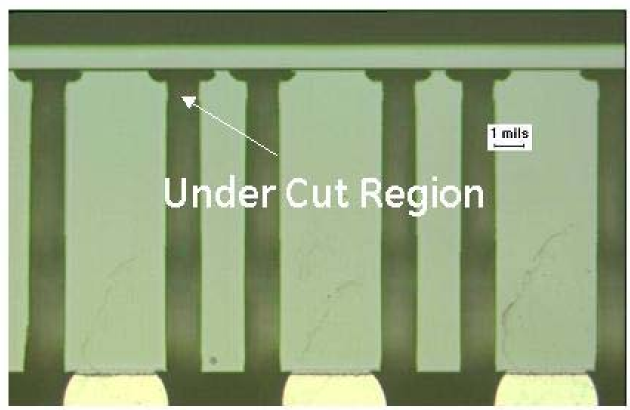

Figure 4: Optical micrographs of the under cut at the base of the pillar.

III. MODULAR TILEABLE ARRAY

A cross-sectional view of the module is shown in Figure 5. The two center rows use functional cMUTs, and the two outer rows use mechanical cMUTs. This initial work shows successful attach of a 2xN row of trenched dummy cMUTs. Each row can accommodate 12 cMUT devices. The first set of mechanical test hardware has been built and shows that we can successfully place topside cMUTs and backside ASICs and achieve complete flip chip attach and maintain the specified flatness of the module. Three mechanical ASIC devices were attached on the backside, each ASIC die is about 10mm x 12mm in size. Figure 6 and 7 show images of the topside array of mechanical cMUTs and the backside with mechanical ASICs.

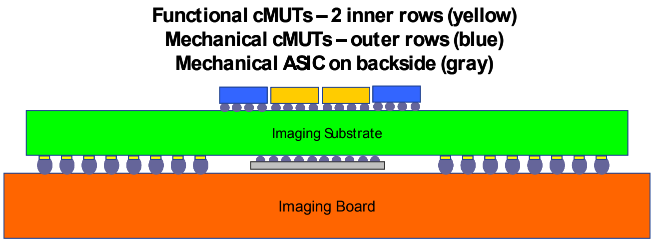

Figure 5: Schematic cross-section of the first phase of the modular package design.

Figure 6: Photographs showing topside mechanical cMUTs

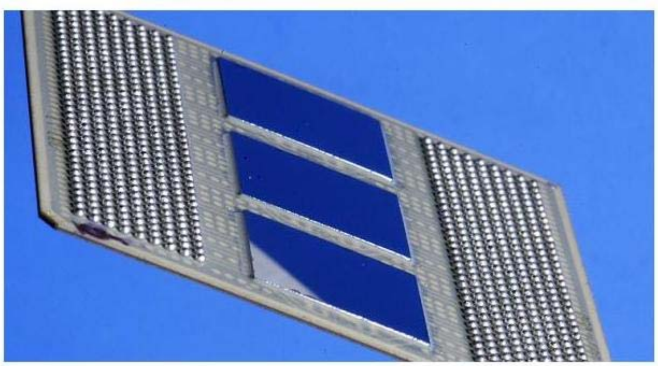

Figure 7: Photographs showing backside mechanical ASICs attached to a laminate interposer.

IV. Prototype Module

To create a functional prototype for initial acoustic measurements, a functional module having a 1x2 cMUT array was attached to a printed circuit board. The circuit board provides connection to the system for acoustic testing and imaging. The resulting module can maintain the specified flatness requirements. A topside view of the 1x2 functional cMUT array attached to the laminate interposer and a cross-sectional view are shown in Figures 8 and 9.

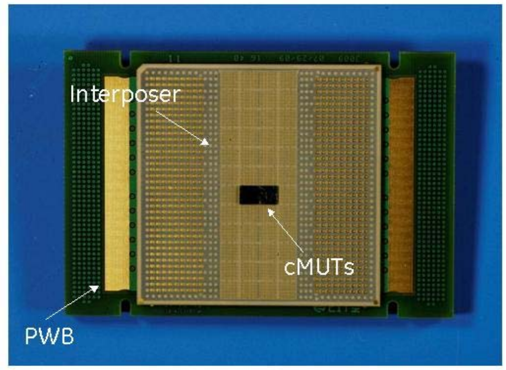

Figure 8: Photograph showing topside view of the 1x2 functional cMUT array on a laminate interposer solder attached to a board.

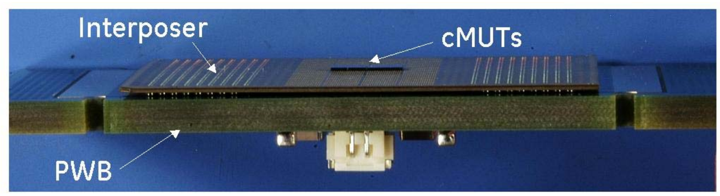

Figure 9: Photograph showing the cross-sectional view of the functional prototype.

V. Acoustic Measurements

The fabricated cMUT-interposer module was tested for pulse/echo response in order to generate the time domain impulse response as shown in Figure 10. The resulting spectrum is shown in Figure 11.

The impulse response of the prototype module appears to roll off faster than the response predicted for the cMUTs by numerical simulation. In the simulation, a one-way 3-db bandwidth of 3.5-11.5 MHz was calculated. In the measurement, the two-way 6-dB bandwidth was found to be roughly 4.8-10.5 MHz. Therefore a narrower bandwidth was observed in the actual prototype. The medium which was used for the measurement is more attenuating than water and this may be a significant factor for this difference.

In addition, we observed a notch in the spectrum around 5.5MHz. This is due to ring-down in the acoustic response which is likely caused by improper acoustic matching in the module structure. Although the magnitude of the ring-down is not large, we are investigating ways to reduce this ringing as it may be an issue for imaging.

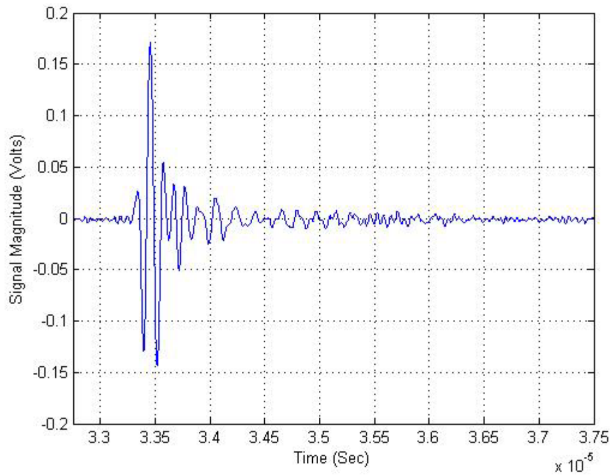

Figure 10: Measured time domain impulse response of the fabricated cMUT-interposer module.

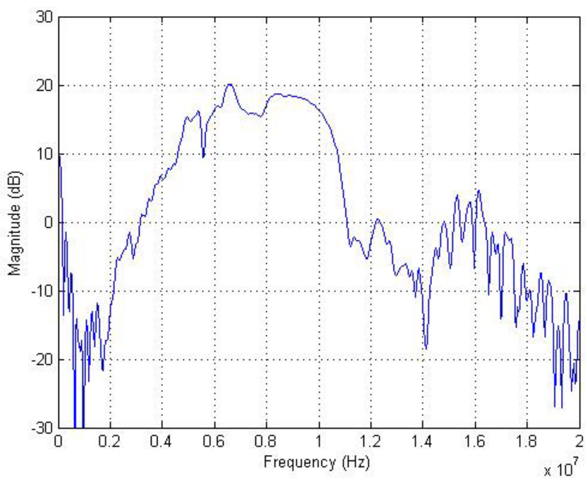

Figure 11: Calculated frequency domain impulse response (FFT of data in Figure 10)

VI. CONCLUSIONS

Despite fragile 250um tall by 85um square pillars, the cMUT chips were successfully attached to the interposer to yield a functioning module. Planarity of the tileable module and spacing of the cMUT chips met required specifications for good acoustic imaging. Acoustic pulse-echo testing showed the complete module stack-up has expected behavior for ring down and bandwidth. Next steps include building and testing a large tileable array and performing acoustic and imaging test.

VII. ACKNOWLEDGEMENTS

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