The Fabrication and Characterization of Capacitive Micromachined Ultrasonic Transducers Using a Novel Wafer Bonding Process

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Abstract:
In this research, we design, fabricate and test one- and two-dimensional capacitive micromachined ultrasonic transducers (CMUTs) arrays using a novel wafer bonding process whereby the membrane and the insulation layer are both silicon nitride. A user-grown insulating membrane layer avoids the need for expensive SOI wafers, reduces parasitic capacitance, and allows more freedom in selecting the membrane thickness while also enjoying the benefits of wafer bonding fabrication.

Summary of Research:
Ultrasonic transducers based upon electrostatic forces have been subject to increasing interest since the mid-1990s as microfabrication technology matured [1-3]. The use of semiconductor fabrication techniques facilitates the fabrication of high quality arrays with broad acoustic bandwidth and the potential to integrate the transducers with the necessary electronics. CMUTs consist of a membrane suspended over a narrow gap with a fixed electrode at the bottom and a patterned electrode on top of the membrane. In transmit mode, one of the electrodes is grounded and the other is biased with a DC voltage and subject to a short voltage pulse causing a deflection of the membrane toward the other electrode. The membrane vibrates with the release of the electrostatic force and energy is coupled into the surrounding media as pressure waves. In receive mode the membrane is DC biased and the incoming pressure waves cause the membrane to vibrate which changes the cell capacitance and causes a measurable current. A typical transducer is made of many elements, which in turn is made of many individual cells which are activated in parallel. The general design of a CMUT cell is shown in Figure 1.

Arrays of elements permit the dynamic focusing and steering of the ultrasound beam. In a one-dimensional array the acoustic beam can be focused and steered in the x dimension. A two-dimensional array can focus and steer an acoustic beam in both the x- and y- dimensions. Electronic beam steering improves the performance of multi-dimensional imaging when compared to mechanical steering options.

The fabrication process of these wafer bonded devices is similar to that used in the SOI wafer bonding process reported by Huang et al [4]. Only three masks are needed to achieve the final 1-D array device. An outline of the basic fabrications steps is as follows.

A highly p-doped Si wafer is used for the bottom wafer which will serve as the bottom electrode. A wafer is used for the membrane wafer.

Low-stress silicon nitride is deposited as a spacer and insulation using low-pressure chemical vapour deposition (LPCVD). Simultaneously, nitride is deposited on the top wafer for what will be the membrane.

While LPCVD nitride is not overly rough it must still be chemically mechanically polished because fusion bonding is very sensitive to roughness. Both the top and bottom wafers are briefly polished using a silicon dioxide particle slurry.
After polishing, the cavities are patterned and etched into the bottom wafer nitride layer using Mask I and a CF₄ reactive ion etch (RIE).

Next, both the top and bottom wafers are cleaned for fusion bonding. The two wafers are bonded at 120°C in a chamber at a pressure of 0.5 µbar. The low pressure ensures the cell is a vacuum, reducing damping losses. The bonded wafers are annealed at 900°C for 4 hours.

After removing the backside nitride layer from the membrane wafer using an RIE etch the handle wafer is completely removed by a 25% KOH etch at 95°C.

Next, a photolithography and CF₄ RIE step is done using Mask II to expose the ground electrodes for metallization. Finally, the top electrodes and contact pads are patterned using Mask III and a lift-off process. Titanium and aluminum are evaporated using an e-beam. Titanium is used as an adhesion layer and about 100 nm of aluminum is deposited on top. An illustration of the completed 1D array is given in Figure 2.

A scanning electron microscope (SEM) image of a completed 15 MHz 1D array is given in Figure 3. A plot of the transmitted acoustic pulse from a 15 MHz device as measured using a commercial hydrophone is given in Figure 4. The arrays were immersed in vegetable oil for this measurement. Vegetable oil is used because it is an insulating fluid, which is necessary because the electrodes are exposed. It also has acoustic properties similar to that of biological tissue.

References:


