A BIOCOMPATIBLE COATING FOR CMUT

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Biocompatible coatings were researched for use with capacitive micromachined ultrasonic transducers (CMUTs) that enables transcutaneous and *in vivo* medical imaging at high frequency. Results show parylene provides a biocompatible interface for CMUTs without adversely affecting performance.

Demonstrated to be the future technology of ultrasonic imaging [1], CMUTs offer low unit cost, broad bandwidth, and are made with batch fabrication techniques employed by the semiconductor industry. With the ability to create features at the micron scale, higher frequency transducers (>50 MHz) can be built with excellent controllability. To use CMUTs in contact with living tissue or inside the conductive and corrosive environment of a living animal, a biocompatible material must coat the device and also provide electrical isolation to the active areas of each element. In addition to being biocompatible, this coating should also ideally match acoustically to the silicon membrane and the surrounding medium to eliminate unwanted reflections that otherwise show up as image artifacts. Parylene and polydimethylsiloxane (PDMS) were selected for this study based on these determining factors, along with their chemical inertness, process compatibility and thermal and mechanical stability.

The behavior of the CMUT was analytically predicted using the theory of plates. The governing equation contains a factor, the flexural rigidity, based on Young's modulus, Poisson's ratio, and plate thickness. To account for the coating, the equivalent flexural rigidity of the composite plate was determined [2]. By computing the equivalent flexural rigidity of the compound membrane, the equivalent silicon thickness was calculated and combined with standard algorithms for suspended membranes to predict resonance [Figure 1]. Analytical and finite element modeling was also used to estimate DC deflection of coated and uncoated membranes of varying thicknesses.

Figure 2 shows the wafer bonding process used for fabrication [3]. A variety of different CMUT arrays were used, including ring arrays and 1D linear arrays. The dimensions of the elements varied between arrays, giving a wide range of center frequencies from 5 to 30 MHz. After the ultrasound transducers were fabricated, the parylene and PDMS coatings were applied [4]. Figure 3 shows (a) multiple 1D arrays and (b) a section of one array.

The characteristics of coated and uncoated transducers were compared side by side. Membrane collapse voltage and resonant frequency in air were measured using a network analyzer [Figure 4]. The resonant frequency for parylene coated CMUTs decreased by an average of 6.5% with a 1.2% standard deviation. The PDMS coating reduced the resonant frequency by an average of 24.2% with a 10.1% standard deviation. The resonance in air was significantly dampened by PDMS, but not by parylene. A 10% increase in collapse voltage was observed for the devices with parylene. A larger variation was seen with PDMS coated devices, with increases ranging from 5-12%. The membrane peak displacements and acoustic crosstalk were measured using a laser vibrometer. The peak membrane displacement in air decreased by 18% and 7% with the parylene and PDMS devices, respectively. In air, no reduction in element-to-element crosstalk was seen in either of the coated devices [Figure 5]. Table 1 summarizes the coating effects on one design, a linear array with 48µm diameter elements. Parylene degradation was tested by submerging devices in tap water. After 48 hours, the devices remained electrically isolated. The CMUT with parylene coating was able to detect an echo signal from a plane reflector in a water tank [Figure 6, 7]. Work is currently underway to test the feasibility of detecting the abdominal aorta in a neonatal mouse. A future high frequency ultrasonic application is monitoring the blood flow in the small arteries of neonatal mice.

Word Count: 594

References

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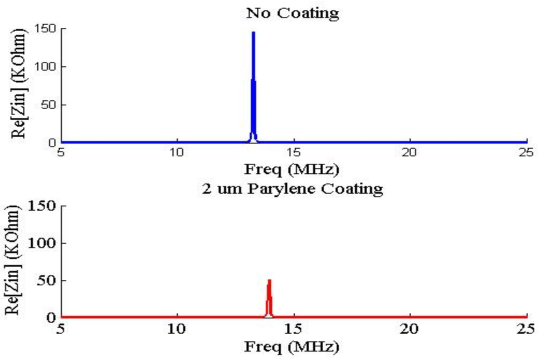


Figure 1: Predicted real part of input impedance in air, based on the compound plate theory.

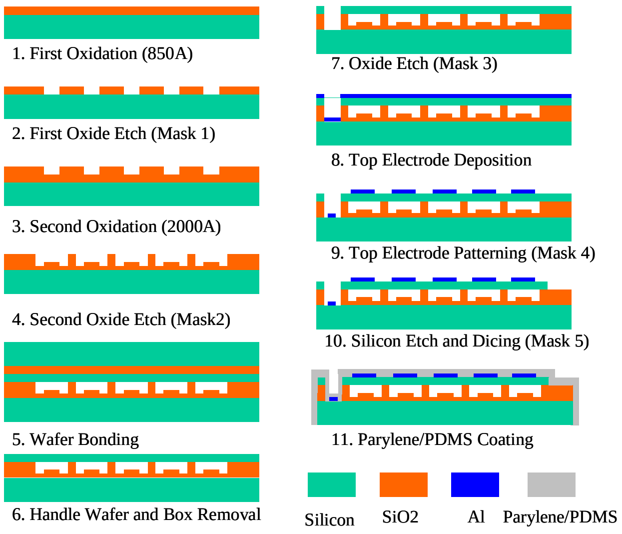
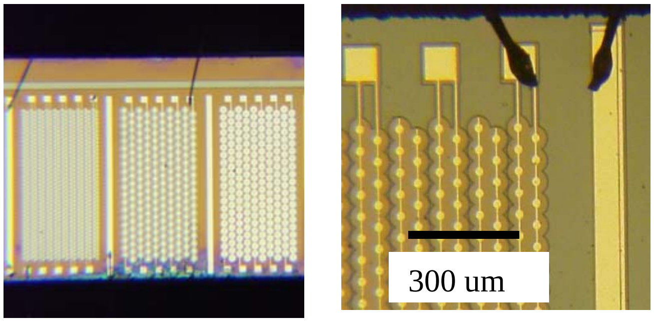


Figure 2: A cavity was etched in a silicon wafer and a silicon-on-insulator (SOI) wafer was wafer-bonded on top of this wafer. The handle and buried oxide layers were then removed, leaving a 2-µm membrane covering the cavities. Parylene was coated by vapor deposition polymerization (VDP), and PDMS was spin coated onto the devices. The thickness of the parylene layer was 2 ± 0.5 µm and the PDMS thicknesses were 5 µm and 8 µm.



(a) **(b)**

Figure 3: (a) Wire bonded 1D arrays coated with parylene and (b) a close up of one array showing 5 elements.

Table 1: Effects of coatings on CMUT

	Uncoated	2 um Parylene Coating	8 um PDMS Coating
Membrane Diameter (um)	48	48	48
Cavity Height (um)	0.06	0.06	0.06
Resonant Frequency in Air (MHz)	13.5	13.7	8
Collapse Voltage (V)	58	62	51
Peak Displacement in Air (nm)	67.8	55.8	62.9

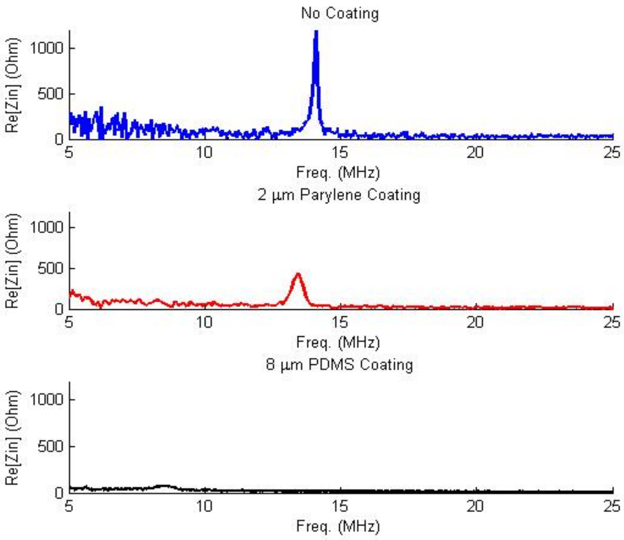


Figure 4: Measured real part of input impedance in air.

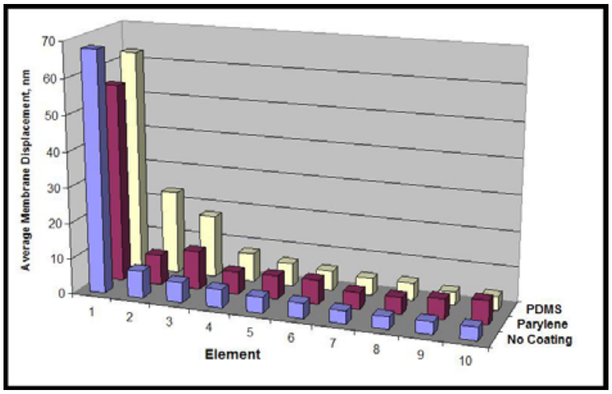
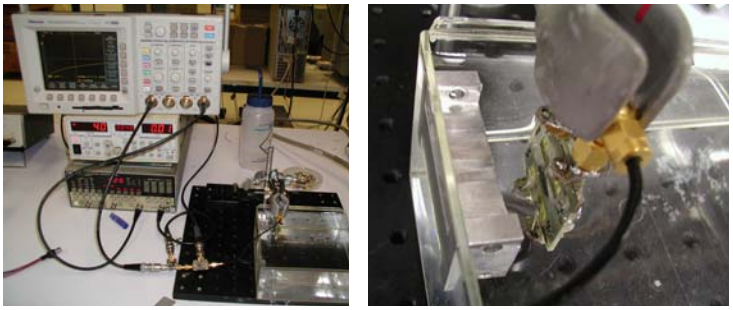


Figure 5: Crosstalk measurement results using laser vibrometer.



(a) **(b)**

Figure 6: (a) Experimental setup for pulse echo measurements with a Tektronix TDS3054B scope, Stanford Research Systems PS310 DC supply, and a HP8116A function generator. (b) Close up view of device and reflector in water tank.

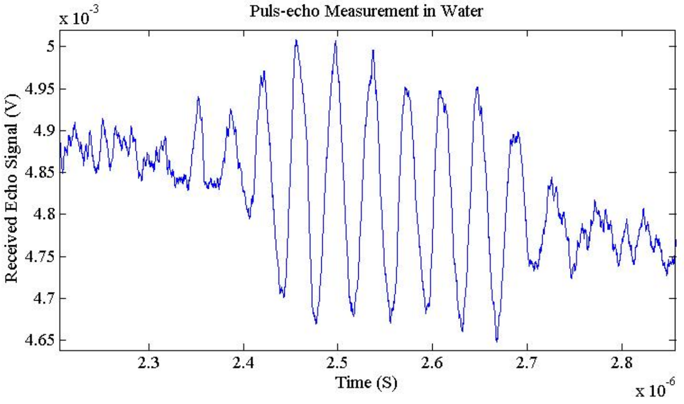


Figure 7: Pulse echo signal received in water.