A Piezoelectric Material P(VDF-TrFE) Thin-Film Process Flow for Ultrasonic Transducers

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Abstract:

Thin-film high-frequency ultrasonic transducers are a good candidate for generating high frequency ultrasound into various materials. The time-of-arrival, dispersion, amplitude, and phase of transmitted and reflected wave pulses can be used to characterize materials such as biological tissue. Piezoelectric polymer transducers are attractive in interrogating biological materials because of good acoustic impedance matching, leading to low voltage drive and higher bandwidth. For these reasons, we developed a microfabrication process for P(VDF-TrFE)-based ultrasonic transducers. The low acoustic impedance of the semi-crystalline copolymer (4.32 MRayls), allows for a better acoustic impedance matching to tissue/water (1.5 MRayls), resulting in increased coupling efficiency. All materials used in this process are CMOS-compatible, which allows for fabrication of transducers directly with CMOS, greatly improving system complexity and integration. Layers in this process were defined using standard contact lithography. The ultrasonic transducers fabricated by this process showed ultrasonic pulse transmission within the frequency range of 400-600 MHz. Signals with amplitudes of 2 Vpp resulted in receive signal amplitudes of 50 mVpp.

Introduction:

There are a plethora of biological applications that would benefit from large scale ultrasonic transducer phased array systems, such as ultrasonic imaging, neural stimulation, and cell trapping. It is of interest to develop a process which will allow the integration of ultrasonic transducers directly with the drive circuits fabricated in a complementary metal-oxide semiconductor (CMOS) process. This could greatly reduce the size and power of the phased array system. Such a system could be utilized to address sensory feedback issues in prosthesis.

Piezoelectric materials, such as bulk lead zirconate titanate and aluminum nitride, are frequently used due to their high coupling coefficient and commercial availability. However, a copolymer of poly[(vinylidenefluoride-co-trifluoroethylene], or P(VDF-TrFE), presents excellent physical characteristics that make it a great candidate for a range of biological applications. The low acoustic impedance (Z_o) (4.32 MRayls) of P(VDF-TrFE) makes this material a good acoustic match with water/tissue, resulting in more effective ultrasonic energy propagation. The copolymer also presents relatively small dielectric constant (4.0), easing transducer drive circuit design.

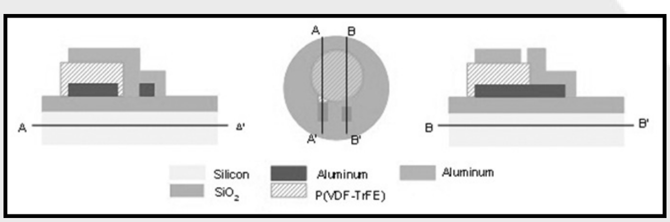

Figure 1: Schematic of fabrication process.

Device Fabrication:

All materials used in this process are CMOS-compatible, which allows for fabrication of transducers directly with CMOS, greatly improving system complexity and integration. Figure 1 illustrates left and right cross-sections of a transducer. Layers in this process were defined using standard contact lithography. The process began with an insulating layer of 500 nm PECVD of silicon dioxide (SiO_2) on a 500 μm thick 4-inch wafer. Aluminum bottom and top electrodes, of 210 nm and 250 nm respectively, were evaporated onto the substrate, and defined by wet etching. P(VDF-TrFE), dissolved in 2-butanone (7.00%w/v), was deposited by spin-coating to create a 1 μm thin layer, which was patterned using SPR 220-3.0 photoresist and etched by dry oxygen plasma etch.

After fabrication, an *in situ* electrical poling method was performed to induce piezoelectricity on the P(VDF-TrFE) film. An electrical field of 60 V/μm was applied on the transducer under 130ºC for one hour. The applied voltage was chosen in accordance with the work done by Li, et al. [1] on their fabrication of a piezoelectric tactile sensor using P(VDF-TrFE).

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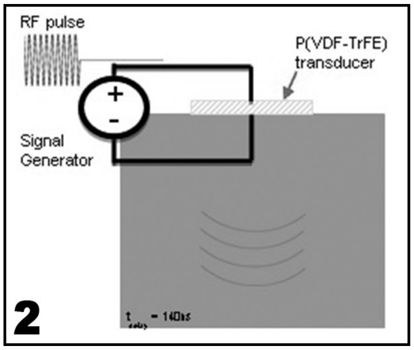

Figure 2: Experimental setup-wave propagation in silicon.

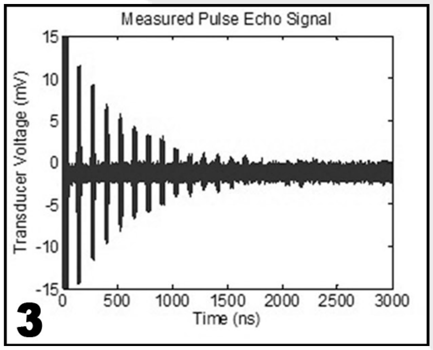

Figure 3: Pulse-echo signals.

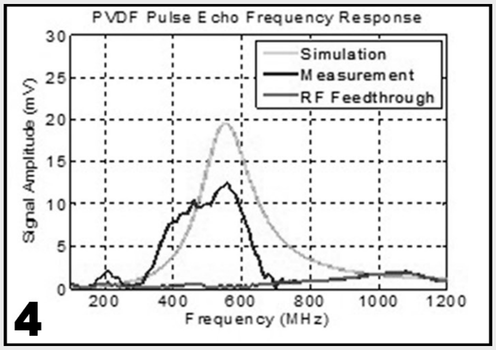

Figure 4: First echo as a function of RF.

Experimental Procedure:

A 40-nanosecond radio frequency (RF) pulse of fixed frequency was applied to the transducer through an RF switch. After approximately 130 ns, a signal was read on an oscilloscope. This signal corresponded to the time of flight of the ultrasound pulse in silicon traveling to the bottom surface, reflecting, and travelling back to the top surface (Figure 2). At the top, the ultrasonic pulse reflected again and made the journey back into the silicon. These repeated reflections were reflected in the captured signals with the same time delay corresponding to the time of flight in silicon (Figure 3).

It was of interest to investigate which signal frequencies allowed for efficient generation of ultrasound. By changing the frequency of the RF signal source, and looking at the amplitude of the first echo, the transducer's frequency response was characterized and plotted on Figure 4. Since the RF switches are not perfect isolators, there existed a small RF feed-through signal at the frequency of interest. The frequency response agreed with the simulation. Discrepancies between the two can be investigated further by considering the acoustic properties of the silicon dioxide layer, as well as considering the radiation pattern losses as opposed to the one dimensional model used for these experiments. The maximum amplitude level detected throughout the samples was 50 mVpp, though the sample here demonstrated a peak value of 24 mVpp. These differences could be accounted for due to RF losses in the printed circuit board traces, cable connections and different wire-bond lengths.

Conclusion and Future Work:

We have successfully characterized a P(VDF-TrFE) process for ultrasonic transducers, and used it to generate ultrasonic waves within the band of 400-600 MHz, using CMOS-compatible materials and processes. Future work will attempt to integrate this process flow with multimodal surgical silicon tweezers for tissue characterization, as well as CMOS for phased array circuit integration. Greater control of the ultrasonic beam is expected to result from the integration of P(VDF-TrFE) transducer arrays directly with CMOS. Alternate poling methods, such as magnetic field poling, will be addressed in the future to allow poling of multiple transducers at a time.

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References:

[1] Li, C., et al., "Flexible Dome and Bump Shape Piezoelectric Tactile Sensors Using PVDF-TrFE Copolymer", Journal of Microelectromechanical Systems, Vol. 17, No. 2, April 2008.

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