Engineering Research Center for Wireless Integrated MicroSystems
Associated Grants and Contracts

PROJECT DESCRIPTION

Title: *Wafer-Level Fabrication of High Performance Piezoelectric MEMS*

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Work Began: 08/01/2008
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Funding Source: DARPA

Project Goals:

Bulk piezoelectric ceramics, unlike deposited piezoelectric thin (μm) films, provide greater electromechanical force, structural strength, and charge capacity, which are highly desirable in many MEMS applications including high-force actuators, harsh-environmental sensors, and micropower scavengers. Previous studies for integration of bulk ceramics in MEMS have faced significant challenges such as non-patternable bond layer, low-bond strength due to high stress and voids in bond layer, or out-diffusion of lead and re-polarization issues due to high-temperature processing. The goal of this research is to develop a batch-mode fabrication technology for integration of bulk piezoelectric materials into MEMS devices via low-temperature, fluxless, patternable, and reliable solder bonding (conductive) and polymer bonding (non-conductive) of bulk PZT on Si wafers, both in die and wafer level.

Approach and Methodology:

Typically, bonding of bulk PZT layers is challenging because commercial PZT layers have rough surface (measured as ~4.5μm) and experience loss of polarization at high temperatures. Both intermediate bonding layers of developed solder and polymer bonds can re-flow and planarize surface roughness. Additionally, the developed solder bond has a re-melting temperature >500°C, which allows processing the wafer further at bonding temperature. Furthermore, bonded PZT samples do not require re-polarization, as bonding temperature is around half of the Curie temperature. Previous studies to pattern thick/thin PZT films for fabrication of piezoelectric devices include ultrasonic machining, laser ablation, FIB milling, DRIE, and wet-etching. However, each of these methods has its own drawback such as microcracks due to mechanical machining, unintentional v-shaped cutting, impractically long processing time, or intolerable under-cutting. In order to enable piezoelectric device fabrication without necessity of patterning PZT, we bonded 200μm × 200μm PZT samples on a Si wafer. Additionally, bonded pieces and wafers can be lapped down to thickness values down to <10μm.

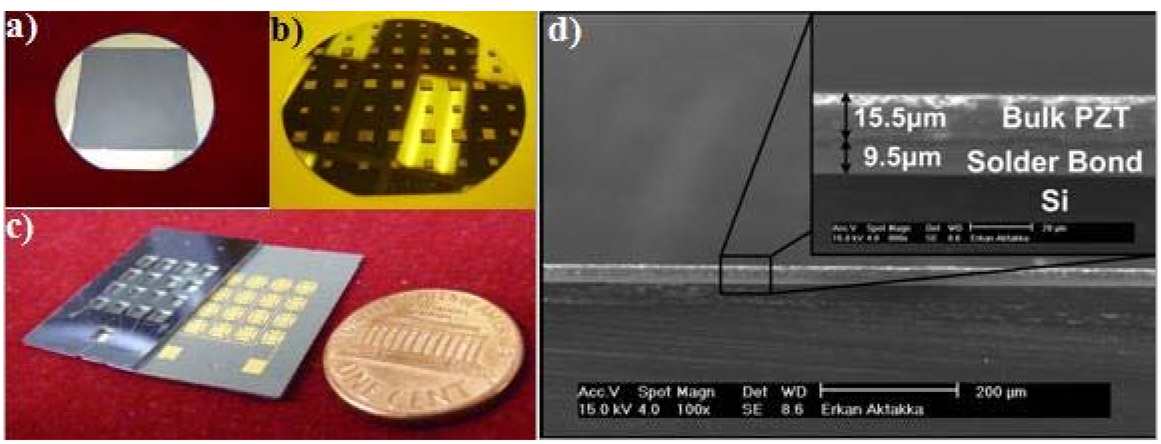

Figure 1: (a) Bonded and thinned PZT wafer on 4" Si wafer; (b) Die-level polymer bonding of PZT on Si; (c) 4 × 4 array of 2mm × 2mm square diaphragm piezoelectric actuators; and (d) Cross section of bonded and thinned PZT layer.

Role in Supporting the Strategic Plan and Testbeds:

The technologies being developed in this project will directly support several other projects in the ERC, enabling future high-stroke high-deflection piezoelectric MEMS actuators and sensors with low-power consumption. Developed wafer-level fabrication methodology for piezoelectric MEMS will form a significant basis for integration of CMOS circuitry into these devices, and will ease implementation of future unique generators for many other applications.

Results and Accomplishments:

Reliable solder and polymer bonding of PZT layers on Si wafers is accomplished [1]. Maximum bond shear strength is measured as 10.0MPa and 3.4MPa for solder and polymer bonded samples, respectively. After bonding, preservation of piezoelectric properties is confirmed by measurements of remnant polarization ($37.7\mu C/cm^2$) and coercive field (16.8kV/cm). Different size ($4 \times 4mm^2$, $2 \times 2mm^2$, $1 \times 1mm^2$) square d31-mode piezoelectric out-of-plane actuators were designed, optimized for electrical actuation, and fabricated at wafer level (Figure 1). Resonance frequencies and dynamic deflections of actuated diaphragms are determined by measuring diaphragm displacement via laser vibrometry. More than $10\mu m$ peak-to-peak deflection is obtained at 90kHz for a 1mm by side square diaphragm. The device performance clearly proves that this technology can be used for fabrication of high-deflection, high-stroke actuators and sensors on wafer level.

Plans for the Coming Year:

Different piezoelectric actuation mechanisms will be investigated, and optimization of device dimensions for piezoelectric actuation will be completed via FEA simulations. Several initial prototypes for different applications, such as an acoustic ejector, and an energy harvester will be designed and fabricated.

Expected Milestones and Dates:

- Technology development for solder and polymer bonding of PZT on Si wafers *(Completed)*
- Simulation, optimization, and fabrication of d31-mode diaphragm actuators *(Completed)*
- Simulation, and optimization of d33-mode diaphragm actuators *(Completed)*
- Design of a high-performance, energy harvester from ambient vibration *(Completed)*
- Fabrication and testing of the energy harvester prototypes (12/30/2009)

Expected Contributions, Deliverables, and Company Benefits:

- Integration of bulk piezoelectric materials into MEMS devices
- Prototype development of design and fabrication technology for piezoelectric energy harvesters
- Integration of CMOS circuitry to piezoelectric MEMS devices

References and Recent Publications:

1. E. E. Aktakka, H. Kim, and K. Najafi, “Wafer-Level Fabrication of High-Performance Piezoelectric MEMS Using Bonded and Thinned Bulk Piezoelectric Substrates,” *Proceedings of Transducer ’09,* Denver, CO, U.S.A., June 2009. (Accepted for Oral Presentation)