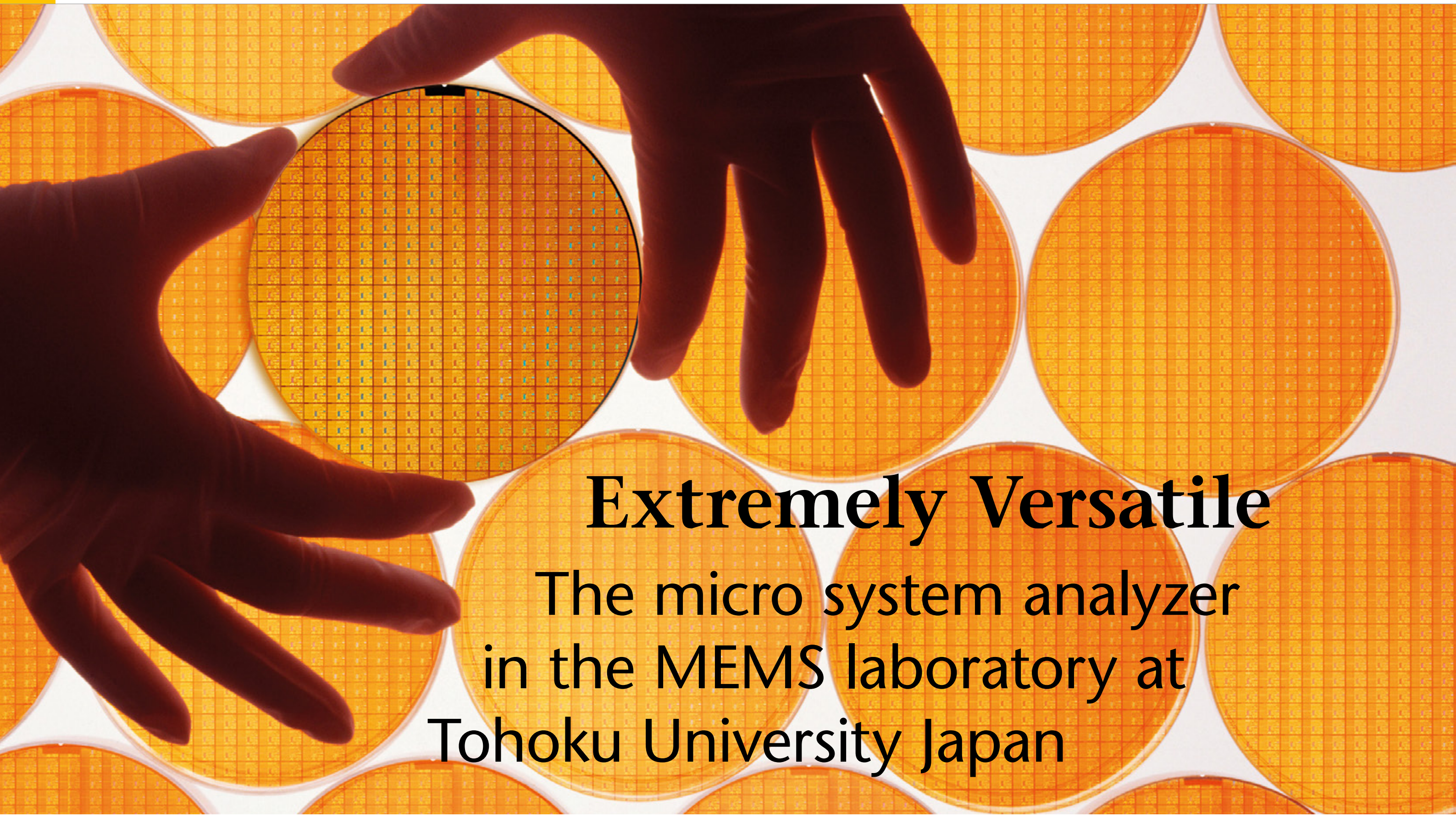

Extremely Versatile

The micro system analyzer in the MEMS laboratory at Tohoku University Japan

In this laboratory, and probably many others throughout the world, Polytec Micro System Analyzers are the most standard MEMS evaluation tools for their mechanical characterization. This article introduces three examples of MEMS studies using Polytec tools in my laboratory.

HIGH FREQUENCY DISK-TYPE MEMS RESONATORS

Mechanical resonance is one of the most fundamental dynamics exhibited by MEMS. It is used for gyroscopes, mass sensors, optical scanners, clock oscillators etc. One natural research direction for MEMS resonators is to pursue higher resonance frequencies and find new applications. Electrostatic and piezoelectric transductions are two major driving principles, and electrostatic MEMS resonators were more intensively studied from an early stage. However, electrostatic transduction suffers from the critical problem that electromechanical coupling is too weak for many applications. Therefore, we decided to adopt piezoelectric transduction for disk-type resonators, which were based on electrostatic transduction in many previous studies. Figure 1 shows piezoelectric disk-type resonators, which are mechanically connected via a center silicon disk [1]. Sputter-deposited aluminum nitride (AlN) was used as a piezoelectric thin film. Figure 2 shows the frequency characteristics up to 400 MHz. Each peak corresponds to a specific resonance mode, and the (2, 4) mode at 292.8 MHz is the main mode which we needed. The mode shapes can be calculated using the finite element

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method (FEM), as shown in Figure 3. However, observing the actual mode shape is not so easy due to its small size and high frequency. In this study, we used Polytec's UHF-120 to observe the actual mode shape of the disk-type resonators [2].

Polytec's UHF-120 is a high frequency laser Doppler vibrometer, which can measure velocity and integrated displacement up to 1,200 MHz. The displacement amplitude resolution is 2 pm @ 4.88 kHz resolution bandwidth. Figure 4 shows measured (2, 3) and (2, 4) mode shapes. The actual mode shapes look somewhat different from the calculated ones shown in Figure 3, demonstrating the necessity to experimentally characterize and validate modeled data. In addition, a locally large amplitude is found at the left upper part, which might be caused by misalignment of lithographic patterning. Unfortunately, we concluded that this type of MEMS resonator was practically useless for commercial frequency control applications, and switched to different acoustic resonators. However, we demonstrated that Polytec's UHF-120 was useful for observing high frequency MEMS resonators.

LATERALLY-DRIVEN PZT ACTUATOR

An actuator is often a limiting factor in MEMS design. Everyone naturally wants strong forces and ▶

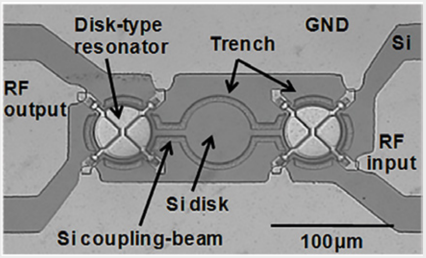


Figure 1: Mechanically-coupled piezoelectric disk-type MEMS resonators

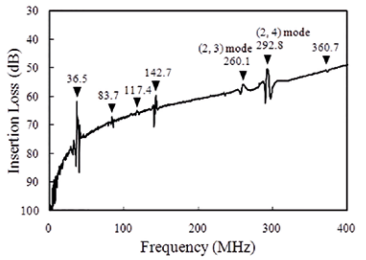
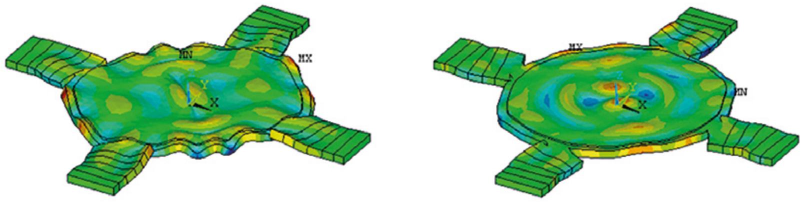


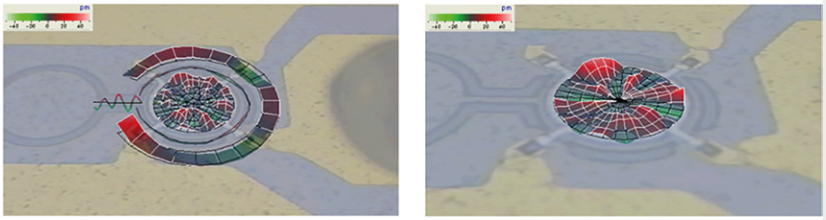
Figure 2: Frequency characteristics of disk-type MEMS resonators shown in Figure 1



(a) (2, 3) mode at 252.6 MHz

(b) (2, 4) mode at 286.8 MHz

Figure 3: Mode shapes calculated by FEM



(a) (2, 3) mode at 260.1 MHz

(b) (2, 4) mode at 292.9 MHz

Figure 4: Mode shapes observed by scanning laser vibrometry using Polytec UHF-120

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large displacements from a small actuator, but this is too much to expect from a MEMS device. On the other hand, people expect new MEMS actuators with better performance and/or new functions to further extend MEMS applications. Figure 5 shows a new type of PZT MEMS actuator, which we developed recently [3]. Normally, PZT MEMS actuators move in an out-of-plane direction, i.e. vertically, because the actuation is based on the bending motion of a PZT thin film. On the other hand, our new actuator moves in the in-plane direction, i.e. laterally. Figure 6 illustrates the mechanism of the laterally-driven PZT actuator. The cantilever is composed of a laterally-stacked PZT/silicon/ PZT structure, which was formed by filling 2 µm wide deep silicon trenches with sol-gel-based nano-composite PZT. On both sidewalls of each PZT beam, thin platinum layers were formed as driving electrodes by atomic layer deposition (ALD). The cantilever itself bends with a bimorph mechanism, and thus our new actuator is much smaller than conventional comb-type electrostatic actuators. The fabricated actuator shown in Figure 5 was characterized using our standard MEMS evaluation tool, Polytec's MSA-500, serving as a scanning

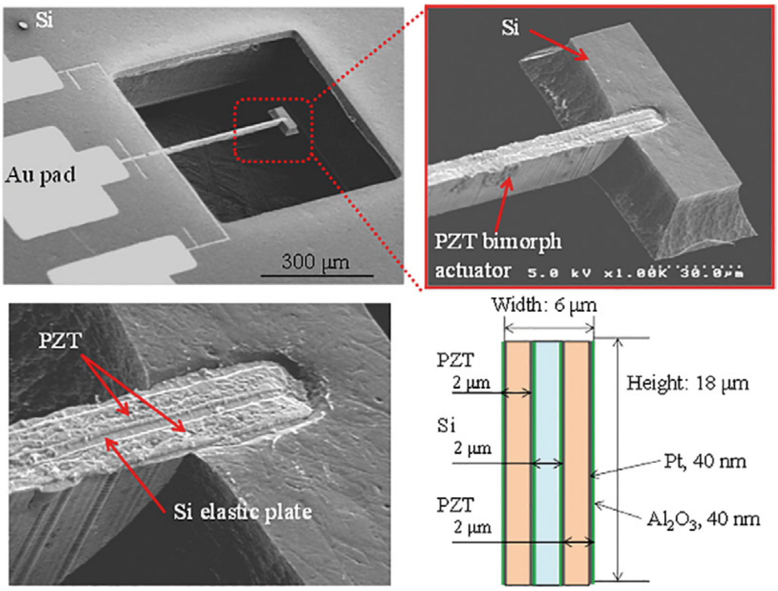

Figure 5: Laterally-driven PZT actuator with high aspect ratio PZT/Si/PZT structure

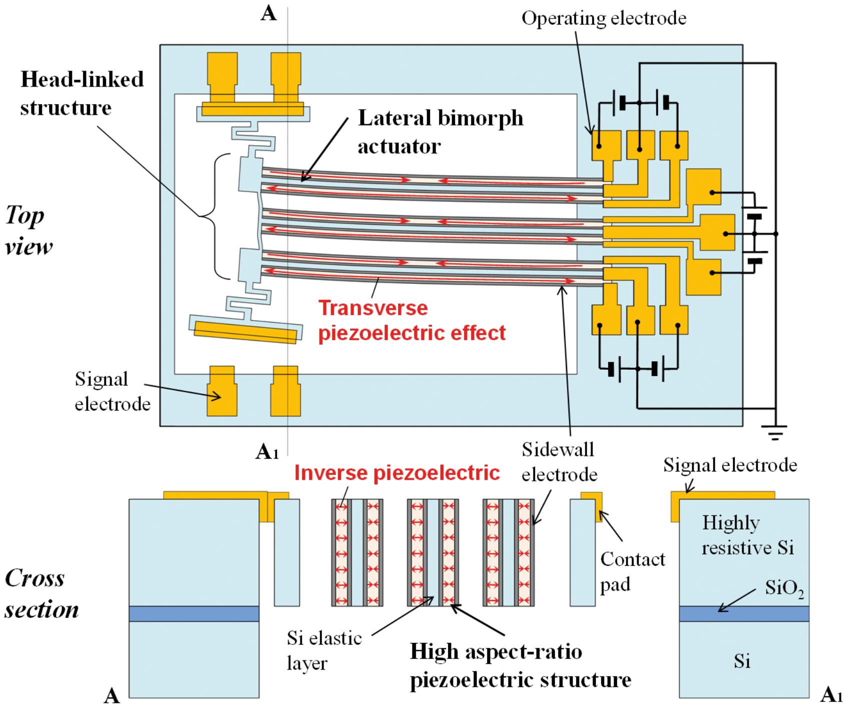

Figure 6: Mechanism of laterally-driven PZT actuator

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[1] PZT: Lead zirconate titanate (PZT) is an intermetallic inorganic compound that consits of lead (Pb), oxygen (O) and titanium(Ti) or zirconium (Zr). It is a ceramic perovskite material that shows a marked piezoelectric effect.

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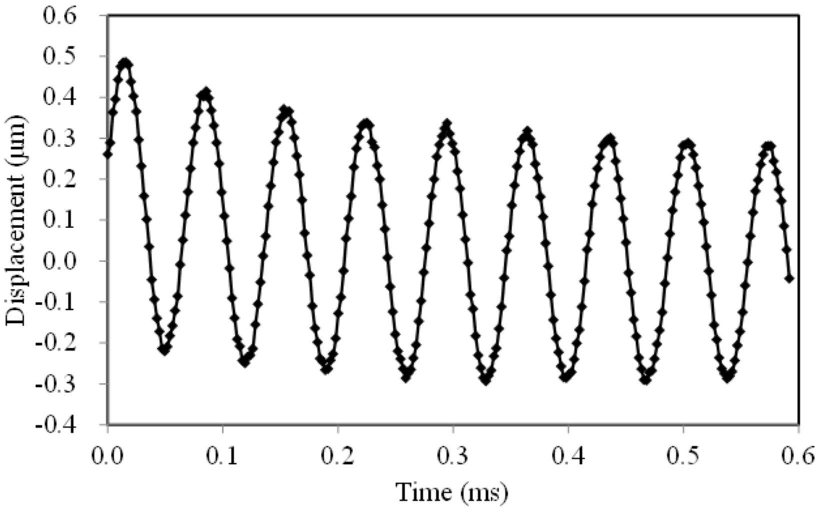

Figure 7: Decay vibration of laterally-driven PZT actuator measured by stroboscopic video microscopy using Polytec MSA-500

laser Doppler vibrometer, a white light interferometer and a stroboscopic video microscope.

The latter is suitable for observing the lateral motion of MEMS actuators. Figure 7 shows a decay vibration of the cantilever measured by the MSA-500. By Fourier transforming the data in Figure 7, the fundamental resonance frequency (f_0) was found to be 14.26 kHz. Also, the density of the PZT (ρ_{PZT}) was measured from the difference in weight after the selective wet etching of the PZT. Then, Young's modulus of the PZT was calculated from f_0 and ρ_{PZT}. The static tip deflection of the cantilever was 5 µm and 10 µm at a driving voltage of 25/0 V (unimorph actuation) and 25/–5 V (bimorph actuation), respectively. Finally, we estimated the d_{31} piezoelectric constant to be 36 pC/N.

WAFER-LEVEL HERMETIC PACKAGING WITH ANODICALLY-BONDABLE LTCC SUBSTRATE

MEMS include very small moving and/or suspended structures, which must be sealed hermetically for protection from moisture, dust and other contamination, air damping control, thermal isolation etc. The packaging has a large impact on the size and cost of MEMS, and thus wafer-level packaging is key for their commercialization. To date, the anodic bonding of a borosilicate glass lid wafer with a silicon MEMS wafer has often been used for wafer-level hermetic packaging. Anodic bonding itself is simple, reliable and of high yield, but how to electrically access MEMS hermetically sealed in a cavity, i.e. electrical feedthrough, is a critical problem. Nikko Company (Ishikawa, Japan) and we have developed the low temperature co-fired ceramic (LTCC) wafer which can be anodically bonded with a silicon wafer [4]. The LTCC material has a coefficient of thermal expansion similar to that of silicon, and contains sodium ions, which provide ion conductivity above 300°C. The anodic bonding characteristic is identical to that of borosilicate glass. Like conventional LTCC wafers, the anodically-bondable LTCC wafer is produced by stacking and firing punched green sheets, and provides screen-printed metal internal wiring, as shown in Figure 8. As detailed in [5, 6], the metal vias in the LTCC wafer and MEMS on a silicon wafer can be electrically connected using porous gold bumps in parallel with anodic bonding. The reliability of hermetic sealing was evaluated using silicon diaphragms. The LTCC wafer and a silicon wafer with diaphragms were anodically bonded in vacuum, and then the deformation of the diaphragms in air was measured by white light interferometry using Polytec's MSA- 500. As shown in Figure 9, the deformation of the diaphragms during a thermal cycling test (40°C × 30 min/125°C × 30 min) was negligible.

High reliability of electrical interconnection through the porous gold bumps was also demonstrated from the resistance ▶

of daisy-chain connections. Another concern besides the reliability is pressure in a vacuum-sealed cavity. It is known that oxygen gas is electrochemically generated in anodic bonding, and thus pressure in the sealed cavity is often higher than that of bonding environment. The pressure in the sealed cavity was measured using the diaphragm with the zero balance method in a vacuum chamber. The sealing pressure was known as the chamber pressure at which the diaphragm was flat. The special optics which compensates the influence of a vacuum window was attached to the objective lens of the MSA-500. Figure 10 shows examples of measured data. If a thin film non-evaporable getter (NEG) was used, the sealing pressure was lower than the detecting limit, which was about 80 Pa in this experiment. ■

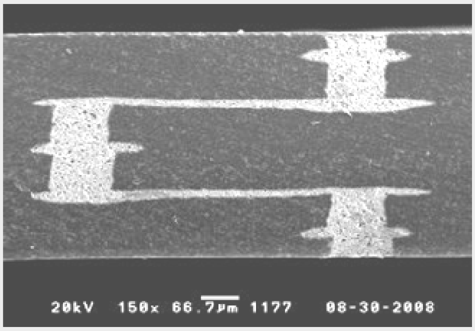

Figure 8: Cross section of anodically-bondable LTCC wafer

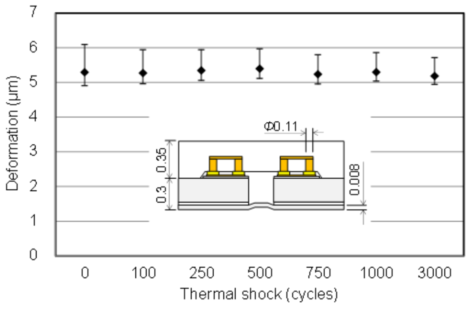

Figure 9: Reliability of hermetic packaging using anodically-bondable LTCC wafer

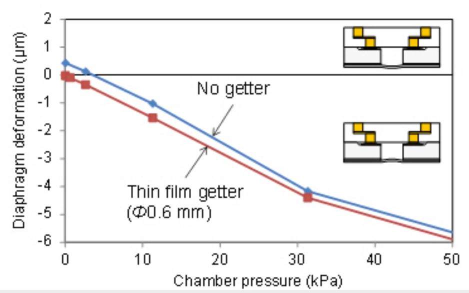

Figure 10: Sealing pressure measurement by zero balance method (Degassing at 400°C for 30 min → Anodic bonding at 400°C and 600 V for 1 min, Cavity volume = 0.26 mm³)

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Acknowledgements

I would like to especially thank Dr. Takeshi Matsumura, Mr. Nan Wang and Mr. Mamoru Mohri for Examples 1, 2 and 3, respectively. Examples 1 and 2 were supported by the "Funding Program for World-Leading Innovative R&D on Science and Technology", and Example 3 was partially supported by the "Creation of Innovation Centers for Advanced Interdisciplinary Research Areas Program".

Finally, I would like to thank my friends at Polytec for giving me the chance to write this article.

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