A Multilayer Thick-film PZT Actuator for MEMs Applications

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Abstract: This paper describes a technique for replacing the traditional bonded bulk PZT transducer, commonly used in MEMS devices, with a screen printed equivalent. Previously, the piezoelectric activity available from screen printed PZT has been lower than the bulk material, but recent developments in material composition and device structure have allowed screen printed structures to deliver powers equivalent to bulk devices.

Keywords Ultrasonic, MEMS, thick-film

INTRODUCTION

Work at Southampton has been progressing to develop an alternative to bonded bulk PZT for silicon MEMS actuators. Thick-film deposition represents a convenient way of depositing active materials, and developments in processing [1] and paste formulation [2] have allowed the technology to be migrated to silicon. This work describes an extension of this processing allowing piezoelectric coefficients to be achieved that are comparable to bulk PZT. The motivation for this development was to design a thick-film actuator to drive a microengineered ultrasonic acoustic separator, previously tested using a bulk element, and results are reported for this new device.

DESCRIPTION OF ACTUATOR

The actuating mechanism is manufactured by co-firing several layers of PZT at 890˚C each separated by an electrode layer. Several test devices were constructed, these consisting of either 1, 2 or 3 PZT layers, printed onto a ceramic substrate, and the results from these test samples were used to design a final actuator for use on silicon. In addition, a device using a bulk PZT drive element, glued to the silicon was constructed to allow a comparison.

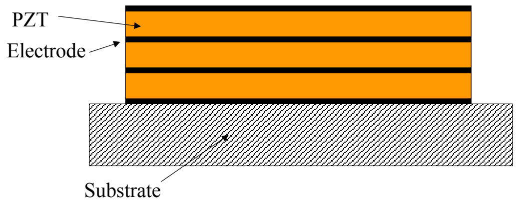

Figure 1 A Multilayer Structure

Figure 1 shows a three layer structure. The PZT paste is formulated within the Research Group [2]. The electrodes are thick-film gold. The structure requires polarisation and this was achieved by applying a 4MV/m field at 150˚C for 30 minutes across each layer in parallel. The main advantage in producing a multilayered structure is that it enables larger displacements to be generated than would be possible with a single layer of the same total thickness, effectively increasing the d_{33} coefficient. This results in lower drive voltages being required.

TEST RESULTS

d_{33} coefficients were measured using a *Take Control* PM35 meter. A layer of waterproof conformal coating was then sprayed on to seal the devices against water ingress.

Impedance Measurements:

The devices were mounted in a frame to allow ease of handling, and mounted face down in a beaker of degassed water. Impedance measurements were taken using a HP 4192A LF impedance analyser. These measurements enabled the transducer resonance frequency to be identified, and it was noted that this varied with the number of layers in a repeatable manner (Table 1).

Acoustic Power Measurements and Electrical Power Calculations:

An acoustic force balance (Ohmic Instruments UPM-DT-1) was used to measure the acoustic output power of the devices. These were then compared with the calculated power input to the device. This was calculated using the measured impedance, the known input voltage amplitude, and output impedance and gain of the driving amplifier.

Type	d_{33} typical (pC/N)	Resonant frequency	Efficiency %
Bulk	246	3.4MHz	18
1 layer	81	5.7MHz	36
2 layer	178	4.9MHz	43
3 layer	323	3.9MHz	35

Table 1: A comparison of results for different devices

The test devices have shown themselves to be more efficient at converting electrical energy into acoustic energy transmitted into water [5], then an equivalent bulk device (figures 2 and 3), and it was concluded that a two layer device would prove suitable for the separator application.

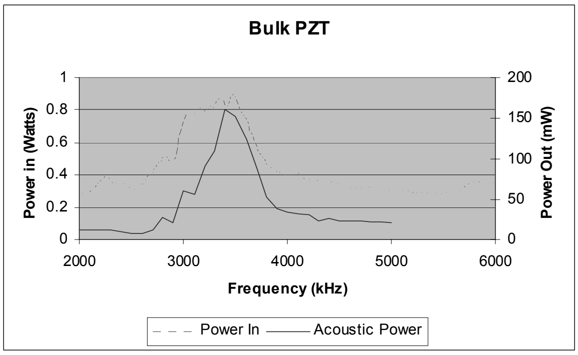

Figure 2 Power measurements for a bulk PZT drive element

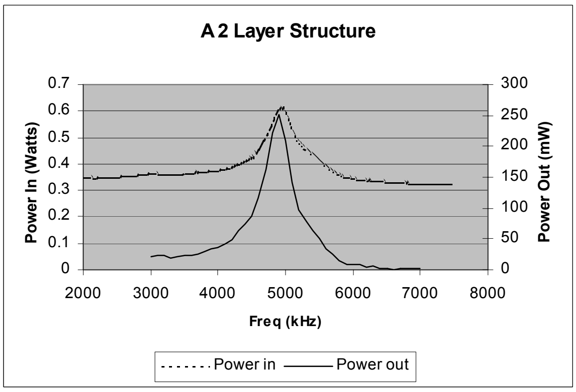

Figure 3 Power measurements for a 2 layer thick-film structure

ULTRASONIC SEPARATOR

The principle of the operation of the separator is given in reference [3] and the model used to predict its operation is given in [4]. The thick-film separator performance was modeled and the results are incorporated in figure 8 for 1 micron latex particles.

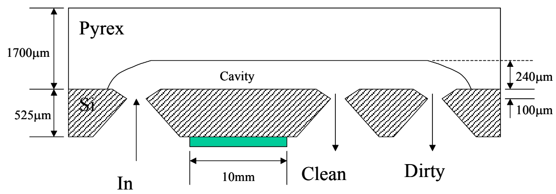

Figure 4 Cross-section of an ultrasonic separator

Figure 4 shows a cross-section of a typical device. In brief, the actuator is used to establish an acoustic standing wave within the cavity, and particles within the fluid are driven to the nodes by radiation forces. In this device we are working with a half-wave cavity.

This concentrates the particles within a layer in the centre of the cavity, and by adjusting the relative flows at the outlets, a 'clean' and a 'dirty' flow can be extracted.

SEPARATOR CONSTRUCTION

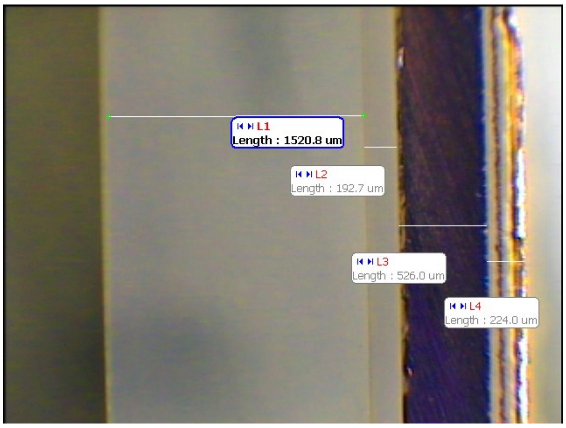

Figure 5 A cross-section of a device

A wafer of devices was fabricated and a two-layer thick-film actuator was deposited on the silicon in place of the bulk PZT. The silicon wafer was a standard 525µm wafer, etched with access ports as indicated in figure 4, and an etched Pyrex wafer was anodically bonded to this wafer to create the device. A 2 layer actuator was printed with gold electrodes, and polarised , as described previously. A sample device was sliced longitudinally and is shown in figure 5. This picture shows (from right to left) the two PZT layers, the silicon carrier layer, the fluid gap and finally the Pyrex backing layer, and gives a good indication of the relative scales of the different layers.

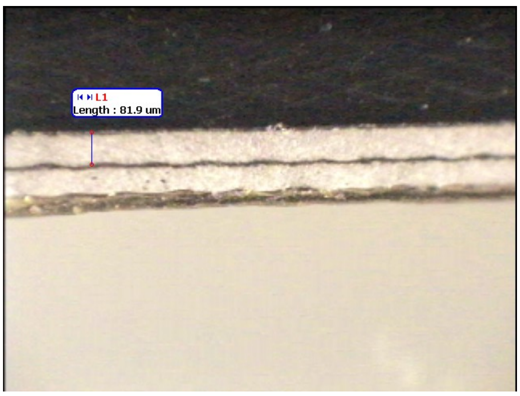

Figure 6 Detail of the PZT layers

Figure 6 shows a more detailed photograph of the thick-film layer. A good uniformity of printing is apparent, with the PZT layer being about 82µm thick. The gold electrode layers are also visible. Impedance measurements indicate that the composite structure has a resonance of about 3.9MHz in air. When filled with water, impedance measurements show that the two predicted half wave modes were present, indicating that the model should give a good indication of the performance of the device. The device was operated at the peak at 4.4MHz.

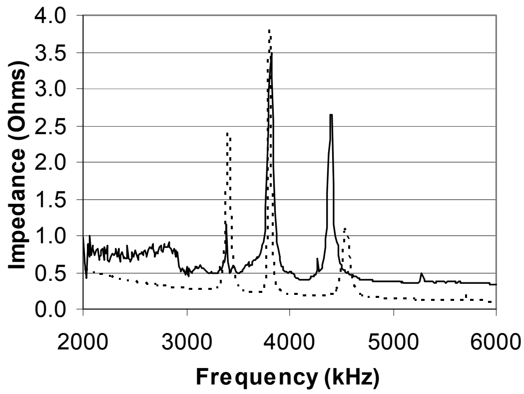

Figure 7 Real part of impedance (solid – measured, dotted - modelled)

SEPARATOR TEST

The experimental procedure was as described in [6], in that turbidity measurements were taken using a Honeywell APMS-10GRCF turbidity sensor, previously calibrated against a haemocytometer for the latex particles used. The total flow rate through the device was 5.1ul/min with a flow rate split between the outlets of 75/25%. The performance of the separator running at 4.4MHz was measured at different drive voltage levels, thus verifying the predictions of the model. Figure 8 shows the measured performance, compared with the predicted performance from the model.

CONCLUSIONS

The successful results show that the thick-film PZT actuator performs well as an acoustic source in this application, and further that the previously developed model for predicting the performance of bulk PZT driven concentrators has been verified for thick-film PZT actuators. In addition, it can be concluded that thick-film actuators are more efficient than bonded bulk PZT actuators for this application. We therefore conclude that thick-film multilayer actuators are a viable alternative to bonded bulk PZT actuators, with the added advantage of being batch processable on a wafer scale.

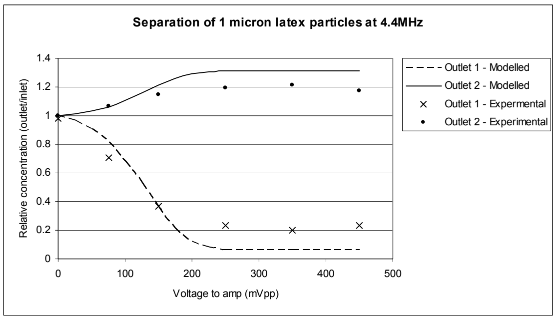

Figure 8 Performance of a thick-film actuated separator

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ACKNOWLEDGEMENTS

The authors with to thank the Engineering and Physical Research Council (EPSRC) for their financial support under grant number GR/R13333/01, and acknowledge the Financial support given by DSTL and Porvair Filtration Group. Special thanks are due to Angela Cotton in the Medical Physics department at Southampton General Hospital for the use of the power balance.