A PZT MULTILAYER THICK-FILM ACTUATOR FOR ULTRASONIC APPLICATIONS

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Abstract *In many MEMS applications there is a requirement for actuating a structure. This paper describes a method of generating acoustic power from a PZT based thick-film structure which gives output power and electrical efficiencies at least as good as, and in some cases better than bulk PZT in the same application.*

Keywords *thick-film, actuation, ultrasonic*

I INTRODUCTION

The traditional method for actuating microengineered structures using PZT has been to use bulk PZT bonded to the structure in question. Work at Southampton has been progressing towards being able to replace this bonded transducer with a screen printed equivalent[1]. In the past, the piezoelectric activity available from screen printed PZT has been much lower than the bulk material, but recent developments in both material composition [2] and device structure have allowed a screen printed structure to deliver powers equivalent to bulk devices. This new printed transducer has been incorporated into a redesign of an ultrasonic microfluidic particle manipulator[3], where the original bulk PZT drive element has been replaced with a screen-printed thick-film device. This paper details the performance measurements achieved with several thick-film structures.

II DESCRIPTION OF ACTUATOR

The actuating mechanism is manufactured by co-firing several layers of PZT at 890 degrees, 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.

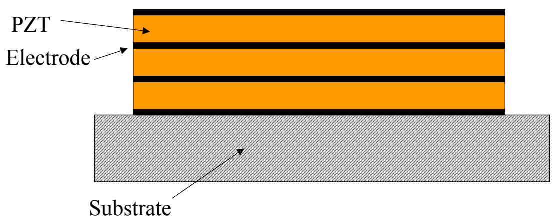


Figure 1 Structure of a 3 layer construction

Figure 1 shows a three layer structure. The PZT paste is formulated within the department [2]. The electrodes are thick-film gold. The structure requires polarisation and this was achieved by applying a 4MV/m field at 150 degrees C for 30 minutes.

III ADVANTAGES OF A MULTI-LAYER STRUCTURE

The main advantage in producing a multilayered structure as shown in figure 1 is that it enables larger displacements to be generated than would be possible with a single layer of the the same total thickness, effectively increasing the d_{33} coefficient. In addition, layering the structure allows lower absolute voltages to generate the required polarising field strength. Figure 2 shows how a two layer structure is connected and polarised.

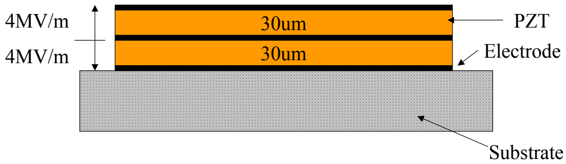


Figure 2 Structure and polarisation of a 2 layer structure

It can be seen that for a given applied voltage there is twice the movement as for 1 layer. This is an effective increase in the d_{33} coefficient of 100%. This comes about because effectively twice the actual voltage is being applied as compared with a single double thickness layer.

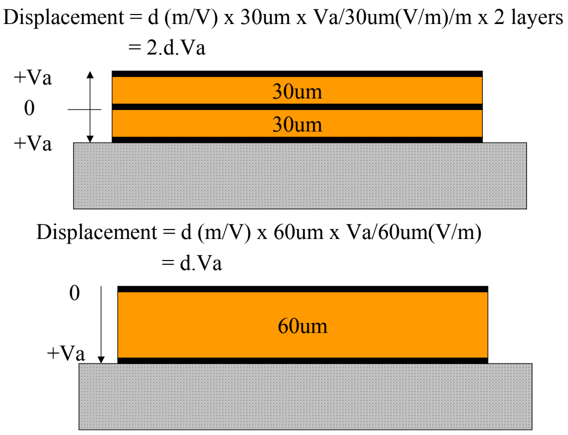


Figure 3 Comparison of displacement for a 1 layer and a 2 layer structure. Va is the applied voltage

A three layer structure is polarised in a similiar way as shown and in principle gives 3 times the movement than for 1 layer. It is possible to keep increasing the number of layers in this way but in practice the sensible limitation is 3 layers.

IV PIEZOELECTRIC MEASUREMENTS

d_{33} coefficients were measured using a Take Control PM35 meter. The results, given in figure 4, show the expected increase in d coefficient, although the results appear to show that the improvement is not a straight multiplication. For example, the triple layer results are approximately 4 times the single layer results, whereas simple theory would predict 3 times. The reasons for this are not apparent at present, and more results are required to determine whether this is due to process variations or a fundamental effect. Most likely it is due to less PZT being degraded during the firing process.

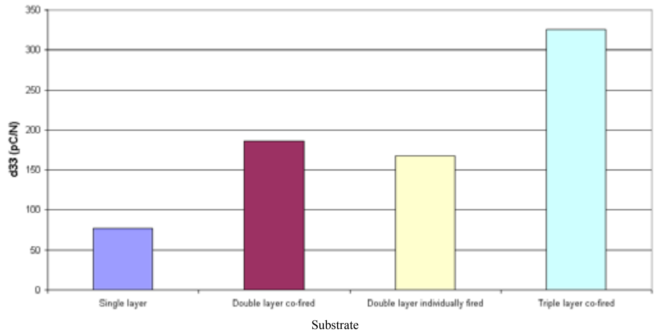
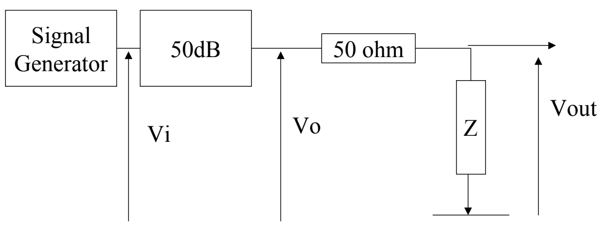


Figure 4 D coefficient results

V POWER CALCULATION AND MEASUREMENTS

Direct measurements were taken of the acoustic output power using an acoustic force balance (Ohmic Instruments UPM-DT-1).

Input power calculations were carried out in order to calculate the efficiency of the devices. The system used to drive the transducers was as shown in figure 5.



Vi = 250mV pk-pk = 88.4mV rms
Vo = 88.4mV * 50dB = 27.954V rms

Figure 5 Experimental system

The amplifier gave a fixed 50dB amplification and had an output impedance of 50 ohms. The impedance of the load was measured using a Hewlett Packard 4192A LF impedance analyser across a range of frequencies. An example plot of the impedance is shown in figure 6.

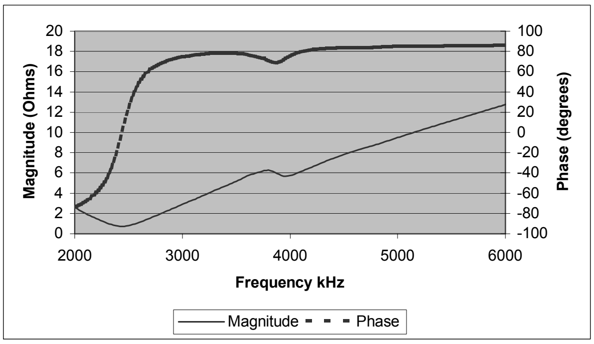


Figure 6 An impedance plot for a three layer device

This allowed the power delivered to the load to be calculated:
Power dissipated is given by Re{VI*} where V is the voltage across the load and I is the current through the load.
Now we can calculate $Vout = (Z/Z+50)*V_o$ as we know that V_o is fixed and we have measured Z.
Now I = V/Z and therefore power dissipated can be calculated as

$$Power = \mathrm{Re}\left\{ V \left(\frac{V}{Z} \right)^* \right\}$$

$$= \mathrm{Re}\left\{ \frac{|V|^2}{Z^*} \right\}$$

$$= |V|^2 \cdot \mathrm{Re}\left\{ \frac{1}{Z^*} \right\}$$

VI RESULTS

The following figures show the measured power out and calculated power in for examples of the 1, 2 and 3 layer devices.

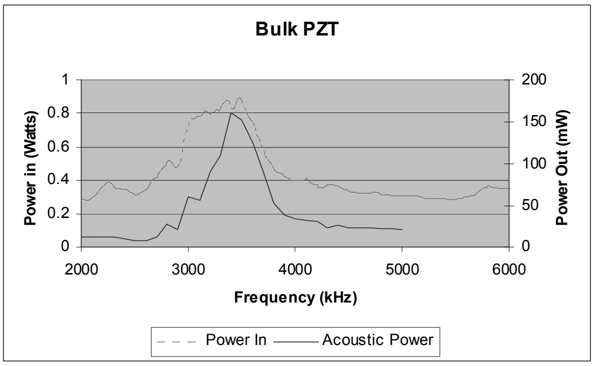


Figure 7 Power results for bulk PZT

As a comparison, a crystal of bulk PZT has been mounted in the same way and tested.

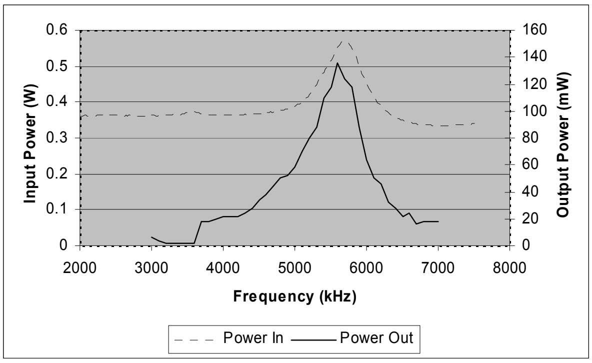


Figure 8 Power results for a 1 layer structure

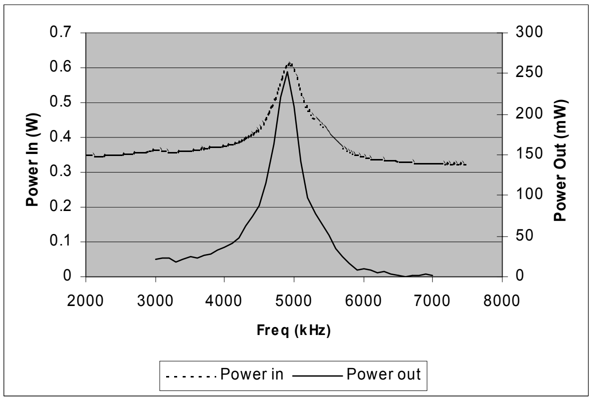


Figure 9 Power results for a 2 layer structure

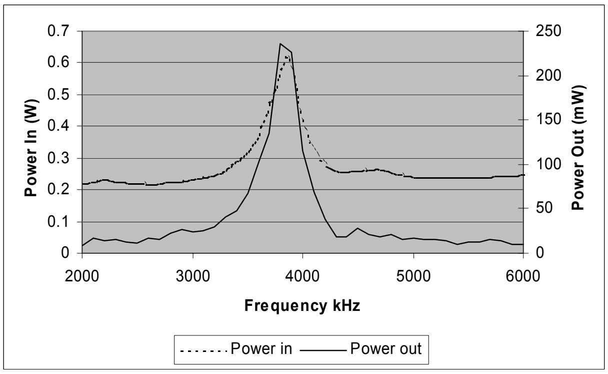


Figure 10 Power results for a 3 layer structure

From these graphs it can clearly be seen that the resonant frequency of the structure changes with the number of layers, moving from about 5.7MHz for a one layer device to 3.9MHz for a three layer device.

The output power from a one layer device is less than for both a two and a three layer device, as expected, but the output from a three layer device is approximately the same as for a two layer device. This result should be compared with the d coefficient results shown in figure 4, indicating that the effective d coefficient for a three layer device is greater than that for a two layer device.

The power output measured from the bulk material is comparable with that from a 1 layer device, although the input power for the bulk material is higher than for the one layer thick-film device. This indicates that the thick-film device is more efficient in this application. Table 1 shows the efficiencies of the tested devices.

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 Key results for measured devices

It is apparent from the table that any of the thick-film structures give good efficiencies in this type of application when compared to a similarly mounted bulk device.

VII CONCLUSION

It is concluded that multilayer thick-film transducers can perform better than bulk PZT transducers structures, in terms of conversion efficiency of electrical to acoustic energy, when used as the drive elements for certain microsystems. Moreover, they are attractive in MEMS type applications, especially microfluidics, as they are easier to produce in wafer scale processes, as they are printed rather than individually bonded, as is the case with traditional bulk PZT elements.

VIII REFERENCES

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IX ACKNOWLEDGEMENTS

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