Acoustic power output measurements for thick-film PZT transducers

N.R. Harris, M. Hill, N.M. White and S.P. Beeby

Direct acoustic measurements have been performed on a range of thick-film PZT ultrasonic transducer constructions, and these are compared with their electrical impedance and calculated input powers. They show good efficiency when driving into water, and a significant improvement over a similarly constructed bulk PZT transducer.

Introduction: Thick-film PZT pastes offer the potential to produce ferroelectric transducers for some ultrasonic applications more conveniently and cheaply, particularly in the field of microfluidics [1]. One important parameter that needs to be established is a measure of the efficiency of converting electrical energy into useful acoustic energy. This Letter describes the construction of a thick-film PZT transducer for use in a microfluidic application and presents an experiment performed to establish the device's efficiency.

Construction: A range of structures were produced using a thick-film PZT paste developed within the ESD group at Southampton University [2]. These consisted of either a single layer, a dual layer or a three-layer sandwich structure, printed onto an alumina tile, although in principle this could be a silicon wafer [3]. The samples were printed and dried as many times as necessary. For example, the two-layer samples had a bottom gold electrode printed and fired, and then a PZT layer was printed and dried. This was then followed by another gold electrode, another PZT layer and finally a top gold electrode. The whole structure was then co-fired at 890°C. The thick-film structures were polarised in a field of 4 MV/m for 5 min at 200°C and then allowed to cool to 60°C with the field applied. In addition, a similar area of bulk PZT was glued onto an identical tile for comparison purposes. d33 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).

Table 1: Summary of results

Type	d_{33} typical, pC/N	Resonant frequency, MHz	Efficiency, %
Bulk	246	3.4	18
One-layer	81	5.7	36
Two-layer	178	4.9	43
Three-layer	323	3.9	35

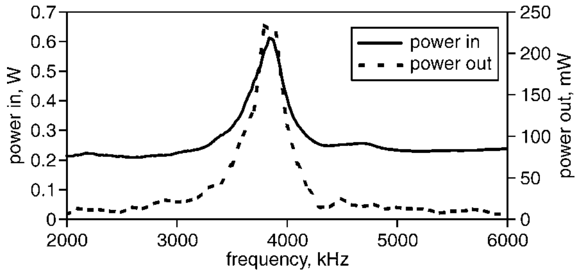

Fig. 1 *Power measurements for three-layer device*

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. Fig. 1 shows an example of the measured acoustic power output compared with the calculated electrical power input for a three-layer device, and Fig. 2 shows the impedance measurements for that device.

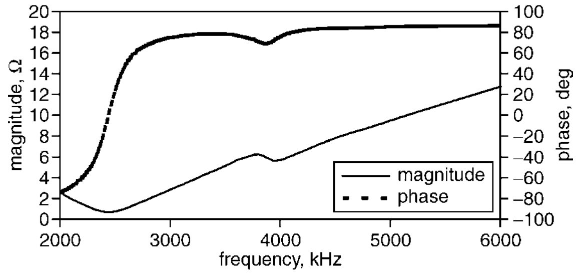

Fig. 2 *Impedance measurements for three-layer device*

Analysis of results: The thick-film devices are more efficient in terms of transforming the electrical energy into acoustic energy than the equivalent bulk PZT construction. The efficiency of the thick-film devices is between 35 and 45% (Table 1). The bulk material gives about 18% efficiency. The lower impedance of the thick-film devices also allows a much lower driving voltage. An interesting result, not yet explained, is that the thick-film devices appear as inductances in that they have a large positive impedance phase angle (Fig. 2). As shown in Fig. 3, the bulk material exhibits a more capacitive impedance phase angle. All measurements were taken under the same conditions, using the same equipment, including the same wire connections, and so this must be a feature of the thick-film structure.

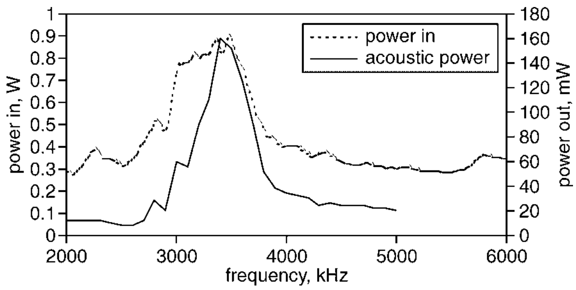

Fig. 3 *Power measurements for bulk sample*

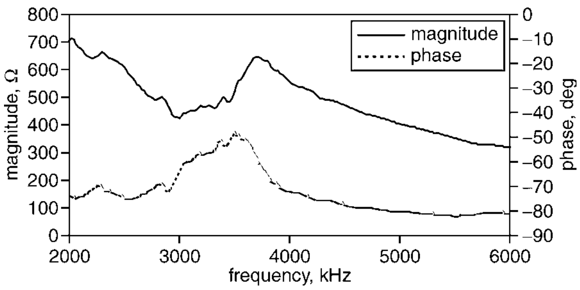

Fig. 4 *Impedance measurements for bulk sample*

Conclusions: 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, and, further, they offer a lower impedance than an equivalent bulk PZT device, making driving at lower voltages a possibility.

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References

1 Harris, N.R., Hill, M., Beeby, S., Shen, Y., White, N.M., Hawkes, J.J., and Coakley, W.T.: 'A silicon microfluidic ultrasonic separator', *Sens. Actuators B*, 2003, **95**, pp. 425–434

2 Torah, R.N., Beeby, S.P., and White, N.M.: 'Improving the piezoelectric properties of thick-film PZT: the influence of paste composition, powder milling process and electrode material', *Sens. Actuators A*, 2004, **110**, (1–3), pp. 378–384

3 Maas, R., Koch, M., Harris, N.R., White, N.M., and Evans, A.G.R.: 'Thick-film printing of PZT onto silicon', *Mater. Lett.*, 1997, **31**, pp. 109–112