*Thin and Thick Films*
*Paper presented at Eurosensors XII, 13–16 September 1998*




# Piezoelectric Thick-Film Polymer Pastes

T Papakostas, N R Harris, S P Beeby, N M White

Department of Electronics and Computer Science, University of Southampton, Highfield, Southampton, SO17 1BJ

**Abstract** A novel piezoelectric paste based on a polymer binder and lead zirconate titanate (PZT) powder has been developed for screen-printing and is described here. An experimental technique for measuring the piezoelectric coefficient $d_{33}$ of this paste is described together with a comparison of these values for different paste formulations.

## 1. Introduction

Piezoelectric thick-film pastes based on glass binders for use in conventional thick-film processing have been reported in the literature, as has their use in several sensing and actuating structures [1-3]. One disadvantage of this type of paste is its requirement for high temperature processing (typically at 950 degrees centigrade), which limits its applications. One way of reducing the processing temperature of the paste is to replace the glass binding element with a lower temperature binder, such as a low temperature polymer. The use of a polymer also opens up avenues of exploration in using alternative substrates, which offers the possibility of flexible screen printed piezoelectric transducers.

## 2. Formulation of Paste

Several batches of paste were hand mixed. These used the same polymer binder, but had varying amounts of the active piezoelectric material added. The piezoelectric material was lead zirconate titanate (PZT) grade 5H, with a maximum particle size of 6μm [4]. The polymer used for this experiment was Ronascreen Green OPSR 500, which has been developed by LeaRonal primarily as a screen printable soldermask. The piezoelectric paste was mixed by adding PZT powder to a known quantity of the polymer until the desired weight ratio was achieved. For the purposes of this paper three pastes will be analysed, and these are pastes that have 90% PZT by weight, 85% PZT by weight and 75% PZT by weight. In the case of the 90% paste, it was necessary to thin the mix by adding a small amount of thinner (ESL400) to give a printable consistency.

## 3. Processing

The three different percentages of the polymer PZT paste were printed onto alumina. Each paste was printed with three different sizes of a test pattern as shown in figure 1. Each pattern consists of a layer of the test ink sandwiched between two conducting layers, to give a capacitor structure as shown in figure 2. All the samples were cured simultaneously whilst being polarised for 1 hour. A selection of samples from the 75% and 85% pastes were polarised for 24 hours. In order to measure the thickness of the layers, a light section microscope was used. The thickness of the electrode layers is between 10 to 15 μm. The

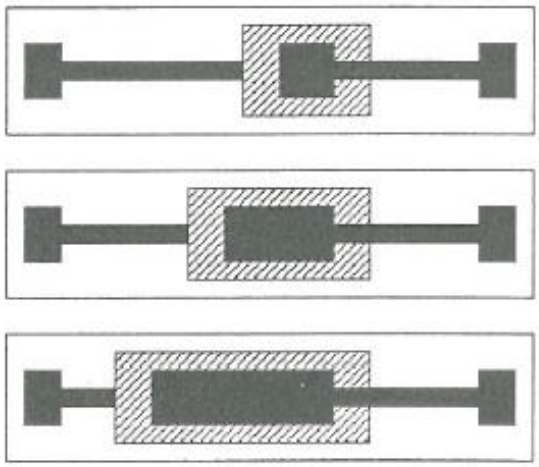

Figure 1 – Printed patterns

PZT layer was deposited using two or four print runs yielding ranges of thickness between 44 to 66 μm and 80 to 121 μm. Initially the bottom electrode layer was printed using a conventional cermet silver palladium paste (ESL 9635-A) fired at 850 degrees centigrade to act as a key for soldering. This was the only high temperature step and was performed purely for convenience of lead attachment. The PZT/polymer mix was then printed and dried in an IR drier at 140 degrees centigrade for 10 minutes. This partially cures the polymer that is fully cured during polarisation. The top electrode layer was then printed using a conventional polymer silver conductor paste (ESL 1107-S) also dried at 140 degrees centigrade for 10 minutes.

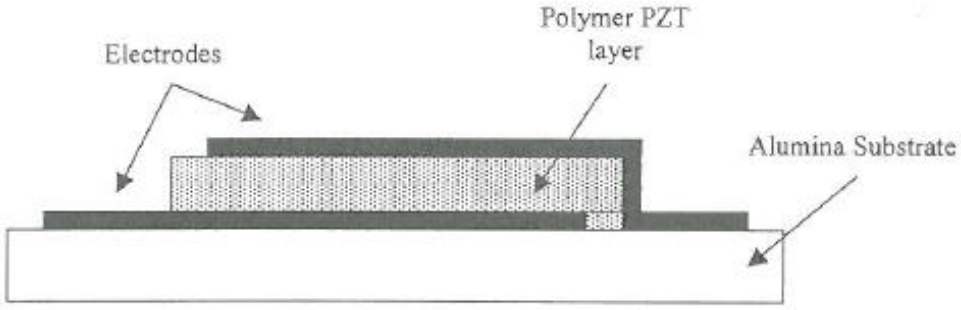


Figure 2 – Capacitor structure

## 4. Polarisation

In order to impart a net piezoelectric effect to the layer, it is necessary to polarise the material. Previous work on thick-film PZT pastes [2] has shown that good results were obtained by heating the sample to 130 degrees centigrade and applying about 3MV/m of electric field for 1 hour before cooling and removing the field. A similar regime was followed for this study. Heating to 130 degrees centigrade has the added feature that it allows simultaneous curing of the polymer while the encased PZT is polarised. It was decided to apply several different field strengths in order to try and identify any optimum conditions. In addition, some samples were polarised for 24 hours to determine the effect of polarisation time on the behaviour of the material and to confirm that maximum potential can be achieved in the time needed to cure the polymer.

## 5. Measurements

The most practical aspect of material such as this is its ability to transduce a stress into a charge. This transduction effect is measured by a constant of proportionality, known as the d constant and it is given in picocoulombs per Newton. The alternative definition, that of an applied electric field causing a strain is not directly applicable in this case due to the material being bonded to a substrate of a different material.

The $d_{33}$ coefficient of each sample was measured using the measuring apparatus shown in figure 3. This has been carefully designed to avoid bending stresses in the sample, which would exaggerate measured results. We used a very high impedance charge amplifier, with a known gain, to measure the charge generated when a force (mass) was applied on the PZT substrate.

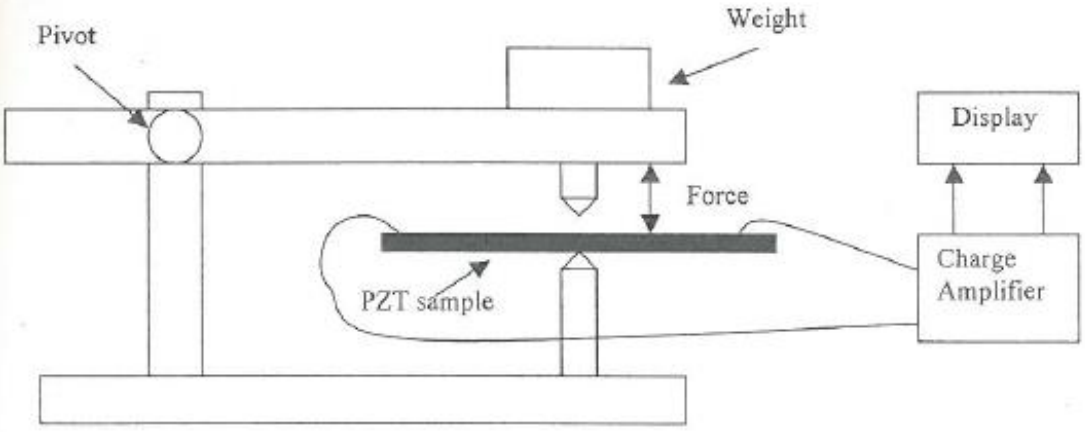


Figure 3 – Measuring apparatus

The system was capable of direct measurement of the $d_{33}$ coefficient and gave repeatable measurements. It also gave good results with bulk PZT-5H samples, giving results within a few percent of the literature values (593pC/N) [4].

## 6. Results

Early indications showed that the structures were sensitive to shear forces e.g. bending of the substrate, and great care was necessary to obtain a true indication of $d_{33}$. For this reason, structures of different printed areas were investigated. Incorrect mounting of the substrates resulted in variations in readings from samples of different sizes. Correct mounting produced measurements with no significant difference between samples.

The results were plotted and are shown in figure 4. The $d_{33}$ range of values obtained by our experiments spans from 4.52 to 14.63 pC/N, which compares well with the literature

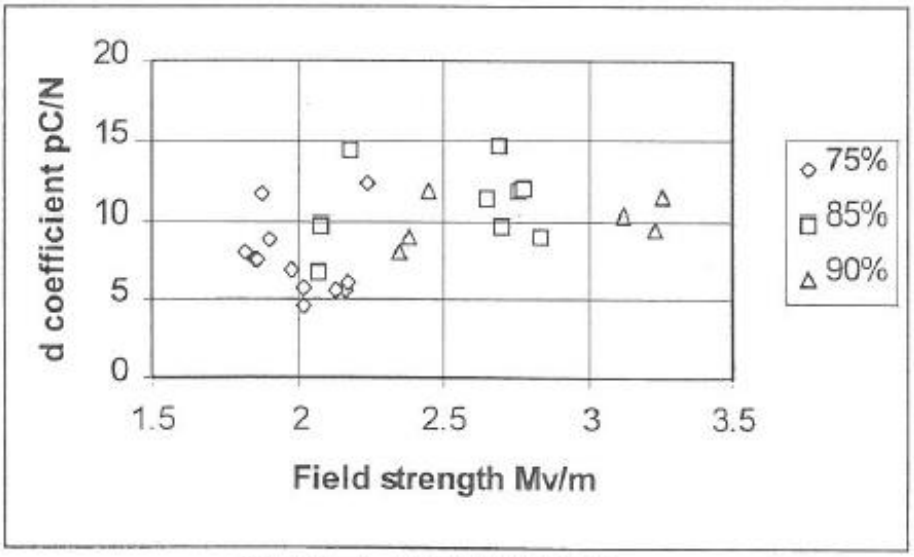


Figure 4 – $d_{33}$ versus field strength

values of similar non screen printed pastes [5]. From the graph it can be seen that the 75% samples show less piezoelectric activity than the other samples. Field strengths in the range observed do not appear to make any significant difference. Also, there is little difference between the 85% and 90% samples.

Figure 5 shows the maximum $d_{33}$ values obtained for pastes polarised for 1 hour and 24 hours. The first indications we have are that the polarisation time does not seem to affect the piezoelectricity of the polymer pastes significantly.

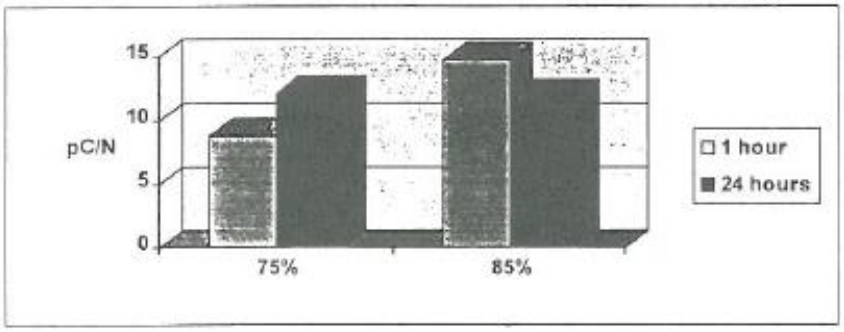


Figure 5 – Max values for pastes polarised for 1 hour and 24 hours

## 7. Conclusion

This paper has shown that it is possible to produce a piezoelectric thick-film ink utilising a polymer binder, which cures at low temperatures. Further it has shown that the piezoelectric activity of such a material is significant and can be altered by the relative ratios of the components. Values of the $d_{33}$ coefficient range from 4.52 to 14.63pC/N. No significant differences in coefficient have been identified when poled for 1 or 24 hours, thus allowing poling to be coincident with curing. The effect of poling field has also been investigated but to date high field strengths seem to offer little advantage. Work is continuing to optimise the mix ratio and polarising conditions. Future work will investigate different types of polymer with the potential of producing flexible sensors.

## 8. References

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## 9. Acknowledgements

The authors gratefully acknowledge the financial support of the EPSRC (grant number GR/K54465) in this project.