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High temperature stack actuator

1. Scope of the Application Note

Ionix Advanced Technologies have developed a proprietary piezoelectric material system from which HPZ580 is a resultant product which operates at higher temperatures than conventional PZT-based piezoelectric ceramics. HPZ580 also exhibits a higher piezoelectric activity than other high temperature piezoelectric ceramics, such as lead metaniobate, bismuth titanate and single crystal piezoelectrics operating continuously up to 550 °C whilst maintaining a piezoelectric activity (d33) higher than 90 pC/N.
Even when utilising ceramic, and not epoxy, insulation, the maximum operating temperature of standard piezoelectric stack actuators is < 200 °C, due to the limitations with the piezoelectric material. Utilisation of high temperature materials, such as HPZ580, could allow for the production of high temperature piezoelectric devices.

A feasibility study was undertaken to determine whether HiT1 materials could be used to make a high temperature stack actuator.

Highlights:

- Proven operation between room temperature and 400 °C
- Stable displacement over a wide range of temperatures
- Highly linear strain-field response over the temperature range
- Cycling between room temperature and 500 °C does not have a detrimental effect on the piezoelectric activity

2. Methodology

Standard production parts of HPZ580 material were bonded using standard electrode ink and diced into 3 x 3mm stacks. The stacks were reticulated using a wafer saw with a 0.4 mm blade, see Figure 1.

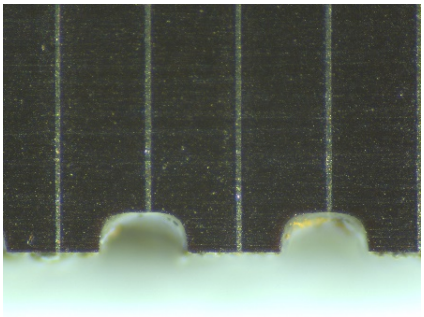

Figure 1 – Image of the electrode reticulation

The gaps were filled using commercial dielectric paste and fired. Electrode was applied to the opposite sides of the stack, connecting alternating layers. The stack was fired and the d_{33} measured using a Berlincourt meter. A CAD image of the final stack is shown in Figure 2.

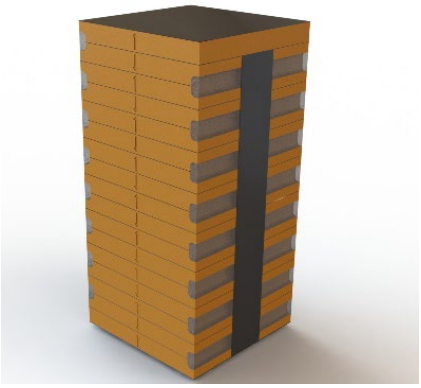

Figure 2 – CAD image of the 17-layer HPZ HiT1 stack actuator

Strain-field measurements were conducted using an aixACCT TF 2000 ferroelectric tester. Strain-field loops were collected at room temperature with increasing electric field strength up to a maximum of approx. 5 kV/mm in silicone oil. The oil was removed and strain-field measured with increasing temperature, using a field strength of 0.24 kV/mm, up to a maximum of 400 °C, with 50 Hz bipolar loops.

Impedance measurements were conducted (Keysight E4990A Impedance Analyser) attached to a high temperature measurement rig inside a tube furnace. Measurements were taken every 100 °C from 100 °C to 500 °C, with a minimum dwell time of 30 minutes used at each temperature. The stack was then cycled between room temperature and 500 °C, with a 30-minute dwell after each temperature excursion. The d_{33} was then measured at room temperature.

3. Results

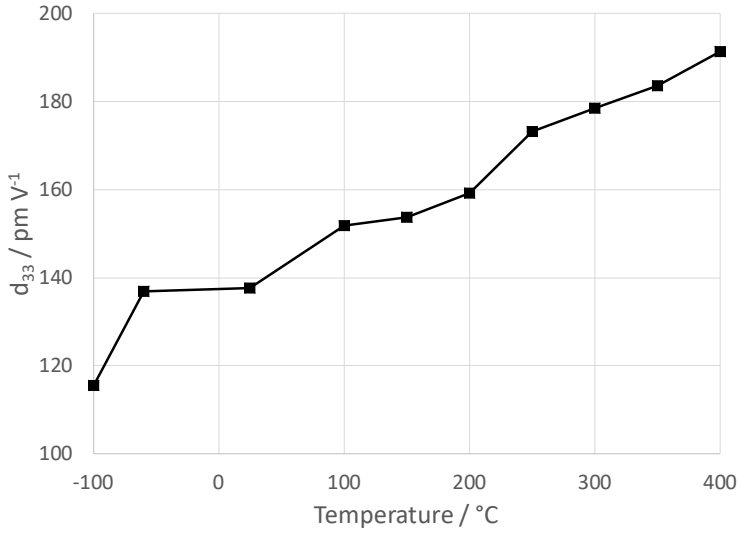

Figure 3 – d_{33} vs temperature for a 17-layer stack actuator

Between -100 °C and 400 °C, using an electric field of 0.24kVmm^{-1}, the average increase in d_{33} is observed to be approximately 0.13% K^{-1}, Figure 3, which compares favourably with PZT.

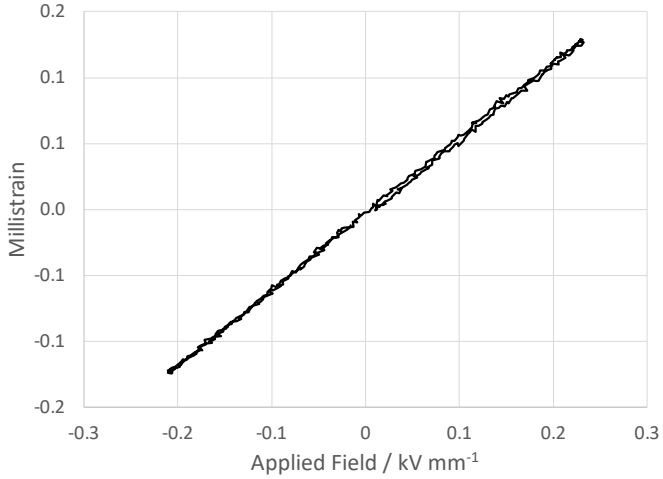

Figure 4 – Strain-field data of a stack actuator at 400 °C.

The strain field loop is extremely linear, there is virtually no hysteresis present, and no evidence of electrostriction. This may have significant implications where extreme linearity is important, such as for micro-positioning applications.

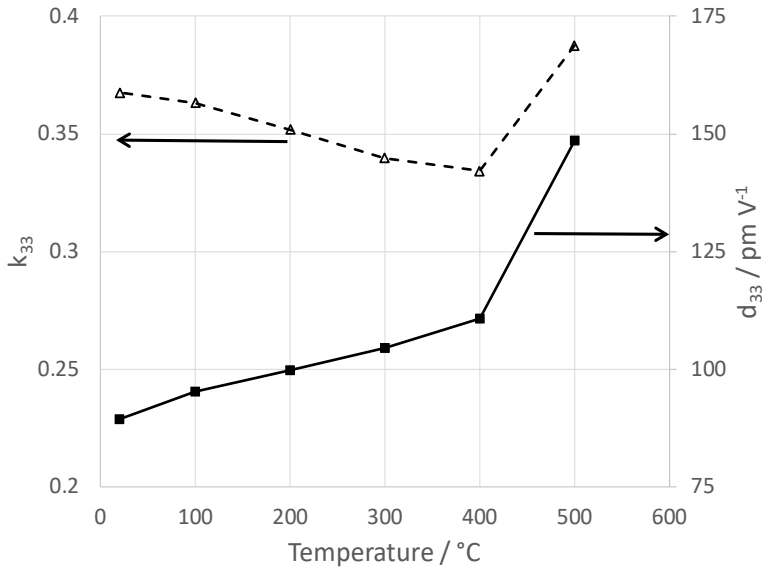

Figure 4 – Temperature dependence of the d_{33} and k_{33} between room temperature and 500 °C determined using impedance analysis

A significant increase in the k_{33} and d_{33} is observed between 400 °C and 500 °C, Figure 4. This phenomenon is also observed in PZT at high temperature, which suggests that repeated exposure to this point prior to depoling may result in a gradual reduction in the piezoelectric activity.

The stack was cycled five times between 20 °C and 500 °C, by inserting and removing the sample from the tube furnace. The heating rate was in excess of 20 Ks^{-1}. No deterioration in piezoelectric activity was observed with repeated temperature excursions, Table 1.

Table 1 – d_{33} values for the stack actuator after cycling between room temperature and 500 °C.

Cycle Number	d_{33} / pmV^{-1} @ 500 °C	d_{33} / pmV^{-1} @ 20 °C
0	-	89
1	150	92
2	146	91
3	146	90
4	146	90
5	149	89

4. Conclusions

- Reliable and repeatable operation of the stack actuator between room temperature and 400 °C was demonstrated
- A highly linear response was observed in this temperature range, which may be of significant interest for high temperature micro-positioning actuator applications.
- The linearity of the piezoelectric response with temperature was shown to be comparable, if not a slight improvement, on that observed for PZT
- Cycling between room temperature and 500 °C demonstrated no degradation of the piezoelectric activity, allowing for exposure to temperatures above the designated operating temperature

Materials Application Note	
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