Lead-Free Piezoelectric Sensors for Cryogenic Applications

Lead-free materials and sensors with low temperature capability for extreme environments

Key Deliverables

- **Addressing challenges of lead-free ceramics**
  - Overcoming low sensitivity
  - Limited to near ambient temperature operating condition
- **Sensor and package resilience**
  - High and low temperature capability, in the same sensor format
  - Extreme thermal shock resistance
- **Testing and validation**
  - Stability of performance over a wide temperature range, both for the piezoelectric element, and the transducer
  - Plug-and-play capability with existing electronic systems

Overview

Ionix have received heightened interest for low-temperature capability materials and sensors, aligned to a range of sectors including semiconductor manufacturing and liquified gas delivery, including the emerging hydrogen economy. In line with Ionix's reputation for extreme environment piezoelectric technology, materials were developed to operate in extremes of temperature. Ionix have recently completed the development of new lead-free materials and transducers, which are ideally suited for cryogenic temperatures.

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The Challenge

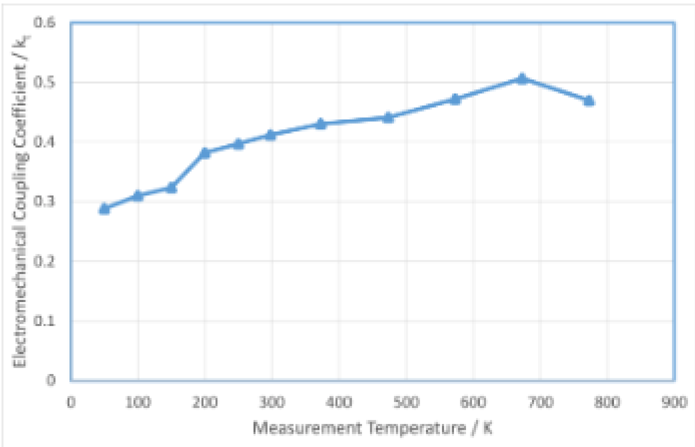
Piezoelectric materials, such as PZT, are tailored for use around ambient temperature conditions and are suited for the majority of applications, including sonar, domestic, and electronics. Many industrial and transportation markets require much lower temperatures. PZT is notorious for losing most of its sensitivity at low temperatures, reducing to between 5% and 10% of activity below 50K. This makes sensing and actuation at cryogenic temperatures extremely difficult, requiring alternative architectures or boosting the electronics. Sensor and actuator packages for low-temperature use must employ alternative materials – many polymers will not survive cryogenic temperatures.

The Solution

Ionix XLF580 is a lead-free piezoelectric material developed by Ionix. The change in performance with temperature is much less pronounced that in PZT, making it suitable for use at low temperatures. The development of new lead-free materials, capable of working over an extremely wide temperature range, without a loss of sensitivity, has been a goal of Ionix's recent lead-free development programme. Materials have been developed that operate over an extremely wide temperature range.

Execution

Characterisation of piezoelectric materials - 5 MHz disks of XLF580 were characterised using conventional piezoelectric analysis using an impedance analyser. These parts were 10 mm in diameter and approximately 0.3 mm thick. A part was mounted into a cryostat (shown right), allowing measurements at 50 K, at the University of Leeds. The figure below shows the electromechanical coupling coefficient, k_t, a parameter that describes the efficiency of the piezo and defines the performance in an ultrasonic transducer. It can be seen that k_t varies from 0.28 to 0.50 over the temperature range 50 – 775K. This provides compatibility with existing systems and electronics and plug-and-play compatibility.



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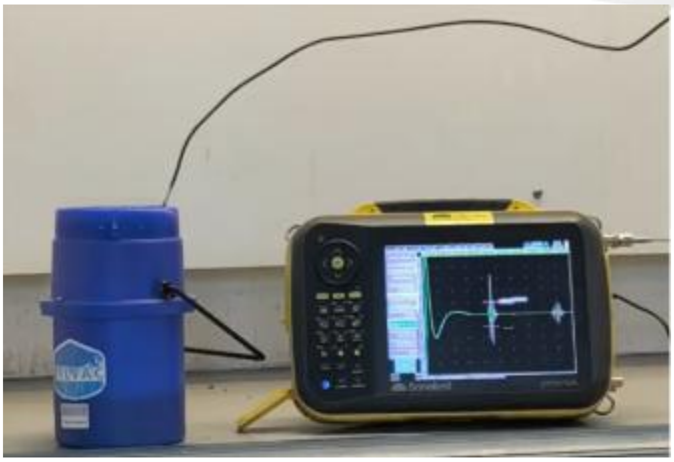
Transducer Characterisation - HotSense™ transducers were manufactured using XLF580. HotSense™ was designed for use at extremely high temperatures. As such, it avoids the use of temperature-sensitive materials such as polymers and adhesives, which can be problematic at low temperatures. Furthermore, HotSense™ has been designed with materials that share compatible thermal expansion coefficients, a critical consideration for high, and in this case, low, temperature operation, and high thermal shock.

HotSense™ was tested by using a Sonatest Prisma flaw detector. The integrated delay line within HotSense™ was used to provide a reflection for a pulse echo measurement. HotSense™ was submerged in liquid nitrogen. Cooling takes about 2 minutes, at which point the liquid nitrogen stops bubbling.



The figure below shows pulse-echo data at room temperature (green trace) and -196°C (grey trace). There is a shift in the time of flight as a result of the change in the speed of sound of the delay line. Also, additional gain is required at low temperatures, which has been adjusted on the pulser-receiver. What is clearly apparent is that the signal-to-noise ratio remains essentially unchanged over the temperature range. When the transducer is heated back to room temperature, the signal returns to the same gain level.