

Piezoelectric Single Crystals for Ultrasound Transducers

Components made by piezoelectric single crystals provide superior performance for health care applications compared to traditional piezoelectric bulk components. One example of a health care application benefitting from single crystal components is intravascular ultrasound (IVUS). CTS Corporation/US is the largest, fully integrated developer and manufacturer of piezoelectric single crystals.

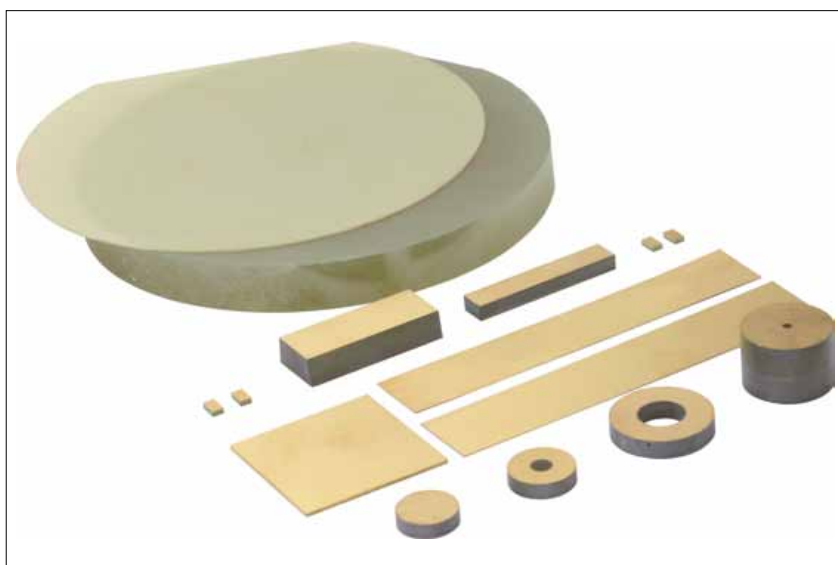


Fig. 1
Piezoelectric single crystal components

Single crystal vs. polycrystalline piezoelectric ceramics

As the name implies, piezoelectric single crystals have a different structure than polycrystalline piezoelectric ceramics. The latter consists of a number of small grains (crystallites) each containing domains in which the polar direction of the unit cells is aligned. The grains and domains are

randomly oriented. The application of a sufficiently high DC electric field (called the poling process) will orient the domains in the direction of the field and lead to a remnant polarization of the material. So even though piezoelectric ceramics seem homogeneous from a macroscopic point of view, their properties are the sum of a multitude of microscopic contributions from grains and domains, which are not all ideally oriented or poled. On the contrary, a single crystal offers a more homogeneous structure with a better controlled crystallographic orientation. As a result, with the right

orientation and poling the piezoelectric coupling factor can be optimised, in other words the electrical-to-mechanical energy conversion is significantly superior compared to polycrystalline materials. Thus, using piezoelectric single crystal components enables a much wider bandwidth than with the use of piezoelectric bulk components.

Phase transition temperature

At a certain temperature T_R/T , the crystal will transition between rhombohedral and tetragonal structure, leading to a loss of poling. Therefore for single crystals, T_R/T represents a functional temperature limit rather than the Curie temperature T_c , which is higher. Lead indium niobate-lead magnesium niobate-lead titanate (PIN-PMN-PT) ternary crystals were developed to obtain improved thermal and electrical properties while maintaining excellent dielectric and piezoelectric properties. The addition of PIN increases T_R/T (Fig. 2), enhancing the transducer reliability by improving resistance to thermal de-poling, as well as allowing crystal application at higher temperatures. In addition, temperature-dependent

Keywords

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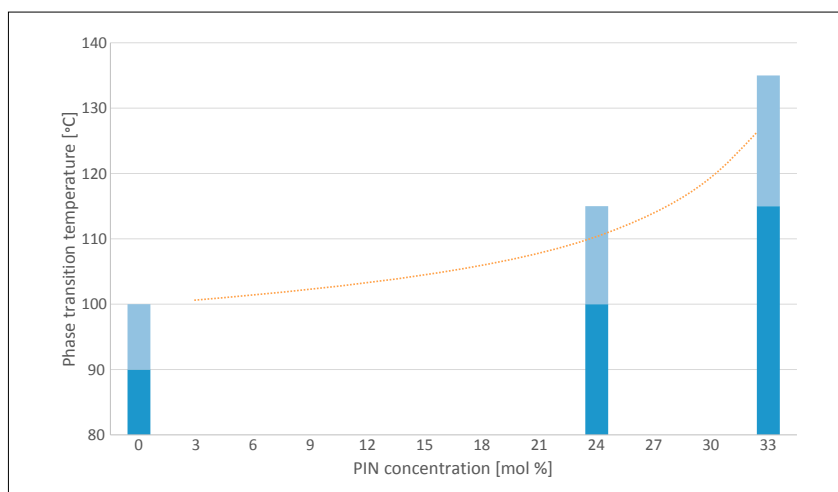


Fig. 2
Effect of PIN addition on the phase transition temperature TR/T

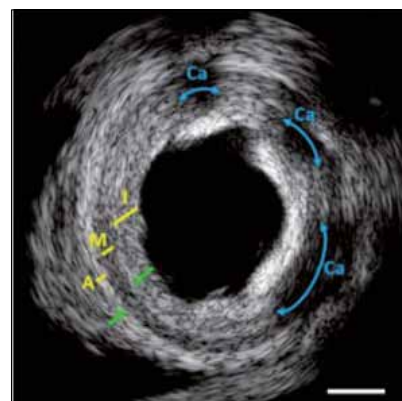


Fig. 3
IVUS images of human coronary artery at 40 MHz from PMN-PT single-crystal transducer: I = intima; M = media; A = adventitia; Ca = calcified plaque; green arrows denote the boundaries of IM and MA (scale bar is 1 mm)

property variation can be noticeably reduced with increased TR/T. As a standard, CTS offers compositions including 24 and 33 % PIN, providing TR/T as high as 135 °C which is a significant improvement compared to 90 °C for PMN-PT.

Example of an ultrasound transducer for health care: IVUS

Intravascular Ultrasound (IVUS) is a medical imaging application widely used for diagnosing coronary artery diseases. The IVUS features a specially designed catheter fitted with a miniaturized ultrasound probe. Using ultrasound imaging technology, it is possible to visualize the inner wall of blood vessels to detect lesions and plaque, as well as monitor treatments such as angioplasty and the application of stents (Fig. 3).

Imaging resolution is inversely proportional to the frequency bandwidth of the transducers. Transducers with higher center frequency and broader bandwidth can provide better image resolution. Polycrystalline piezoelectric ceramics have been widely used for ultrasound transducers in IVUS systems. With the introduction of single crystals, it is now possible to design small aperture ultrasound transducer in IVUS with improved sensitivity. The components made from piezoelectric single crystals provide much higher electromechanical coupling coefficient, resulting in broader bandwidth and higher sensitivity. As a result, the signal to noise ratio can be improved and, com-

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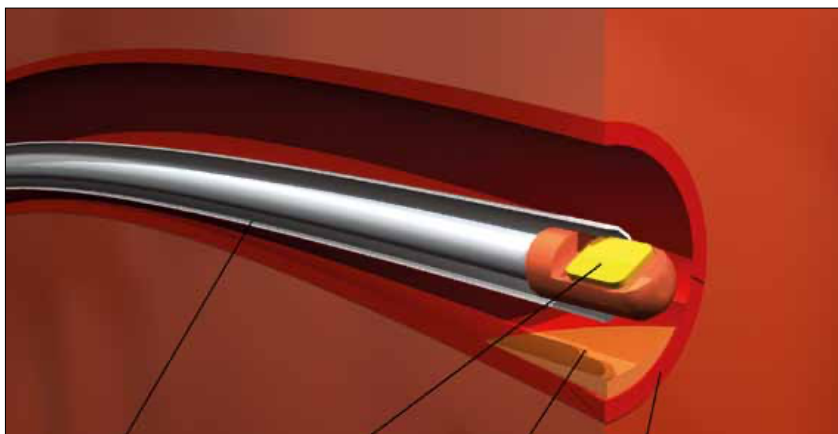


Fig. 4
Drawing of the basic working principle of an IVUS



Fig. 5
CTS single crystal manufacturing

bined with the higher frequency capability, a better resolution of the 3D imaging can be achieved.

An IVUS probe typically uses a single element of crystal composite, with a cross-section of typically $0,5 \text{ mm} \times 0,5 \text{ mm}$. The transducer is rotated continuously to provide 360° imaging using high frequency ultrasound (Fig. 4). CTS supplies crystal composite with matching and backing layers to customers for an easy integration into IVUS probes.

Manufacturing of single crystals

Processing and sintering of polycrystalline piezoelectric ceramics (e.g. PZT) is well established and polycrystalline products have been used in applications for approximately 80 years. In comparison, the single crystal growth process is a relatively new technology that was developed about 20 years ago and has only been used in commercial applications for less than 15 years.

The manufacturing process of polycrystalline piezoelectric ceramics starts with mixing different oxides and additives (dopants), calcining raw material mix, ball-milling and shaping the powder. Shaped pieces then get sintered at high temperature, to form dense ceramic material. The manufacturing process of piezoelectric single crystal, on the other hand, involves melting of the raw material at a much higher temperature than sintering. Melt is cooled at a controlled rate and single crystal piezoelectric material is grown on a seed in a controlled manner. Only high purity chemicals are used with no addition of other component like growth flux. Depending on the type of application where the finished single crystal component is to be used, the crystal is cut in a specific orientation, fitted with electrodes and poled.