PureWave Crystal Technology  White Paper

Realizing dramatic improvements in the efficiency, sensitivity and bandwidth of ultrasound transducers

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Background

The piezoelectric material in an ultrasound transducer is a fundamental determinant of system image quality. Piezoelectric transducer elements are responsible for delivery of ultrasound energy into the scanned tissue and for converting returning ultrasound echo into electric signals. Their coupling efficiency in converting electrical energy to mechanical energy or vice versa is a key determinant of image quality and penetration.

Despite many innovations over recent decades in signal processing and beamformer architecture, the same piezoelectric material, PZT (lead-zirconate-titanate) or PZT composites, has been the best-in-class material used for medical imaging for almost 40 years. This is a polycrystalline compound (ceramic) that, due to imperfect alignment of the individual dipoles, achieves at best only 70% polarization with corresponding constraints in the electromechanical coupling efficiency of the material.

A new type of piezocrystal was discovered by Japanese and Russian scientists in the 1970s which showed improved electromechanical properties compared to PZT-type ceramics\(^1\). However, research on this type of piezocrystal was limited for many years due to the difficulty in growing the crystals (which were consequently limited in size to a few millimeters). Researchers, including Philips engineers, made fundamental technology breakthroughs in the 1990s in both crystal growth and crystal properties. Piezocrystals exhibit a quantum improvement in electromechanical coupling compared to the traditional PZT-type ceramics\(^2-4\).

An extensive Philips research program initiated in 1997 and partially funded by the United States Office of Naval Research (ONR) and the Defense Advanced Research Projects Agency (DARPA) explored possible medical applications of piezocrystals. This led to the development of PureWave crystal technology – an entirely new transducer technology designed with unique piezocrystals that offer significantly improved efficiency and bandwidth compared with conventional PZT ceramics\(^4-5\). PureWave crystal technology coupled with advanced transducer technology (uniquely designed matching layers and backing material) heralds a new generation in 2D and 3D image quality, color and CW/PW Doppler sensitivity.
Technology

PureWave Crystals vs. PZT Ceramics

To create an overall piezoelectric effect, materials such as PZT ceramics must be subjected to a poling process (application of an external electric field) to align dipoles within polycrystalline materials. In conventional PZT ceramics, due to the constraint of the grain boundaries, only a fraction of dipoles can be aligned by an electric field and not all dipoles contribute to the acoustic response of the material.

PureWave crystal material, however, is more uniform and exhibits fewer defects, lower losses and no grain boundaries. When these crystals are poled at the preferred orientation(s), near perfect alignment of dipoles (~100%) can be achieved (see Figure 1) resulting in dramatically enhanced electromechanical properties.

Crystal Growth Comparison

To prepare conventional PZT ceramics, fine powders of the component metal oxides are mixed and then heated to form a uniform powder. The powder is mixed with an organic binder and baked into a dense polycrystalline structure.

To produce PureWave crystals, the fine ceramic powder is formed using a process similar to PZT powders, however the rest of the process is unique. The powder is then melted into liquid in a platinum crucible at 1400˚ C using a specially designed high temperature furnace with a precisely controlled temperature profile. To nucleate the crystal from the melt at the desired orientation, a seed crystal is pulled (or drawn) away from the melting zone slowly (less than 1 mm/hour) and the crystal is grown layer by layer atomically to form a homogeneous crystal “boule” or cylinder. Boules are orientated along the desired crystallographic orientation(s) to
maximize the crystal properties and then sliced into multiple wafers. Philips has been at the forefront in innovating piezocrystal technologies by developing crystal growth and post processing techniques for fabricating large homogeneous crystals for medical imaging applications (see Figure 2). This breakthrough approach from crystal growth to transducer design is unique to Philips.

The PureWave crystals are purer, more uniform, have lower losses and are able to transfer energy with greater precision and efficiency. PureWave crystals exhibit very high electromechanical coupling factors as demonstrated by the following statistics:

- The efficiency of converting electric-to-mechanical energy improves by as much as 68–85% (as shown in Figure 3) compared to PZT ceramics currently used in ultrasound transducers.
- PureWave crystals exhibit ten times the strain (or ability to change thickness under an electrical field, as shown in Figure 4) compared to traditional polycrystalline PZT-type ceramics. They are therefore ideal for use in ultrasonic imaging applications.
Transducer Design Implications

The current family of Philips transducers already exhibits impressive bandwidth and sensitivity as compared to the rest of the ultrasound industry. Replacing the presently used PZT materials with the new PureWave crystals achieves significant additional gains in bandwidth and sensitivity. Using PureWave crystal technology in conjunction with precisely engineered multiple matching layers and backing material, it is now possible to cover frequency range of current two best-in-class broadband transducers with a single probe.

Application Advantages

PureWave crystal technology with extended transducer bandwidth and sensitivity offers significant performance advantages, particularly in penetration and imaging resolution. The ability to gather, process and display more diagnostic information results in images of remarkable clarity and fine detail with greater uniformity throughout the entire image field.

Particular benefits are noted in technically difficult studies, allowing successful delineation of the entire endocardial border in a higher percentage of patients. It also provides benefits in cost efficiency as well as workflow by reducing the need to change transducers during examinations.
PureWave crystal technology allows better use of harmonics, presenting additional options for signal processing. The greater sensitivity afforded by PureWave crystal technology provides the flexibility to transmit and receive harmonic frequencies at full sensitivity level for enhanced harmonic performance. Figure 5 shows the comparison of traditional broadband technology to the PureWave crystal technology for harmonic applications.

Furthermore, transducers with PureWave crystal technology can be operated at full sensitivity for multiple pairs of transmit/receive harmonic frequencies (see Figure 6). Superior sensitivity at multiple second harmonic frequencies means that clinicians can select from a wide harmonic frequency range to address different imaging needs.

PureWave crystal technology provides significant benefits in both tissue and contrast harmonic applications. In tissue harmonics, the increased sensitivity provides improved penetration and border delineation, achieving results in difficult patients that could only otherwise be attained with LVO contrast. The resulting harmonic images have significantly reduced clutter with greatly enhanced structural detail as seen in the resolution of the endocardium and fine structures such as valves and chordae tendinae. The wider bandwidth and superb coverage of lower frequencies from the PureWave crystals provide the main benefit for contrast harmonics. The higher sensitivity allows clinicians to detect bubbles more easily.

The new S5-1 transducer with PureWave crystal technology perfectly demonstrates the concept of a “one-probe” solution, spanning the frequency ranges of two state-of-the-art broadband probes (see Figure 7). This means that one transducer can be used for a greater range of patient types, thereby offering significant workflow advantages along with the performance and image quality enhancements already discussed. Additionally, it opens the door for advanced applications currently not available using conventional broadband transducers.

In addition to covering a wider range of frequencies than current transducers, the S5-1 also provides significantly better sensitivity at the color flow and spectral Doppler frequencies.
PureWave Crystal Technology for all Ultrasound Applications

The performance advantages of PureWave crystal technology are not just confined to low frequency cardiac applications. Sensitivity and efficiency gains are evident in the design of other transducers such as linear and curved linear transducers, realizing electromechanical coupling efficiency improvements of 68-85% respectively. PureWave crystal technology has brought transducer design technology to a new level.

Conclusion

PureWave crystal technology provides dramatic improvements in the efficiency, sensitivity and bandwidth of ultrasound transducers. This breakthrough has allowed the development of next generation transducers such as the S5-1 which offers superb 2D imaging resolution, more sensitive contrast harmonics, improved color flow sensitivity, enhanced endocardial border delineation, and superb low frequency tissue harmonics.

Color flow and apical 4-chamber view cardiac images acquired with S5-1 transducer with PureWave crystal technology.
References