CRYSTAL CLEAR SUCCESS

Innovations in crystal manufacturing benefit medical ultrasounds and other technologies

Ultrasound, or sound waves with frequencies above the limits of human hearing, has been used by bats for millions of years to navigate and find prey in the dark. While echolocation comes naturally to these creatures, humans only discovered the existence of non-audible sound in the late 1700s. Since then, rapid advances in our understanding of ultrasound have led to key developments in medical imaging and sonar systems.

Modern ultrasound technology relies on transducers to create ultrasonic waves. Commonly made from what are called piezoelectric materials, these transducers convert electrical energy into sound by stretching and compressing. When an alternating current is applied, they vibrate at high frequencies.

Traditionally, lead zirconate titanate (PZT) ceramics, given their affordability and ease of manufacture, have been used to produce ultrasounds. In 1997, however, researchers reported the discovery of a far superior piezoelectric crystal called lead magnesium niobate/lead titanate (PMN-PT). This new material allowed for more efficient energy conversion and higher signal-to-noise ratios. The manufacturing process for PMN-PT, however, proved to be challenging and expensive.

But then crystal-growth specialist H.C. Materials Corporation found a solution.

The Bolingbrook, Illinois-based company developed a cost-effective method of growing PMN-PT crystals, and went on to create the largest PMN-PT crystal fabrication line in the world. The improved manufacturing process enabled a new generation of ultrasound-based medical imaging devices with higher bandwidth, leading to better image resolution. It wasn't long before medical technology giants Siemens, GE, and Philips were all using H.C. Materials' piezoelectric crystals in their high-end imaging products.

"We developed this technique for crystal growth that ended up being a practical and commercial success," said Pengdi Han, former CEO of H.C. Materials. "Today, we support a worldwide revenue market for high-end and high-quality ultrasound imaging for medicine. Our success is a story that was very unique."

Han developed the novel crystal growth process — which took almost a decade to perfect — under multiple Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) contracts from the Navy. The SBIR/STTR funding aimed to upgrade the quality of piezoelectric crystals for use in sonar, hydrophones, adaptive optics, and acoustic guidance and countermeasure systems. In 2016, CTS Corporation, a leading designer and manufacturer of sensors, actuators, and electronic components, acquired H.C. Materials.

"H.C. Materials eventually merged into CTS Corporation, which is the number one manufacturer of PZT ceramics, and I think it is a good home for my company. The Navy was also happy to have this deal," Han said. "Last year we sold $80 million worth of crystal elements — half for the medical market and half for Navy-related projects — so the deal has overall been very successful."

H.C. Materials has provided high-energy density acoustic transducers for Navy sonar systems, such as super high-sensibility acoustic sensors

Back in his home country of China, Han began his career with university degrees in electrical engineering and crystal chemistry. He spent several years working as an academic researcher with a focus on crystal growth techniques before shifting to the field of superconductivity. But after immigrating to the U.S. in 1988, Han found himself being drawn back to the world of crystals.

In 1997, researchers at Pennsylvania State University reported on the PMN-PT crystal, which exhibited a piezoelectric response five to ten times higher than other materials of its kind. The results stunned the field, but manufacturing challenges prevented these crystals from being grown in large sizes suitable for practical applications.

"This crystal contains lead oxide, about 70 percent by weight. At the high temperatures needed for crystal growth — up to 1,400 degrees Celsius — the only available material to use as a container is platinum," he said. "But the platinum is attacked by melting lead, so the container always leaks. Also, the evaporation of lead oxide is very toxic and dangerous."

The harmful conditions to workers and the environ-

U.S. Air Force photo/Airman 1st Class Ryan Conroy

The SBIR-supported innovations by H.C. Materials have benefited both the military and commercial sectors.

ment, as well as the costs of losing material through leakage, led many researchers to simply give up on growing PMN-PT crystals despite their attractive properties. But given his extensive background in crystal-growth techniques, Han believed he had the knowledge to overcome these issues. He founded H.C. Materials in 1998 with a focus on crystal growth and fabrication.

Supported by the Office of Naval Research, who had interest in creating a better sonar transducer with PMN-PT, Han began work on the leaky-container problem. He first thought impurities in the platinum might be causing the lead oxide to attack the crucible, but later found out that tiny microbubbles were to blame. Once he was able to fabricate an interstitial-free platinum crucible without microbubbles, the leakage stopped.

Another challenge came from growing the crystal in larger sizes even while maintaining compositional homogeneity. PMN-PT consists of two separate compounds: lead magnesium niobate and lead titanate. If one compound grows faster than the other, the ratio of the two compounds will change, along with the crystal's physical properties. By modifying the crystal growth direction, however, Han realized the overall composition would stay the same. This method, called the modified Bridgman growth system, allowed the company to grow spheres and cylinders 3 to 4 inches in diameter.

Although the research and development process took several years, Han's hard work eventually paid off. H.C. Materials has provided high-energy density acoustic transducers for Navy sonar systems, such as super high-sensitivity acoustic sensors for accelerometers and deformable mirror control for missile guiding. In the medical field, the company sells crystals to major manufacturers of high-end ultrasound imaging devices. Overall, Han's modified Bridgman growth system and related commercial fabrication line has been critical to the achievement of a new generation of acoustic transduction devices.

H.C. Materials, Corp. (CTS Corporation)
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