Impact of ferroelectricity

By Susan Trolier-McKinstry

Since the discovery of ferroelectricity 100 years ago, ferroelectric materials are everywhere in our electronics-based society. Learn how they drive a $7 billion industry.

Ferroelectric materials are ubiquitous in electrical and electromechanical components and systems. Ferroelectricity is associated with large dielectric and piezoelectric coefficients, particularly when the composition is adjusted to position the solid near a phase boundary. This characteristic allows high volumetric efficiency dielectric charge storage, as well as high displacement actuators at modest voltages. The ability to reorient the spontaneous polarization between crystallographically-defined states is essential in allowing poling of ceramic materials to obtain net piezoelectric or pyroelectric responses.

Capacitors

The largest industrial use of ferroelectric materials is in multilayer ceramic capacitors. The poor availability of mica-based crystals during World War II spurred development of air- and moisture-stable, high volumetric efficiency dielectrics. The subsequent dawn of the electronics age led to production of several trillion $BaTiO_3$-based capacitors around the world on an annual basis, with hundreds to thousands used in each current generation smart phone or computer. The size of this market is approximately $6 billion. Among the major capacitor suppliers around the world are Murata, Taiyo Yuden, Samsung Electromechanics, Kyocera (AVX), TDK, Yageo, and Kemet.

Medical ultrasound is the second most widely adopted imaging modality in medicine. It works thanks to ferroelectric materials.

The relatively closely-spaced ferroelectric phase transitions in $BaTiO_3$ enable a high relative permittivity over a broad temperature range. Equally important is the processing science that fostered progressive miniaturization of the dielectric layers thickness over the last several decades—the so-called Moore's law of capacitors—which has helped enable miniaturization of many electronic devices, including cellular phones.

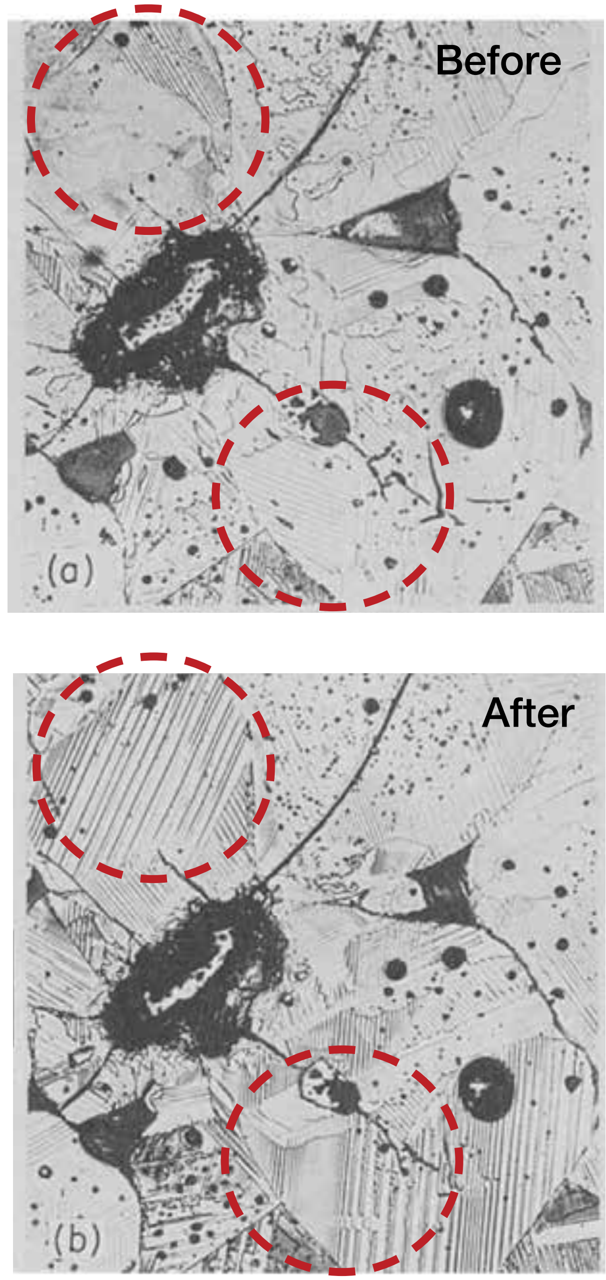
Industrial production is dominated by tape casting, electroding, and lamination to produce multilayer components at progressively decreasing case sizes. At present, commercial parts with layer thicknesses less than one micron with thin, highly-conductive nickel metal layers are readily available, with projected future miniaturization down to dielectric thicknesses of about 0.3 micron. The rich defect chemistry of these systems allows production of high reliability parts, even in the case where low oxygen partial pressure firing induces a high concentration of oxygen vacancies.

Piezoelectric applications

A second major use of ferroelectric materials is in piezoelectric ceramics, single crystals, and composites for actuators, sensors, and transducers. In the future, it is possible that ferroelectric piezoelectrics will also be widely adopted for kinetic energy harvesting systems for distributed low-power systems, including emplaced sensors for the Internet of Things. The world-wide piezoelectric ceramics market is approximately $1B annually. This market is dominated by lead zirconate titanate-based (PZT) materials; numerous formulations are utilized to tailor the piezoelectric responses, the coupling coefficients, and the field-induced hysteresis.

Among the main uses of these piezoelectrics are precise positioners, sonar systems, fish finders, medical ultrasound transducers, fluid flow meters, ultrasound systems for nondestructive testing, high precision accelerometers, transformers, and many other applications. Of these, medical ultrasound is the second most widely adopted imaging modality in medicine and offers tremendous capability in high resolution imaging of subsurface features without necessitating ionizing radiation (see image of infant). At this point, an enormous number of lives have been saved through the use of medical ultrasound employing ferroelectric–polymer composite transducers. Notably, the diversity of form factors and compositions needed for this range of applications of piezoelectric materials means that production for any given component in the piezoelectrics markets tend to be smaller. There are numerous suppliers of piezoelectric ceramics, including Channel Technologies, Murata, American Piezoceramics, Piezo Kinetics, Meggitt (Ferroperm), Morgan Electroceramics, TDK, PI Ceramics, Sinocera, and many others. In other cases, ferroelectric single crystals are used for domain engineered high strain piezoelectrics, or for surface acoustic wave devices.

While capacitors and piezoelectrics comprise two of the largest uses of ferroelectric materials, many other electrooptic components are also of commercial importance, e.g., $LiNbO_3$ for frequency doublers, optical modulators, and more; positive temperature coefficient of resistance thermistors for self-limiting heaters; pyroelectric based room occupancy sensors and fire detectors; and computing memory elements (including PZT and $SrBi_2Ta_2O_9$).



Credit: DeVRIES, R.C. and BURKE, J.E. (1957), Microstructure of barium titanate ceramics. *Journal of the American Ceramic Society*, 40: 200-206. doi:10.1111/j.1151-2916.1957.tb12603.x

Microstructure of barium titanate (a) before and (b) after application of an electric field. The ferroelectric response of barium titanate causes reorientation of its domain structure, most easily seen in the circled areas.

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