FERROELECTRIC CERAMICS IN ELECTRONICS

R.S. Chimni

Ferroelectric ceramics are of considerable importance in the fields of electronics and allied branches of engineering. They are used in innumerable devices, mainly because they can be converted into rugged piezoelectric materials which can be produced in convenient shapes and sizes.

The desired electrical and mechanical properties can be obtained, within limits, by selecting a suitable mix of ingredients which go into the manufacture of a particular ceramic. They thus score over single crystal piezoelectrics. Certain applications also make use of the fact that the dielectric constant of the ceramics is dependent upon the applied electric field strength.

Their use in ceramic pick-up cartridges and piezoelectric gas lighters is well known. What is less known is the fact that they are used in such diverse fields as memory devices, milk emulsifiers and microphones. We find them in detonation fuses for missiles, delay lines for colour TV and radar, dispersers of pigment and in many other devices.

In order to understand these materials we may briefly touch upon the piezoelectric effect and shortcomings of piezoelectric elements made out of natural or artificial piezoelectric single crystals.

Piezoelectric effect

Piezoelectric effect was discovered by two brothers, Pierre Curie and Jacques Curie, in 1880 at Sorbonne. Piezoelectric effect is the appearance of equal and opposite charges on the surfaces of certain materials when mechanical force is applied on them in a particular direction. The quantity of charge that appears is proportional to the force applied. If the direction of the force is reversed, the sign of charges is also reversed. This is called direct piezoelectric effect.

The piezoelectrics display inverse effect also, i.e., they get deformed by the application of an electric field. The direction of deformation is also reversed if the direction of the applied field is reversed. The piezoelectrics therefore provide a convenient device for changing electric energy into mechanical energy and mechanical energy into electrical energy. (A device which converts one form of energy into another form is called a transducer.)

Piezoelectric properties of any matter are evaluated by piezoelectric constants. These are ratios of charge and mechanical force along an axis. The constant for quartz along piezoelectric axis is 2.2 pico Coulombs per Newton For rochelle salt it is about 1000 times larger.

Piezoelectric crystals

The Curie brothers discovered piezoelectric effect in certain crystals like quartz, tourmaline and rochelle salt Many more crystals, including crystals of sugar, were found to have piezoelectric properties in subsequent years. For the next 65 years, i.e., up to about 1945 all the piezoelectric devices were based on plates, rods, rings etc cut out of crystals such as rochelle salt, ADP (ammonium dihydrogen phosphate), quartz etc.

Piezoelectric and physical properties of elements cut out of crystals are determined by the properties of the crystals This imposes restrictions on the shape and size of the piezoelectric elements (plates, rods etc) which have to be cut in a particular manner due to the fact that the direction of various axes cannot be altered in a crystal generally.

The range of temperature and humidity within which some of the crystal materials can be used is very limited For example, rochelle salt cannot be used above 45°C and relative humidity has to be within 40 per cent and 70 per cent if the crystal plate is unprotected. ADP can be used up to 125°C and lithium sulphate up to 75°C.

Some of the problems and limitations of single crystal material have been overcome with the developmnt of ferroelectric ceramics. (Ceramic is generally defined as a product obtained through the action of fire upon an earthy material. The word 'ceramic' is from the Greek word 'keramos' meaning 'pottery' and is probably related to the older Sanskrit root meaning 'to burn')

It may be pointed out here that single crystal quartz is still the best material for purposes of frequency control and precision accelerometers.

Ferroelectrics

Ferroelectrics are dielectric analogues of ferromagnetics (iron, steel etc). They have spontaneously polarised domains (microscopic regions) and show hysteresis when a varying electric field is applied (like B-H curve of ferromagnetics). The polarised domains can be aligned by an external electric field.

Like ferromagnetic materials, they have an upper temperature, known as ferroelectric Curie temperature beyond which they cease to be ferroelectric. (Rochelle salt has an upper, + 24°C, and a lower, -18°C, Curie temperature) Their dielectric constant depends upon the applied electric field if saturation does not take place.

Ferroelectric properties were noticed in 1921 for the firs

Mr Chimni, 51, is working at Controllerate of Inspection (Systems), Secunderabad as principal scientific officer since 1973. In all, he has spent nearly 30 years in the electronics field under the Ministry of Defence, mostly at CIL, Bangalore.

time, and up to the middle of forties all ferroelectrics known were single crystals such as rochelle salt, barium titanate and potassium dihydrogen phosphate.

Barium titanate ferroelectric ceramics

In 1942 barium titanate was found to have certain special properties as a dielectric. These were investigated and it was found to be ferroelectric. This in itself was not of much engineering importance. It was found later that barium titanate displays ferroelectric properties in multicrystalline form, i.e. it is ferroelectric in ceramic form with Curie temperature of 120°C.

The ceramic form of barium titanate, it was found, can be converted into piezoelectric material by heating it beyond 120°C and allowing it to cool in the presence of a constant electric field. On cooling, the material is converted into piezoelectric material with polarisation in the direction of the applied field. After removal of the field the material retains about 80per cent of its initial piezoelectric response

Barium titanate ceramics are resistant to heat and humidity and have high mechanical strength and are therefore more useful in certain applications than some of the single crystals.

Improvements in ceramic ferroelectrics

Subsequent to the discovery of the useful properties of barium titanate ceramics, a number of substances with related crystal structure were found to have similar properties. Some of them are zinc, strontium and cadmium titanates, lead zirconate, several niobates, tantalates etc.

Ferroelectric ceramics have been made based on the above-mentioned and other similar materials. By having a suitable mix of some of the above-mentioned and other similar materials and additives, ferroelectric ceramics having properties required for various applications can be obtained. For example, Curie temperature can be raised by addition of lead titanate and it can be lowered by addition of strontium compounds.

Due to forces acting between crystals the electrical polarisation of the ceramics is more stable than that of a single crystal. In this way it has been possible to produce ceramics comparable with rochelle salt in sensitivity and with quartz in chemical stability.

The table below gives dielectric constants and Curie temperature of a few ferroelectric ceramics.

Material	*Dielectric constant*	*Curie temperature*
1. $BaTiO_3$ (Barium Titanate)	1500	120°C
2. $BaTiO_3$—80% + $PbTiO_3$—20% (Barium Titanate + Lead Titanate)	1500	350°C
3. $PbNbO_3$ - 80% + $BaNbO_3$ — 20% (Lead niobate + Barium niobate)	400	425°C
4. $PbNbO_3$ — 60% + $SrNbO_3$ — 40% (Lead niobate + Strontium niobate)	755	310°C

It will be seen from the table that a wide range of Curie temperatures and dielectric constants can be obtained. In the same way, desired physical and mechanical properties can be obtained for low stress and high stress applications. Elements can be made in the form of bows, tubes, plates, disks, or a multitude of elements can be set in any suitable arrangement. By suitably shaping the ceramics it is possible to concentrate and focus energy generated in the work area.

The most widely used ferroelectric ceramics are solid solutions of lead zirconate and lead titanate with various additives and varying proportions of the two main ingredients. These materials have a piezoelectric coefficient around 10^{-10} Coulomb per Newton. They are commonly known as lead zirconate titanate and marketed as PZT with distinguishing digits by Clevite Corporation of USA and as PXE by Mullard in UK.

Methods of manufacture

As stated above, the properties of the ceramics depend upon the ingredients which go into their manufacture. Depending upon the properties desired, the ingredients are selected, carefully weighed and mixed in the required proportions. The powders are thoroughly mixed and heated for a long time. The matter so obtained is repowdered and a binder is added. The powder is compressed into the desired shapes and is fired in a kiln under strictly controlled conditions. The elements so obtained are cleaned and electrodes are plated on them. The final step is to impart piezoelectric properties to the elements by subjecting them to an electric field. The elements are polarised so that opposite faces have opposite charges, and a piezoelectric axis is formed between the electrodes.

Applications of ferroelectric materials

The application of ferroelectric materials can be divided into two types. One type of application makes use of piezoelectric properties while the other type makes use of the fact that ferroelectrics are non-linear dielectrics, i.e. dielectric constant varies with the applied voltage.

The applications making use of piezoelectric properties can be divided, for ease of discussion, into the following categories:

(a) Applications in audio engineering
(b) Applications under water
(c) Applications in industry
(d) Miscellaneous applications.

It should be remembered that all the above-mentioned applications are based on the fact that the piezoelectric element is capable of converting mechanical vibrations into electrical oscillations and vice versa up to frequencies in the range of several megahertz.

Applications in audio engineering

The main use of ceramics in audio engineering is in the manufacture of phonograph pick-up cartridges and ceramic microphones. In case of ceramic pick-up, the stylus usually bends the ceramic element and thus produces voltage proportional to the force applied to the element. Ceramic pick-ups are not affected by humidity and heat as is the case with pick ups using rochelle salt. The ceramic material used is usually barium titanate or lead zirconate. An output of about 500 mV can be easily obtained.

Ceramic microphones make use of lead zirconate titanate element. They are not very popular due to certain shortcomings such as a very high impedance and are not suitable for use with long cables unless a preamplifier is provided.

Underwater application

Ceramic elements are used extensively in hydrophones, sonar and underwater transponders as they are particularly suitable for producing and detecting acoustic waves in water. Piezoelectric solids are much better matched acoustically to water than to air. Barium titanate and lead zirconate titanate are often used for underwater applications.

Uses in Industry

Ferroelectric ceramic elements are used in pigment dispersers, ultrasonic cleaners, certain tools, soldering irons, flaw detectors, thickness gauges etc. In case of flaw detectors, short pulses of ultrasonic waves are applied to the material under test. The waves are reflected from flaws within the material. Flaws are detected by observing the reflected waves.

Miscellaneous applications.

There are many other applications such as filters, accelerometers and delay lines used in colour TV, in moving target indicator, artificial permanent echo generator for radar monitoring etc.

In case of delay lines, the electrical waves are converted into acoustic waves and made to travel a short distance before they are again converted into electrical waves. This is achieved by the use of ceramics. Since acoustic waves travel at much less velocity, delay in transmission is achieved.

Applications as non-linear devices

The ferroelectric ceramics find use as non-linear dielectrics. They are used in memory devices making use of the fact that by application of suitable electric field the direction of polarisation can be reversed. The ceramics can be used in dielectric amplifiers, non-linear capacitors with controllable capacitance, frequency multipliers etc.

Future

With advances in science, particularly in solidstate physics, it is expected that new ceramic materials will be made. The presently known materials will be improved and put to new uses. Ferroelectric ceramics have come a long way in only three decades. They have a vast potential yet to be tapped. □