Quartz Sources
Experience. Quality. Reliability.

# Quartz Crystal Theory

## *What is Quartz?*

The technical formula is $SiO_2$ and it is composed of two elements, silicon and oxygen.
In its amorphous form $SiO_2$ is the major constituent in many rocks and sand. The crystal-line form of $SiO_2$ or quartz is relatively abundant in nature, but in the highly pure form required for the manufacture of quartz crystal units, the supply tends to be small.
The limited supply and the high cost of natural quartz have resulted in the development of a synthetic quartz manufacturing industry. Synthetic quartz crystals are produced in vertical autoclaves. The autoclave works on the principle of hydrothermal gradients with temperatures in excess of 400 °C and pressures exceeding 1,000 atmospheres. Seed quartz crystals are placed in the upper chamber of the autoclave with natural quartz (lascas) being placed in the lower chamber. An alkaline solution is then introduced which when heated increases the pressure within the chamber. The autoclave heaters produce a lower temperature at the top chamber in comparison to the bottom. This temperature gradient produces convection of the alkaline solution which dissolves the natural quartz at the bottom of the chamber and deposits it on the seed crystals at the top. Alpha crystals produced by this method can have masses of several hundred grams and can be grown in a few weeks. If the temperature reaches 573 °C a phase transition takes place which changes the quartz from an alpha to a beta (loss of piezoelectric property.

Quartz crystals are an indispensable component of modern electronic technology. They are used to generate frequencies to control and manage virtually all communication systems. They provide the isochronous element in most clocks, watches, computers and microprocessors. The quartz crystal is the product of the phenomenon of piezo-electricity discovered by the Curie brothers in France in 1880.

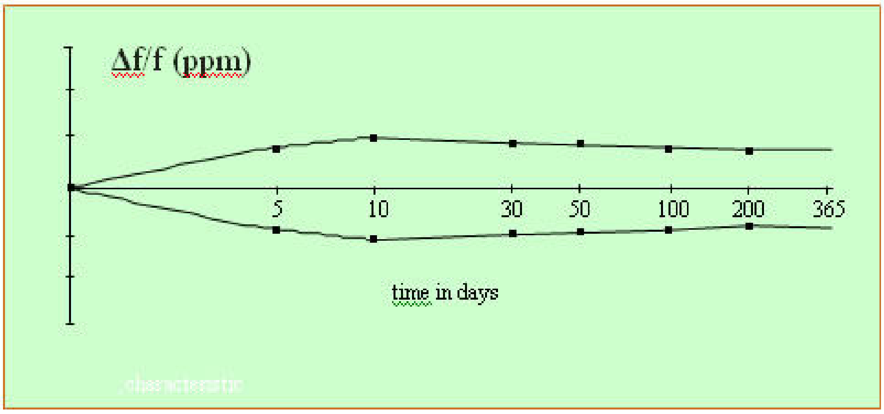
## *How it works?*

Piezoelectricity is a complex subject, involving the advanced concepts of both electricity and mechanics. The word piezo-electricity takes its name from the Greek piezein "to press", which literally means pressure electricity. Certain classes of piezo-electric materials will in general react to any mechanical stresses by producing an electrical charge. In a piezoelectric medium the strain or the displacement depends linearly on both the stress and the field. The converse effect also exists, whereby a mechanical strain is produced in the crystal by a polarizing electric field. This is the basic effect which produces the vibration of a quartz crystal.

**Quartz resonators** consist of a piece of piezoelectric material precisely dimensioned and orientated with respect to the crystallographic axes. This wafer has one or more pairs of conductive electrodes, formed by vacuum evaporation. When an electric field is applied between the electrodes the piezoelectric effect excites the wafer into mechanical vibration. Many different substances have been investigated as possible resonators, but for many years quartz has been the preferred medium for satisfying the needs for precise frequency generation. Compared to other resonators e.g. LC circuits, mechanical resonators, ceramic resonators and single crystal materials, the quartz resonator has proved to be superior by having a unique combination of properties. The material properties of quartz crystal are both extremely stable and highly repeatable. The acoustic loss or internal fraction of quartz is particularly low, which results in a quartz resonator having an extremely high Q-factor. The intrinsic Q of quartz is $10^7$ at 1 MHz.

Mounted resonators typically have Q factors ranging from tens of thousands to several hundred thousands, orders of magnitude better than the best LC circuits. The second key property is its frequency stability with respect to temperature variations.

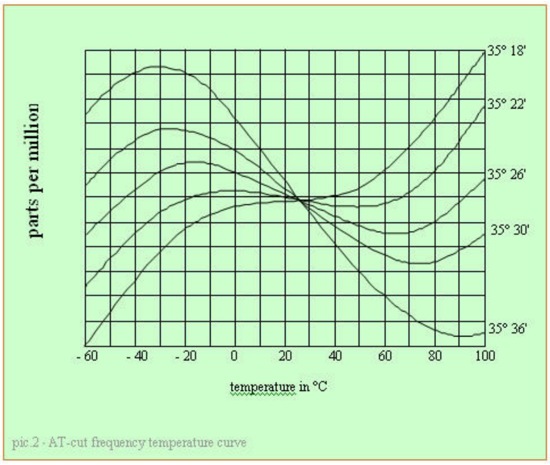
**Aging of the quartz** (pic.1) resonator is related to the stability of its mechanical components. Short and long term stability manifests in frequency drifts of only a few
parts per million per year and are readily available even from commercial units.
Precision crystal units manufactured under closely controlled conditions are only second to atomic clocks in the frequency stability and precision achieved.



characteristic

### *What makes quartz so important?*

The AT-cut characteristic (pic. 2) is the most commonly used type of resonator. It has a frequency temperature coefficient described by a cubic function of temperature, which can be precisely controlled by small variations in the angle of cut. This cubic behaviors is in contrast to most other crystal cuts which give a parabolic temperature characteristic. It makes the AT-cut well suited to applications requiring a high degree of frequency stability over wide temperature ranges. Other important characteristics are aging and quality factor Q.



pic.2 - AT-cut frequency temperature curve

## *Models of vibration, cuts and frequency ranges.*

The AT-cut resonator uses the thickness shear mode of vibration (pic.3). A standing wave is set up in the crystal blank by the reflection at both major surfaces of traverse waves traveling in the thickness direction. The major mechanical displacement is in the plane of the crystal at right angles to the direction of wave propagation. At resonance an odd number of half wave lengths are contained in the thickness plane of the crystal blank. Therefore the thickness is the primary frequency determining dimension.

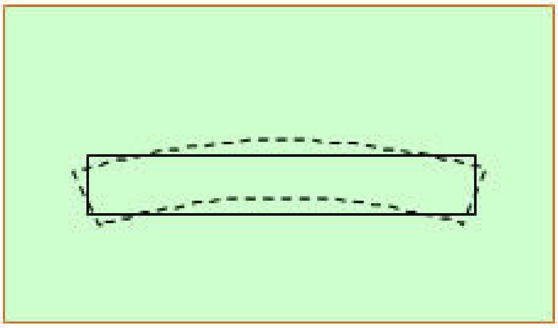
The AT-cuts (pic.5) are commonly manufactured in the frequency ranges:

| | |
|---|---|
| 1MHz ~ 32 MHz | as fundamental |
| 30MHz ~ 250 MHz | as overtone (3rd; 5th; 7th; 9th) |

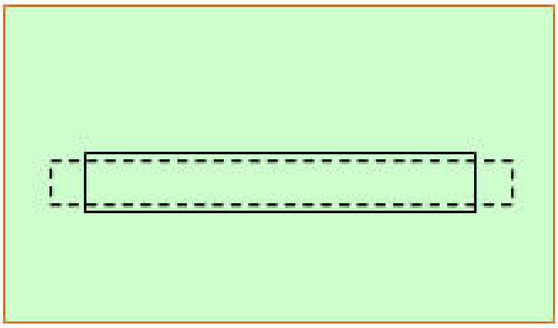
Below about 1 MHz the thickness shear mode resonators become too cumbersome and unwieldy for general use and other modes of vibrations are used:

a) below about 100 kHz flexural, length extensional mode
b) 100 kHz face shear, CT; DT; SL cuts (pic.6)

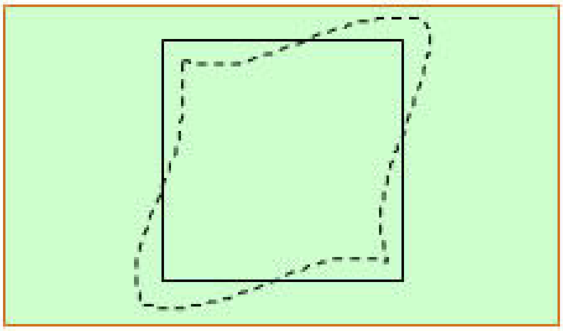
For each mode of vibration there is an optimal angle of cut which controls the frequency deviation of the quartz crystal over the temperature range.



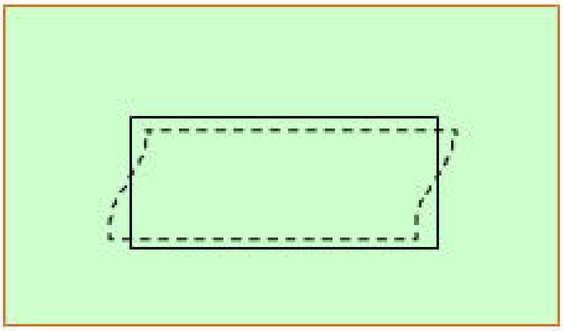
Flexure mode



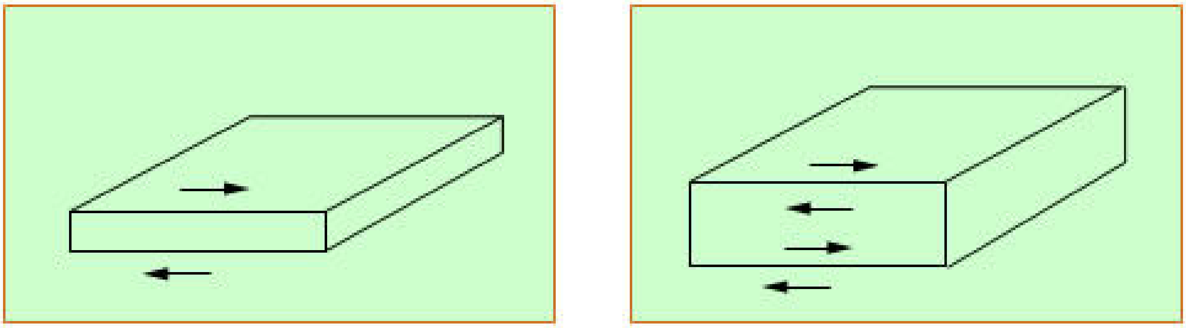
extensional mode



Face shear mode



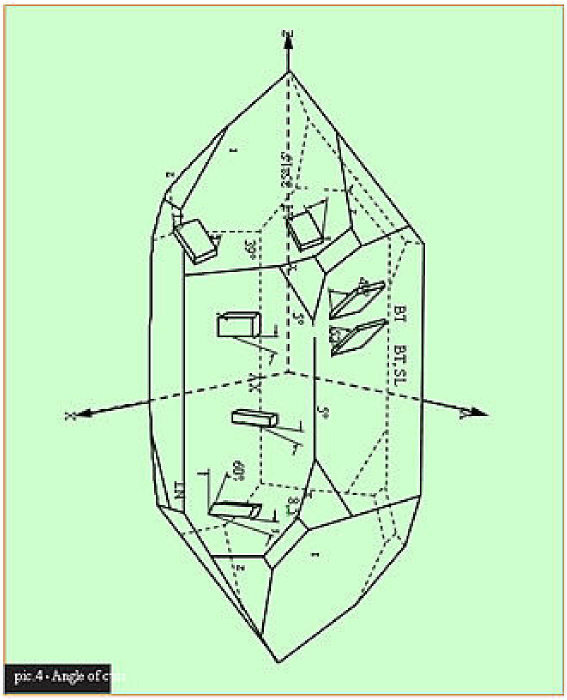
Thickness shear mode



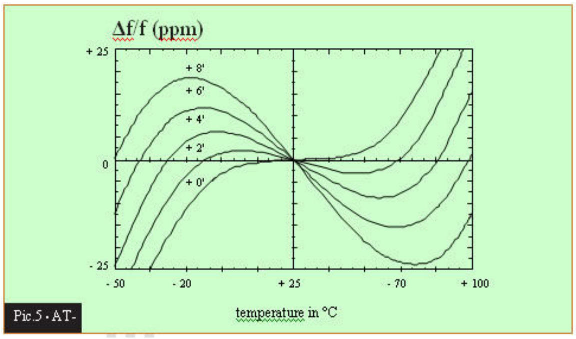
Fundamental mode thickness shear

Third overtone thickness shear

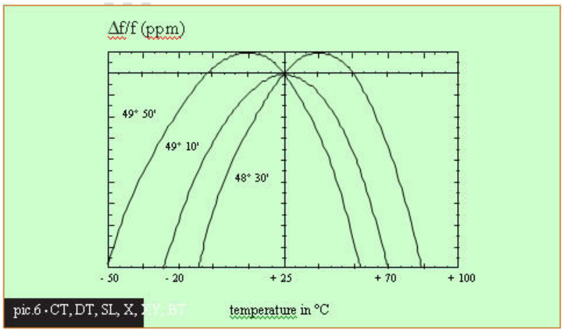
pic.3 · Modes of vibra



pic.4 · Angle of c



Pic.5 · AT-



pic.6 · CT, DT, SL, X, XY, BT