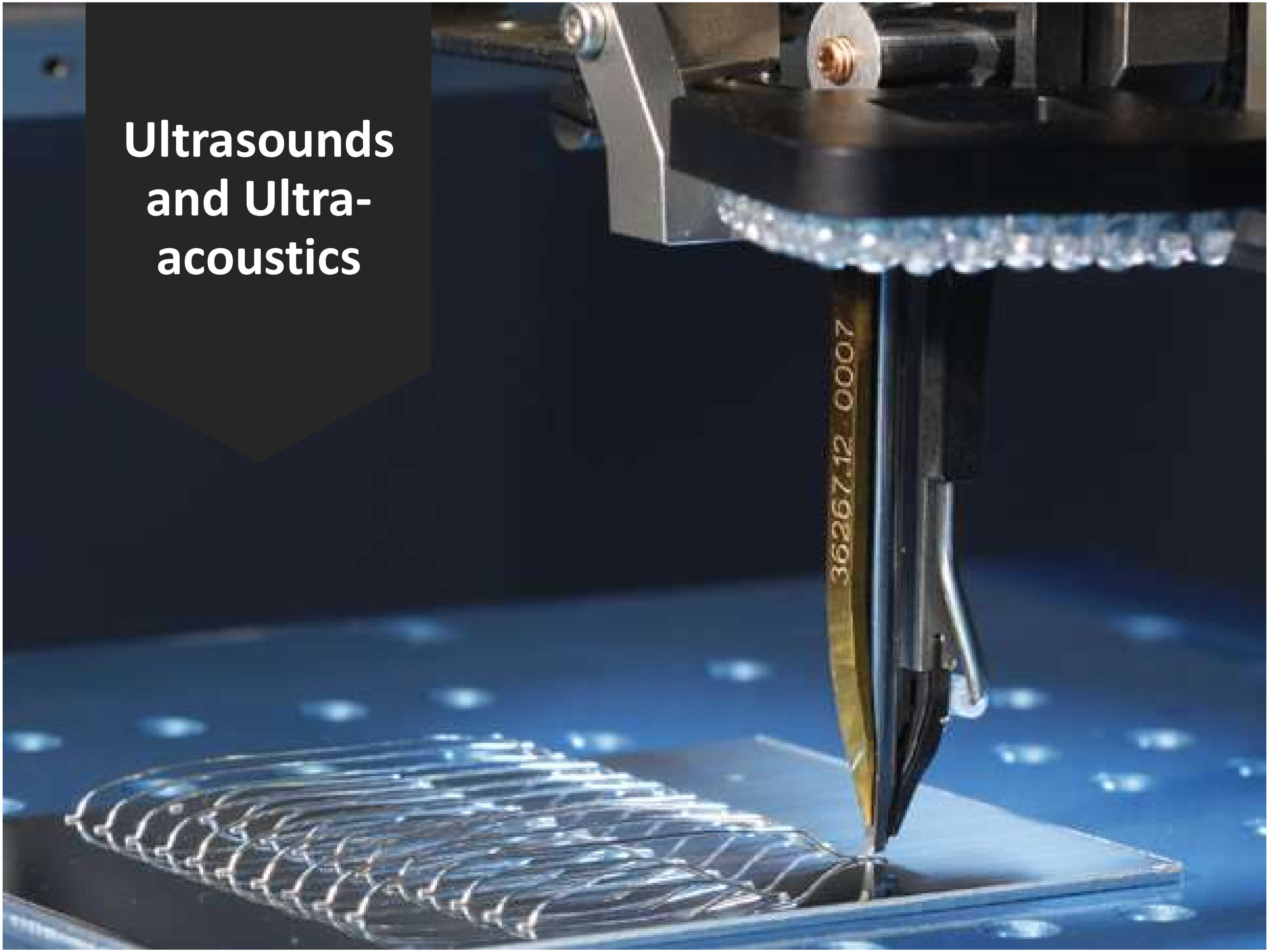
Ultrasounds and Ultra-acoustics



Ultrasounds= mechanical vibrations with a frequency larger than 20 kHz: in the range 20kHz-10GHz

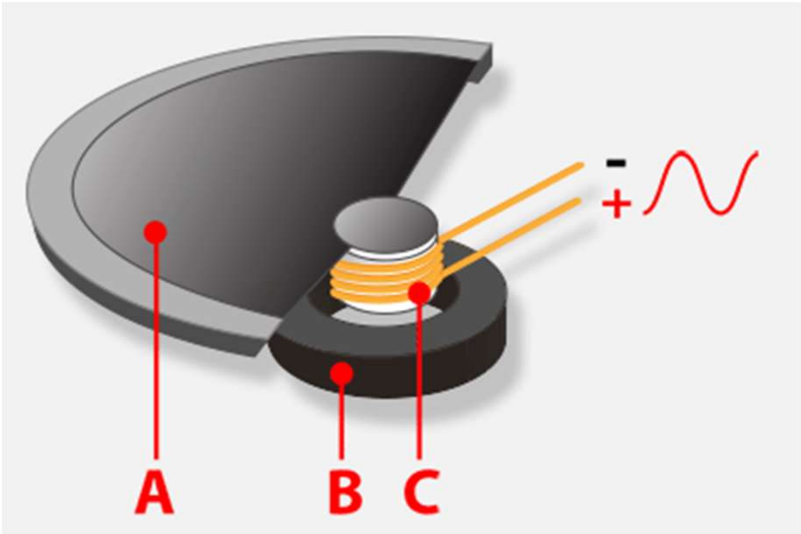
Ultrasound is no different from 'normal' (audible) sound in its physical properties, except in that humans cannot hear it.

However, some specific properties, related to their higher frequency (smaller wavelength)

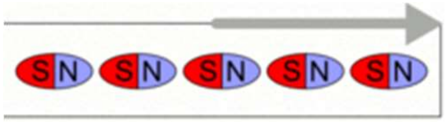
- Due to their small wavelengths, the diffraction is negligible. Hence, they can be transmitted over a long distances without any appreciable loss of energy.
- Otherwise, their propagation can be described by laws specific to the geometric optics of reflexion, refraction, etc…
- When they are passing through a medium, at discontinuities, they are partially reflected and this property is used in Non-Destructive Technique (NDT).
- Widely used in non-destructive medical Imagistics: echography, echo-Doppler…

Production of ultrasounds

- Mechanical generators (up to 200 kHz)
- Electro-acoustical generators: above

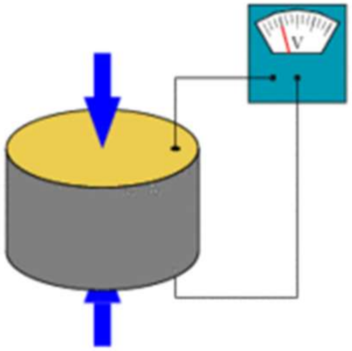


Mechanical generator: loudspeaker for producing normal sounds



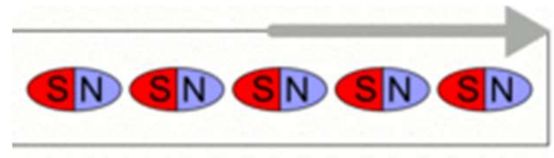
- ***For medium frequencies***: magnetostriction effect

- ***For higher frequencies***: electrostriction (inverse piezoelectric) effect

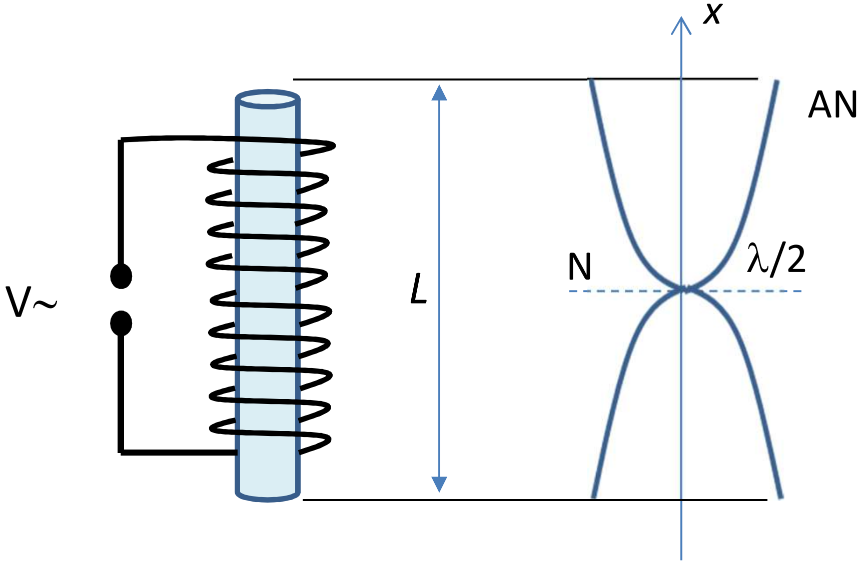


1. The magnetostrictive generator

Magnetostriction effect



Ferromagnetic materials (Fe, Co, Ni, alloys…) present the property to change their shape or dimensions (volume) during the process of magnetization.



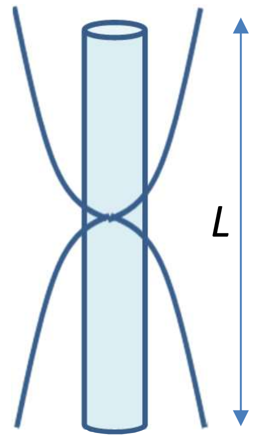
An alternative magnetic field (produced by an alternative voltage V which leads to alternative current I) produces oscillations of the free ends o a ferromagnetic rod.

The frequency of the ends oscillations is controlled by the frequency of the current producing the magnetic field.

The oscillation amplitude is maximum if the current frequency is at resonance with the one of the first mode of longitudinal vibration of the rod (see fig).

$$L = \frac{\lambda_0}{2} \Rightarrow \lambda_0 = 2L$$

$$\text{but } \lambda = \frac{v}{f} \Rightarrow \boxed{f_0 = \frac{v}{2L} = \frac{1}{2L}\sqrt{\frac{E}{\rho}}}$$



E= longitudinal elastic modulus
ρ= density of the rod material

From:

$$\boxed{f_0 = \frac{v}{2L} = \frac{1}{2L}\sqrt{\frac{E}{\rho}}}$$

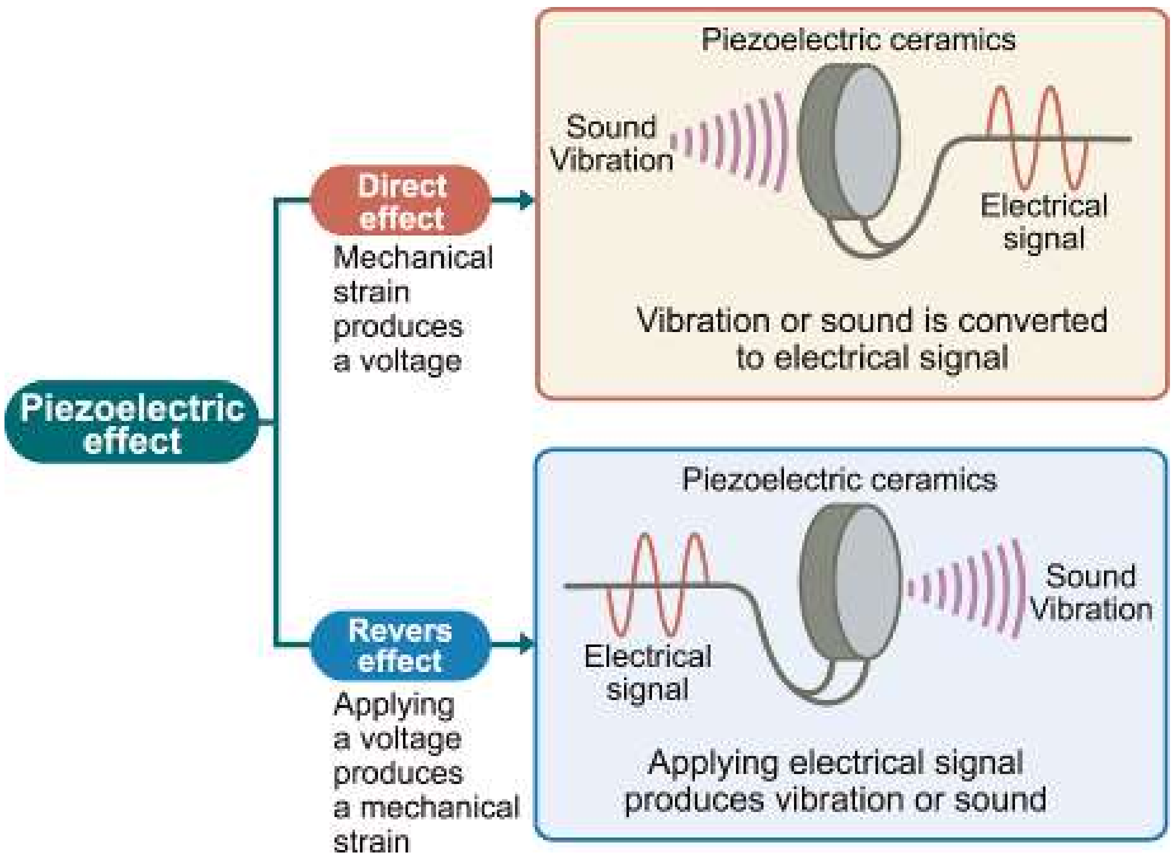
To increase the frequency f_0 one has to decrease the length L and the density ρ.

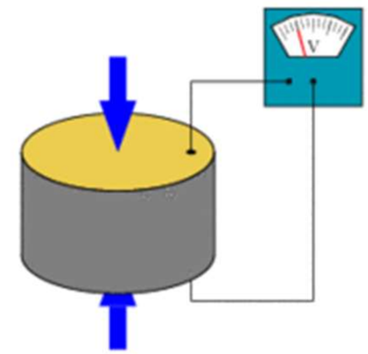
➔ High frequency limitation (for fundamental f_0) due to technological limitation in length decrease.

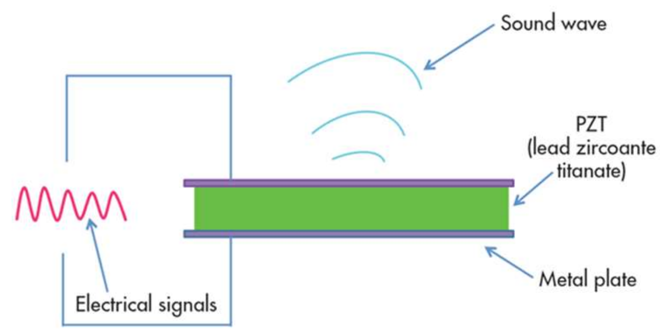
➔ Harmonics have larger frequencies (nf_0) but smaller amplitudes.

2. The electrostrictive generator

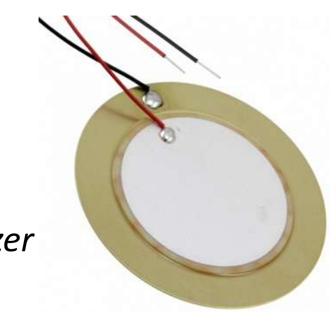
Electrostriction effect
Inverse piezoelectric effect





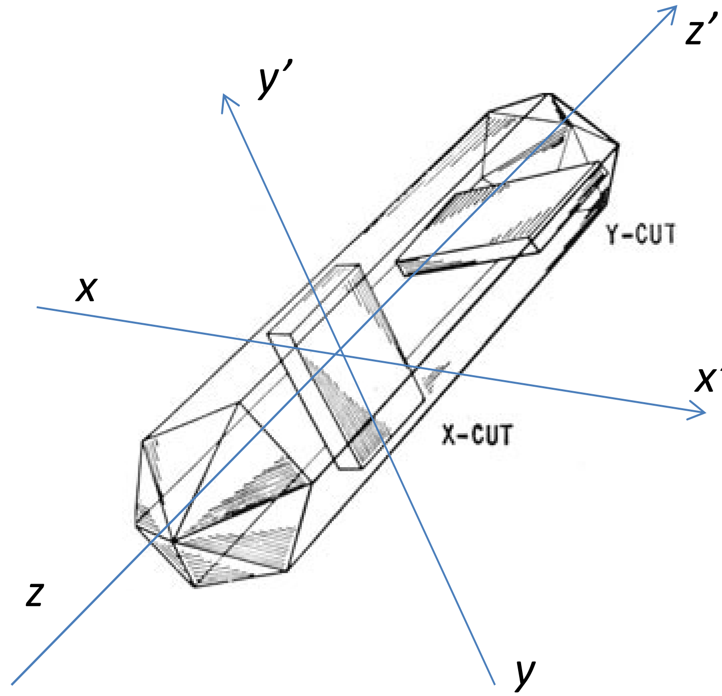


Ex. Piezo buzzer

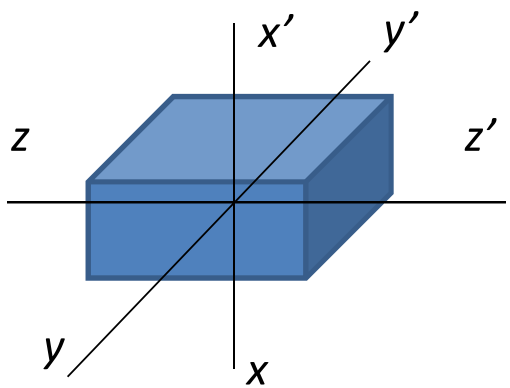


From quartz crystal to piezo

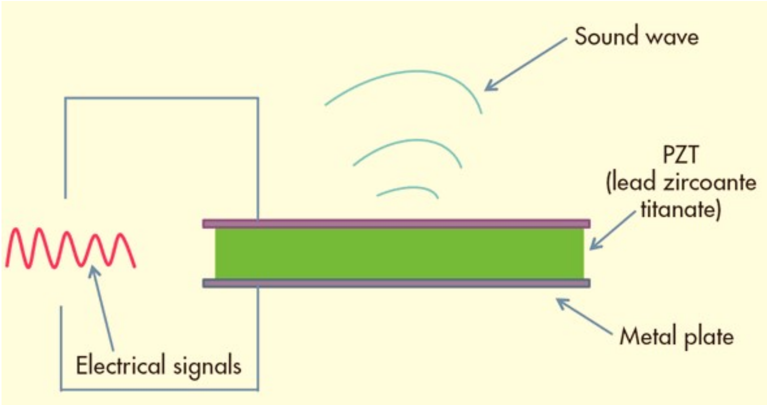
zz' =optical symmetry axis
yy'=mechanical symmetry axis
xx'=electrical symmetry axis



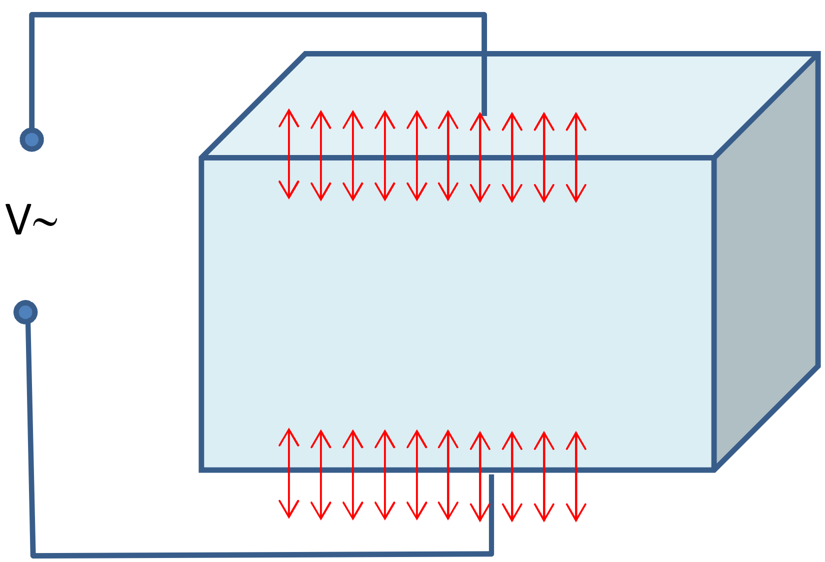
To provide piezoelectric properties, a quartz crystal has to be cut from the original crystal in the following way (x cut):

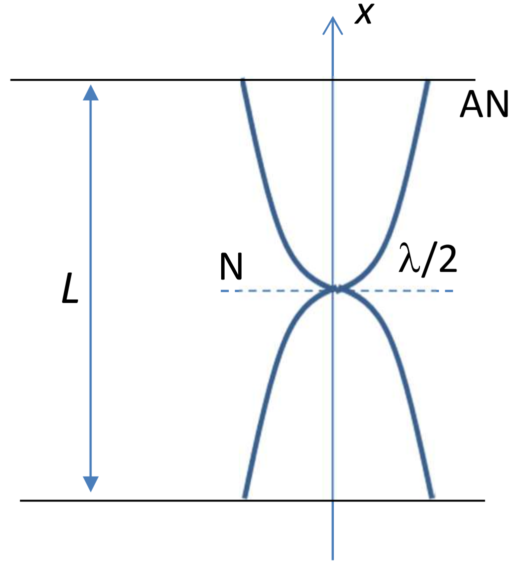


The facets on which electrical charges appear will suffer mechanical deformations are parallel with the optical symmetry axis zz' and perpendicular to the electrical axis xx'.



Or quartz





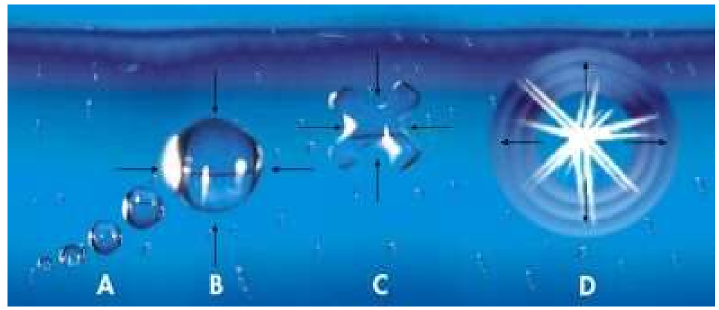
Similar discussion with respect to maximum amplitude of oscillations at resonance leads to:

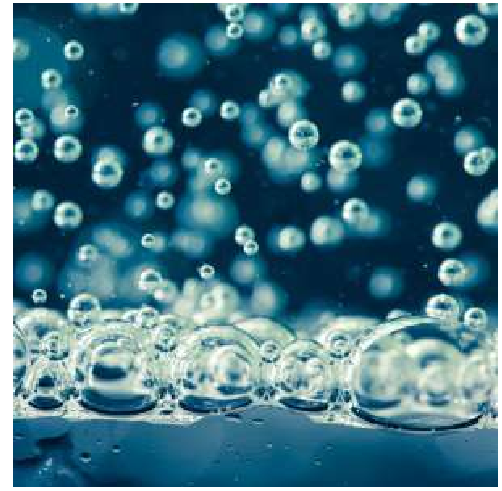
$$f_0 = \frac{v}{2L} = \frac{1}{2L}\sqrt{\frac{E}{\rho}}$$

Technologically L can be very small (from atomic planes to macroscopic thickness), the frequency may be very large: up to tens of GHz

Phenomena specific to ultrasounds

Beyond conventional phenomena common to any elastic wave in case of the ultrasounds they are some specific phenomena.





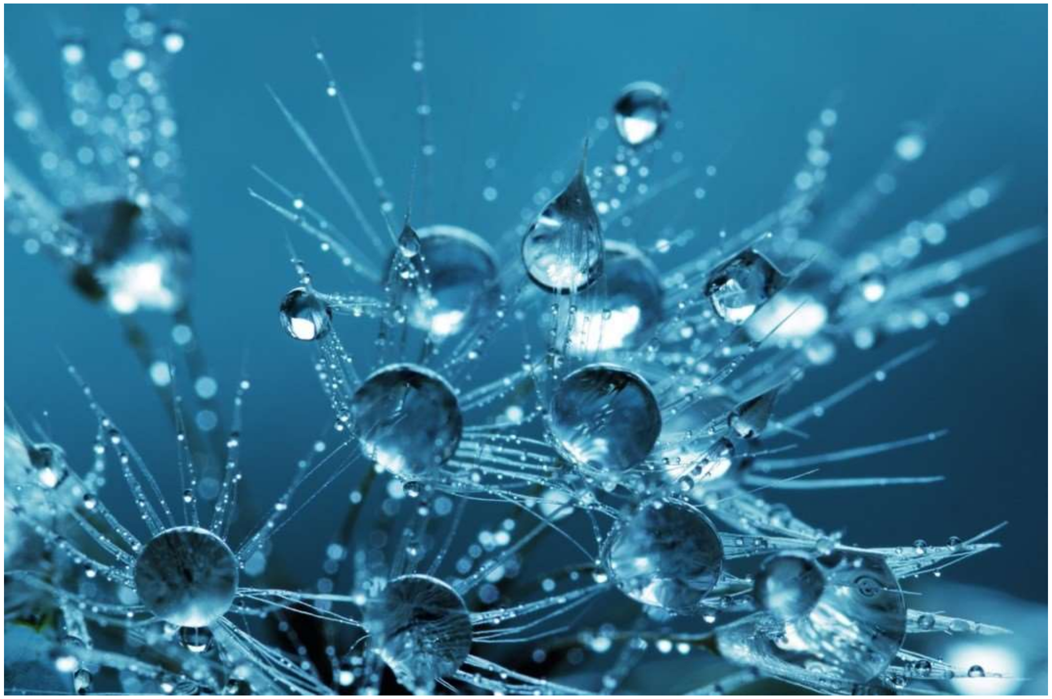
The cavitation

- Specific phenomenon which appears during the propagation of ultrasounds with high energy in liquid media.
- Sound propagation implicates successive compressions/expansions of travelling medium. For high energy US, during the expansion, in places where there are particles in suspension, air bubbles, vapors- the liquid can be fractured. In those places holes appear (cavities) toward which dissolved gases from liquid enter.
- In a next stage corresponding to compression, the cavity reduces its volume and the pressure inside increases up to thousands of atmospheres (Implosion).
- The process of cavity formation is assisted by a local temperature enhancement (up to 5000K) and even electric discharges.

! 6000K – the temperature of the basis of the Sun's chromosphere

- Due to this huge pressure, the cavities break-out producing intense hydraulic shocks. These effects are widely used in technics for mechanical engineering (cleaning in US baths, drilling, welding, polishing)…

Ultrasonic cleaning /US baths



Applications of ultrasounds

- ❑ Ultrasounds have multiple applications in technics, medicine, navigation,…
- ❑ Upon the way that the structure and the properties of the propagation medium are modified or not:
  - ➢ passive applications
  - ➢ active applications

Active applications

- ❑ Solid materials engineering/processing (polishing, cutting, welding, wire-bonding…)
- ❑ Enhancement of speed of reaction for chemical processes
- ❑ Destruction of viruses, bacteria, micro- organisms.
- ❑ Ultrasonic humidifier
- ❑ Surgery/medicine, breaking of kidney stones…
- ❑ Dispersion of substances, sedimentation, filtering, emulsification, extraction, crystallization…
- ❑ Weapons

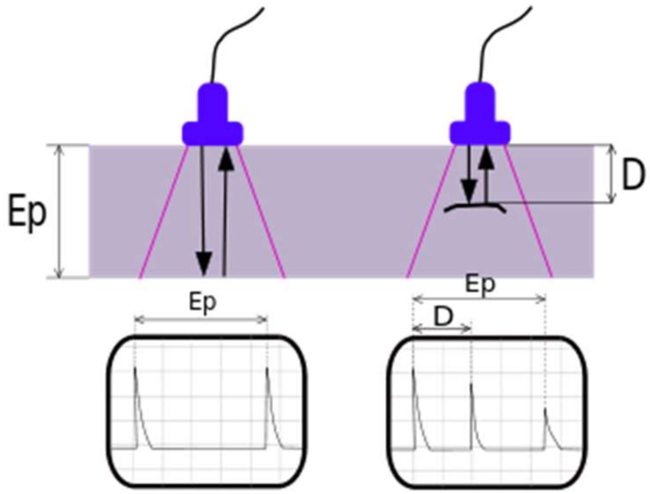
Passive applications

ultrasonic beams used to obtain information about quality, shape, dimensions…of investigated materials and systems

- ❑ Ultrasonic defectoscopy
- ❑ Echography/Doppler echography
- ❑ Sonar
- ❑ Ultrasonic tomography
- ❑ Ultrasonic microscope (Sokolov): allows to get zoomed images of deffects in samples

Ultrasonic testing /defectoscopy

US: f= 0.1-15 MHz



- Ultrasonic testing is often performed on steel and other metals and alloys, though it can also be used on concrete, wood and composites,…
- Measuring thickness (corrosion affected), identify defects, cracks, …
- Used in many industries including steel and aluminium construction, metallurgy, manufacturing, aerospace, automotive and other transportation sectors.

Microelectronics- ultrasonic wire bonding

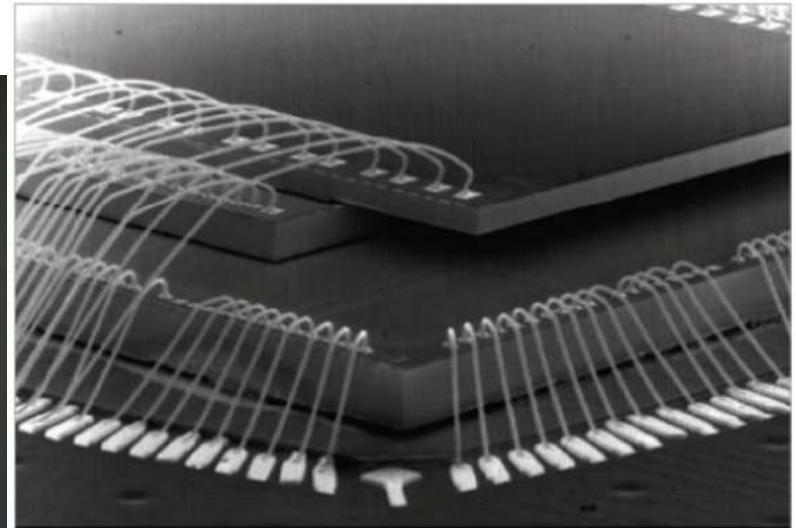
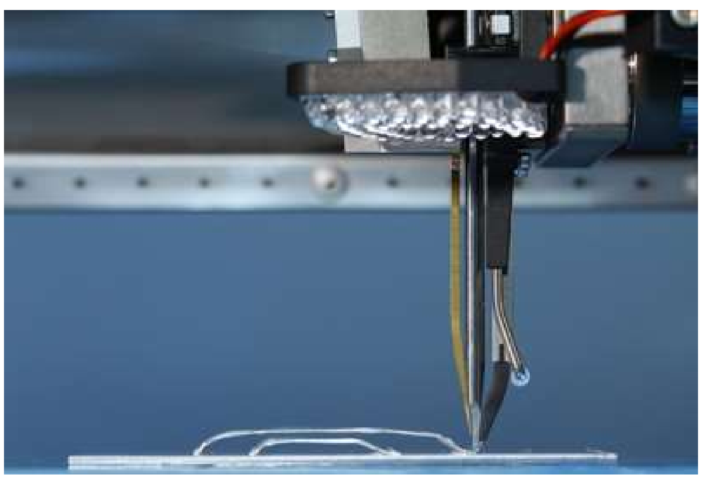
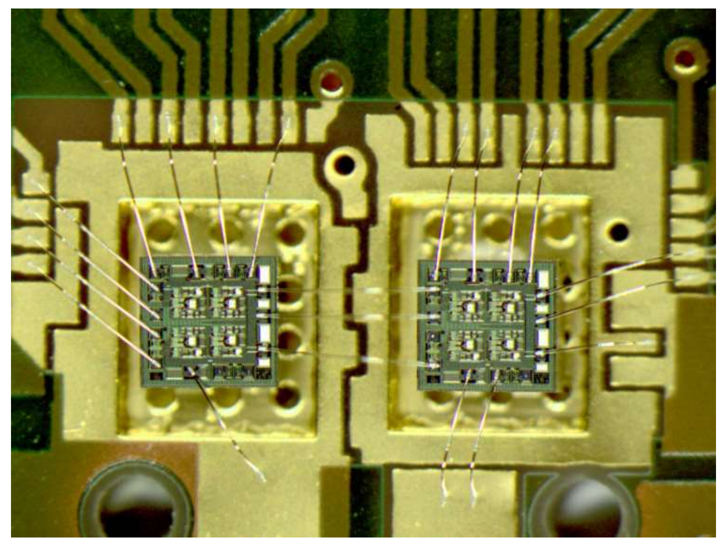


그림 1 Three–die, wire–bond semiconductor assembly (Example Source: Intel Corporation)



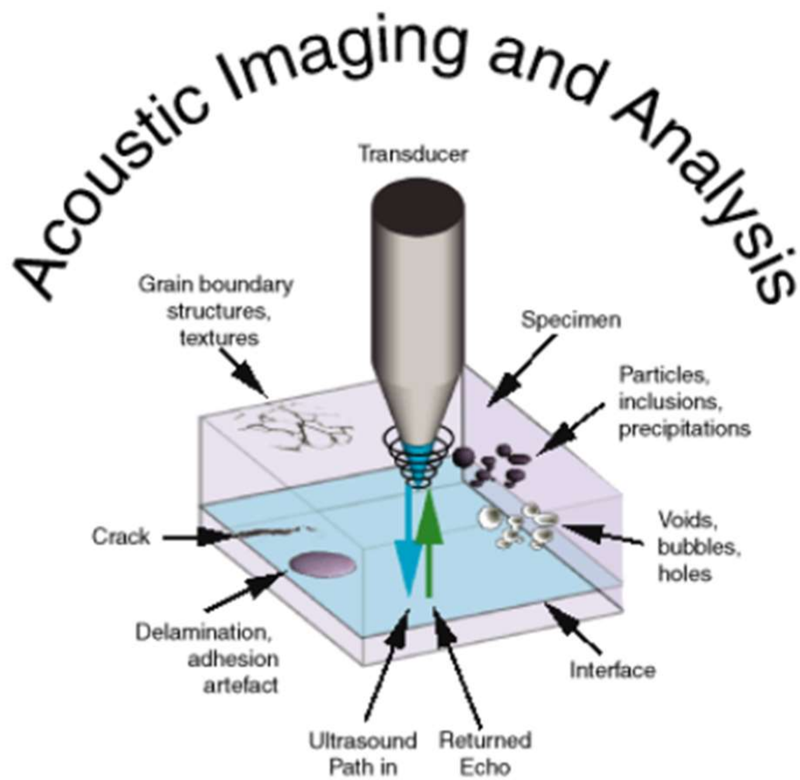


Acoustic microscope

Principle enounced by Y. Sokolov 1940: *sound waves with a frequency of 3 GHz (λ=v/f~100nm) would have a resolution equal to that of an optical microscope (visible light 390-700nm)*. However, at that time the technology required to generate such sound waves did not exist. Since then the technology has been developed, and the high frequencies required for Sokolov's microscope are found in the microwave systems used for radar and for satellite communications (*transducers are used to convert microwaves into sound waves*). During the 1970s several groups of researchers in the United States employed these frequencies to build sound systems.

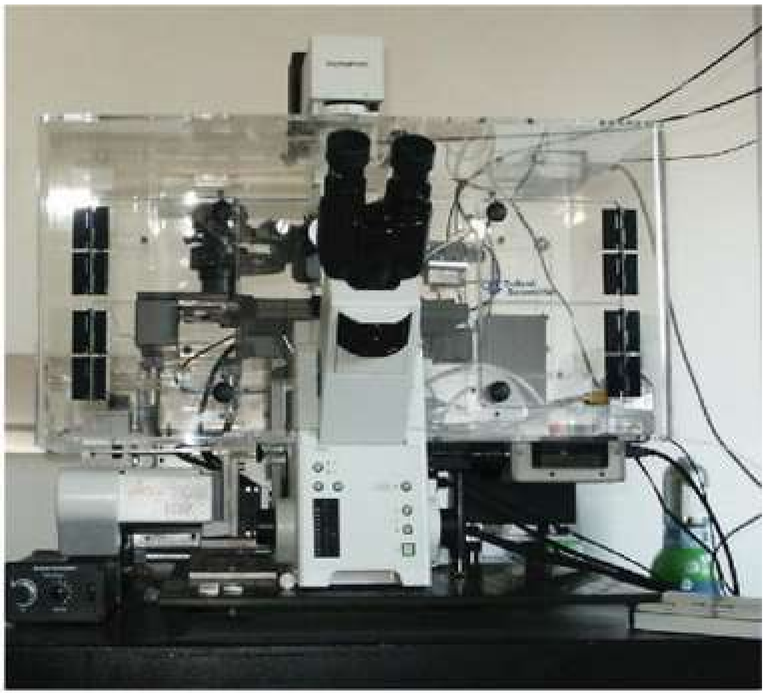
The acoustic microscope was developed as a tool for studying the internal microstructure of nontransparent solids or biological materials. In acoustic microscopy, a sample is imaged by ultrasound waves, and the contrast in reflection furnishes a map of the spatial distribution of the mechanical properties.

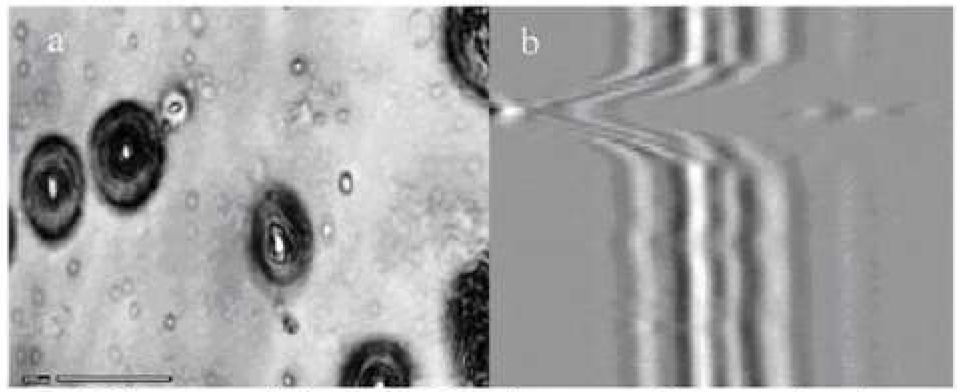
A traditional microscope allows you to see the surface, maybe even the subsurface, of a specimen but the acoustic microscope focuses in on a specific point and obtains images from deeper layers.



Acoustic Microscopy is important not only in the medical field but also in the microelectronics industry.

- ❑ SAM in analytical labs to determine the quality electronics components.
- ❑ SAM helps to establish if electrical components have bad leads, which could cause the product to not perform correctly or at all.



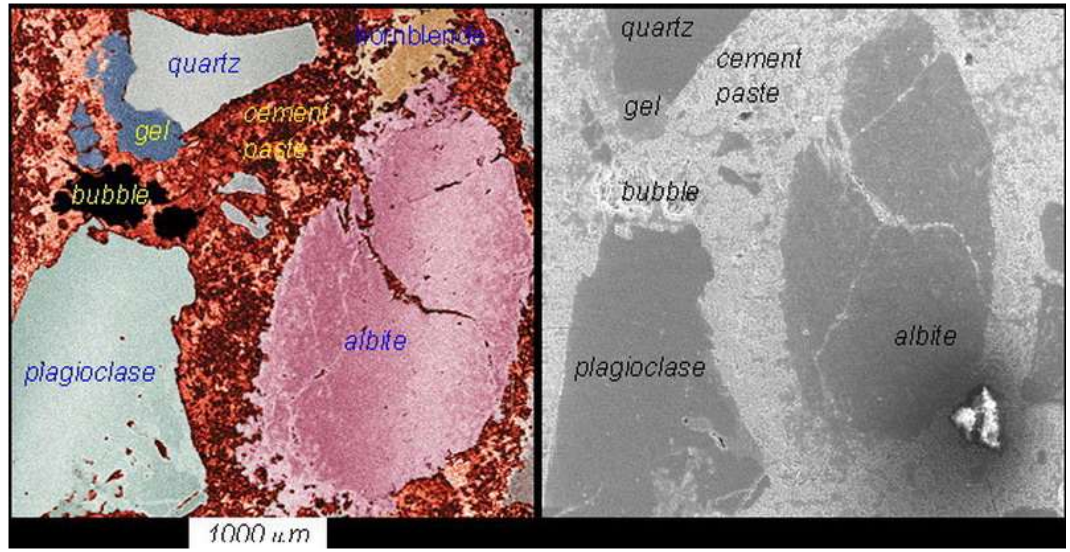


SAM image made by OXSAM of an epoxy layer on aluminum at 300 MHz showing subsurface defects: (a) C-scan; (b) B-scan.

Combined optical (Olympus IX81) and time-resolved Scanning Acoustic Microscope, SASAM, Fraunhofer-Institute for Biomedical Technology, St. Ingbert, Germany.

Material science and engineering

Acoustic (left) and SEM (right) images of concrete sample made with granitic aggregate grains and Portland cement paste. The acoustic image was made at 400 MHz.



Application of SAM for Elastic Characterization of Biological Cells

SAM is helpful in studying heart disease, arterial problems, lymph nodes and live cell cultures.