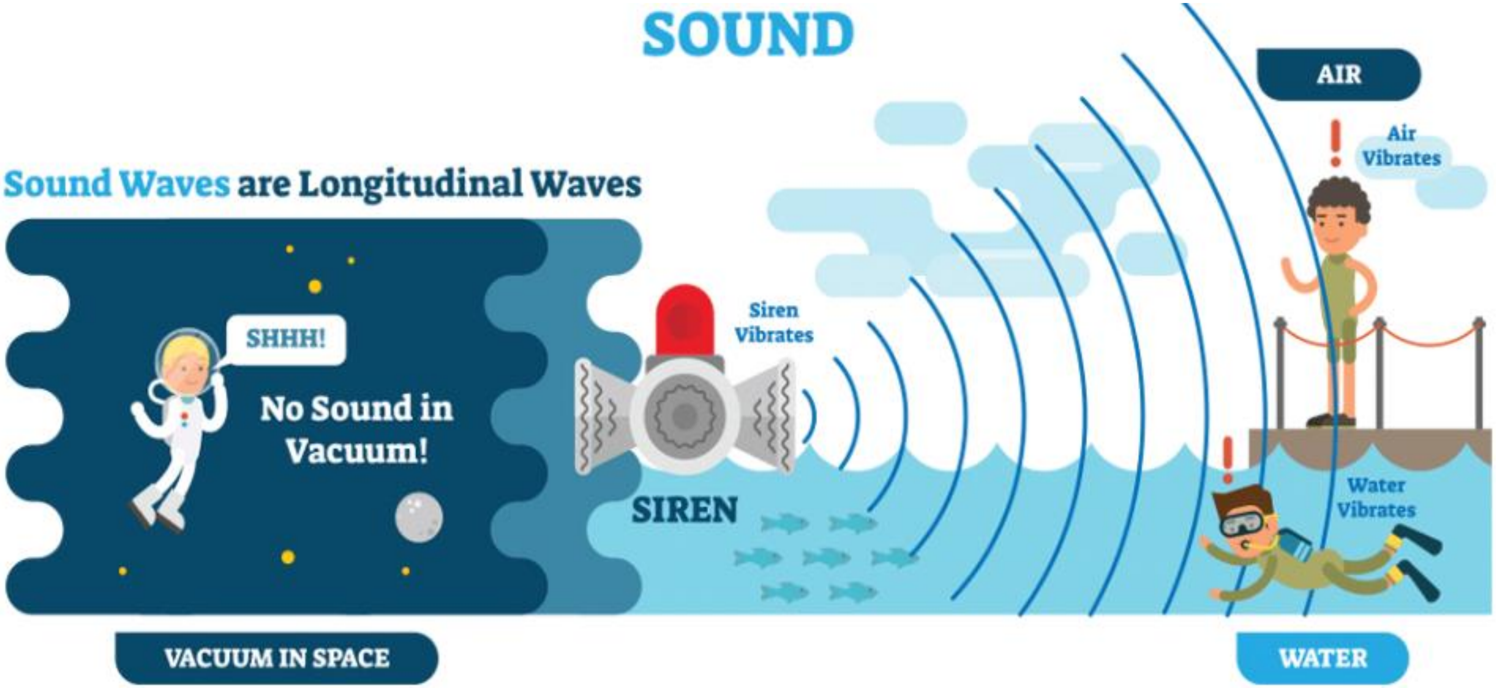


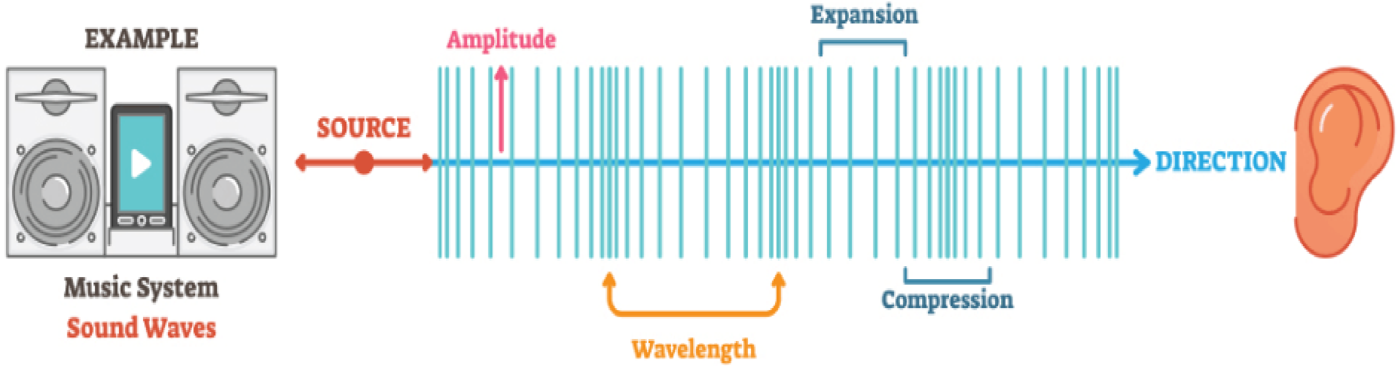
SOUND
Sound Waves are Longitudinal Waves
SHHH!
No Sound in Vacuum!
SIREN
Siren Vibrates
AIR
Air Vibrates
Water Vibrates
VACUUM IN SPACE
WATER

# ACOUSTIC WAVE SENSOR

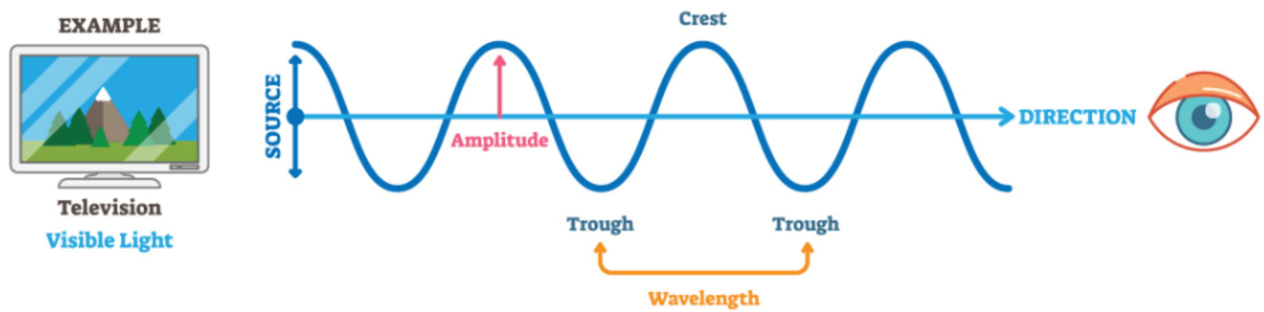
- Any changes that were made to the mechanical wave will be reflected in the output electric signal.
- Acoustic waves are **mechanical and longitudinal waves** (same direction of vibration as the direction of propagation) that result from an oscillation of pressure that travels through a solid, liquid or gas in a wave pattern.

https://youtu.be/H0MJstxNDQM

# LONGITUDINAL WAVES



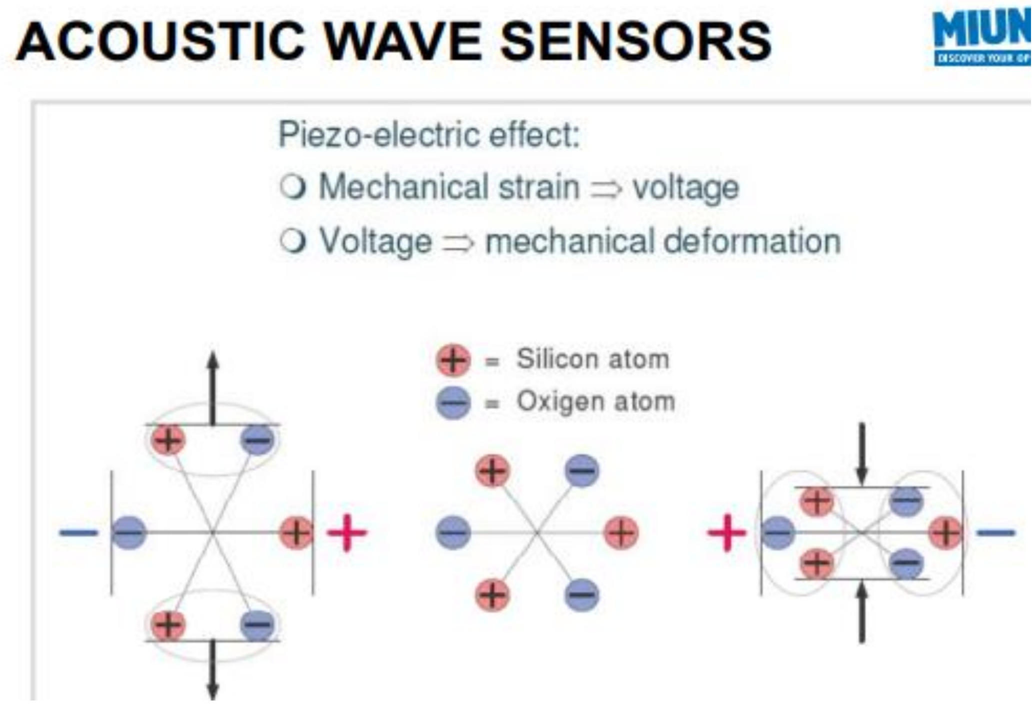

# TRANSVERSE WAVES



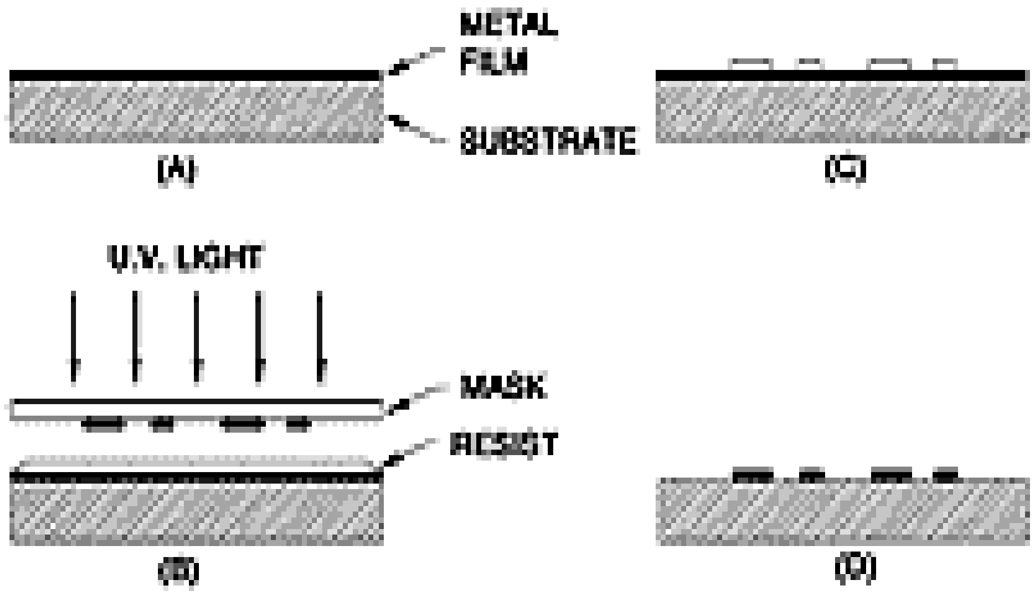
- Sound wave can be described by five characteristics: **Wavelength, Amplitude, Time-Period, Frequency and Velocity or Speed**. The minimum distance in which a sound wave repeats itself is called its wavelength.
- Ultrasonic waves are acoustic waves that are so high in frequency that humans can't hear them;
- The Propagation of sound. Sound is a sequence of waves of pressure which propagates **through compressible media such as air or water**.

# Acoustic Wave Sensor Principle:

Piezoelectric acoustic wave sensors **apply an oscillating electric field to create a mechanical wave, which propagates through the substrate and is then converted back to an electric field for measurement**.

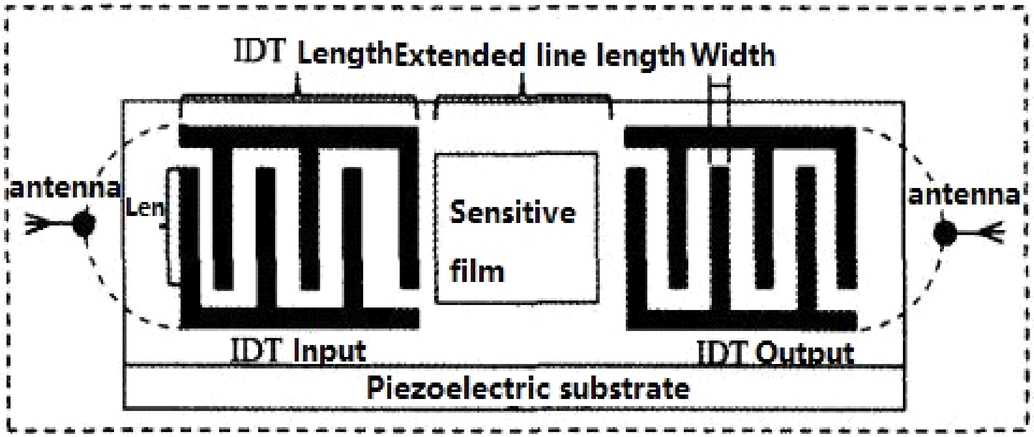


- all acoustic wave devices and sensors use a piezoelectric material to generate the acoustic wave.
- **Piezoelectricity** refers to **the production of electrical charges by the imposition of mechanical stress**. The phenomenon is reciprocal. Applying an appropriate **electrical field to a piezoelectric material creates a mechanical stress.**
- Piezoelectric acoustic wave sensors apply an oscillating electric field to create a mechanical wave, which propagates through the substrate and is then converted back to an electric field for measurement.




➢ Acoustic wave devices are manufactured by means of a photolithographic process similar to that used to make ICs. The only difference is that no junction exists in acoustic wave sensors.

# Fabrication of Acoustic Wave Devices



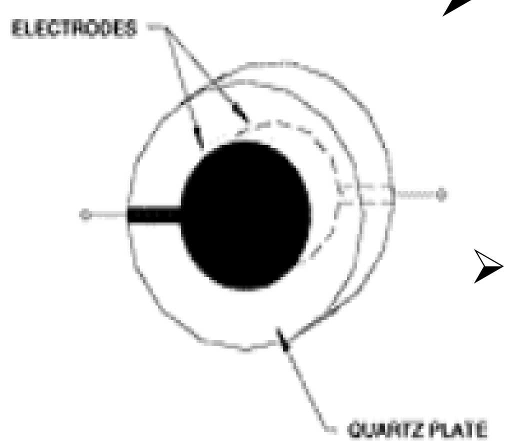

SAW sensor structure

- The device is spin-coated with a photoresist and baked to harden it. It is then exposed to UV light through a mask

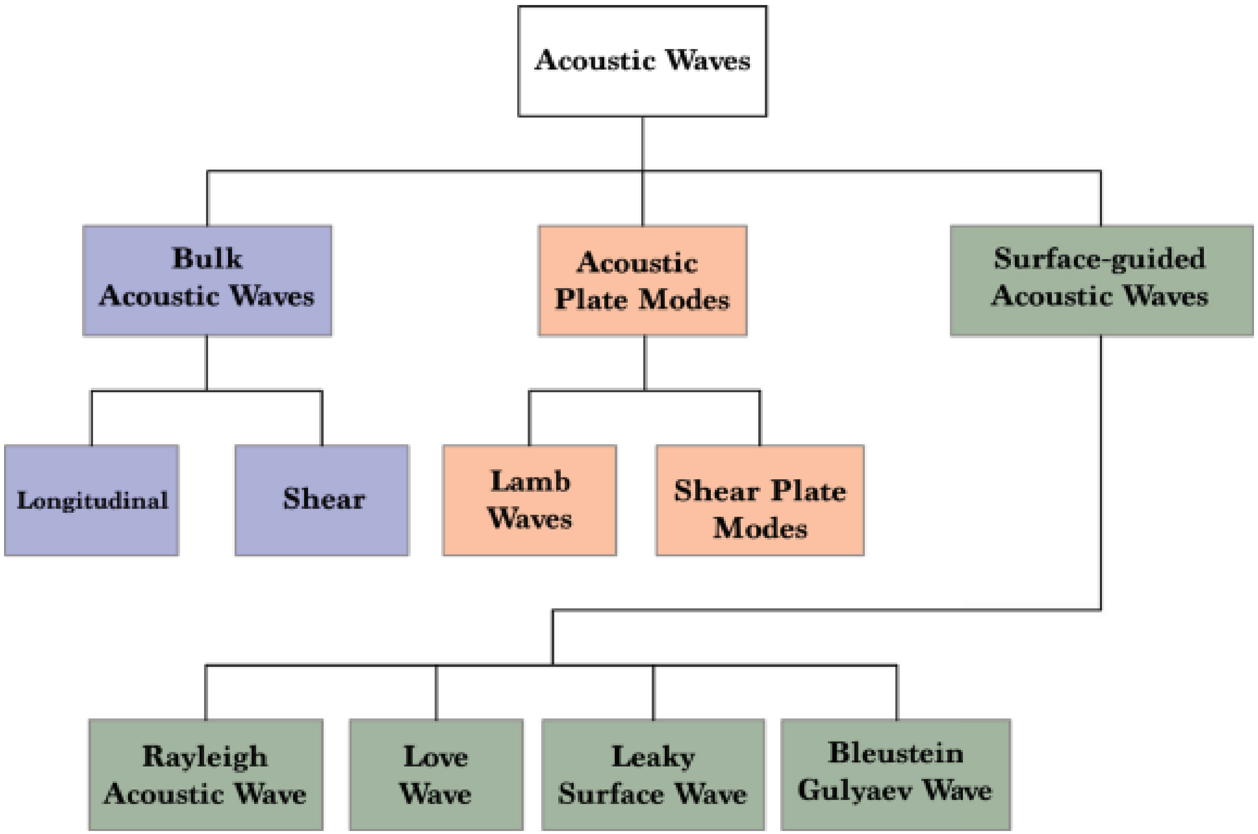
- The exposed areas undergo a chemical change that allows them to be removed with a developing solution. Finally, the remaining photoresist is removed. The pattern of metal remaining on the device is called an interdigital transducer, or IDT.

- By changing the length, width, position, and thickness of the IDT, the performance of the sensor can be maximized.

## Acoustic Wave Propagation Modes:



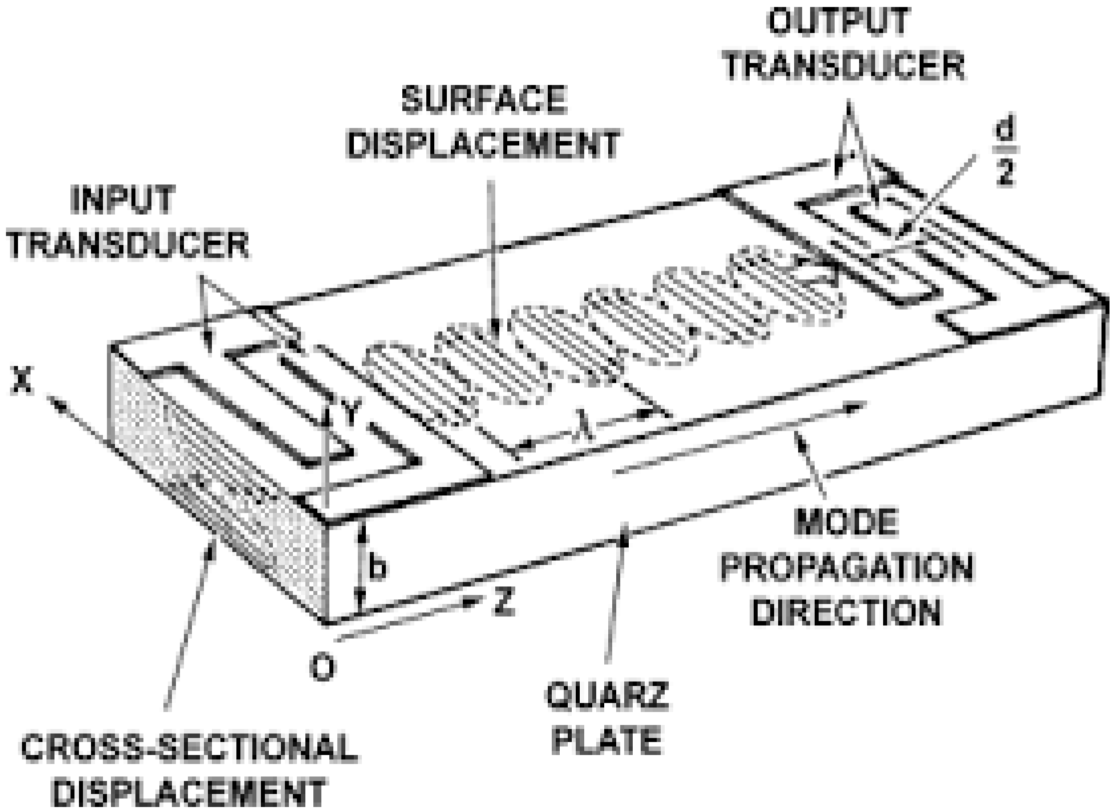

- Acoustic wave devices are described by the mode of wave propagation through or on a piezoelectric substrate.
- The IDT of each sensor provides the electric field necessary to displace the substrate and thus form an acoustic wave. The wave propagates through the substrate, where it is converted back to an electric field at the IDT on the other side.
- Although it is the oldest acoustic wave device, the thickness shear mode resonator is still used for measuring metal deposition rates.


Acoustic Waves
Bulk Acoustic Waves
Acoustic Plate Modes
Surface-guided Acoustic Waves
Longitudinal
Shear
Lamb Waves
Shear Plate Modes
Rayleigh Acoustic Wave
Love Wave
Leaky Surface Wave
Bleustein Gulyaev Wave

# BULK ACOUSTIC WAVE

- A wave propagating through the substrate is called a bulk wave. The most commonly used bulk acoustic wave (BAW) devices are the thickness shear mode (TSM) resonator and the shear-horizontal acoustic plate mode (SH-APM) sensor.

- The Displacement direction of longitudinal and shear waves, while the longitudinal is parallel to the propagation direction and shear wave is perpendicular to it.


OUTPUT
TRANSDUCER
SURFACE
DISPLACEMENT
INPUT
TRANSDUCER
d
2
X
Y
λ
b
Z
O
MODE
PROPAGATION
DIRECTION
QUARZ
PLATE
CROSS-SECTIONAL
DISPLACEMENT

- While propagating, elastic waves suffer attenuation of their amplitude. There are three main mechanisms that cause this effect.

1. *Losses due to the scattering of the wave propagating through inhomogeneous media* (temperature independent; dominant for polycrystalline solids (AlN, ZnO thin films));
2. *Losses due to the scattering of the wave through thermal lattice vibrations* (temperature dependent);
3. *Temperature variation within the solid due to the change in its volume compensated by an energy transportation through thermal diffusion to neutralize the difference* (longitudinal waves only).

For each specified propagation direction, three independent acoustic waves exist. For most propagation directions in anisotropic solids, these waves do not exist in their pure form, but appear in a more general form as a *quasi-longitudinal* and two *quasi-shear waves*. In general, quasi-longitudinal waves have a higher velocity than any shear wave, while its polarization is predominantly oriented along the wave vector. The quasi-shear waves exhibit polarizations orthogonal to the *quasi-longitudinal* polarization. The quasi-shear waves are further classified as *fast-shear* and *slow-shear* waves, which have different phase velocities, and are orthogonal to each-other's polarizations.

It is common to use the polarization relative to the substrate surface for the discussion of surface acoustic waves, so that shear plane waves are referred to as *shear-vertical* (SV) when polarized perpendicularly to the surface, and *shear-horizontal* (SH) when parallel to it

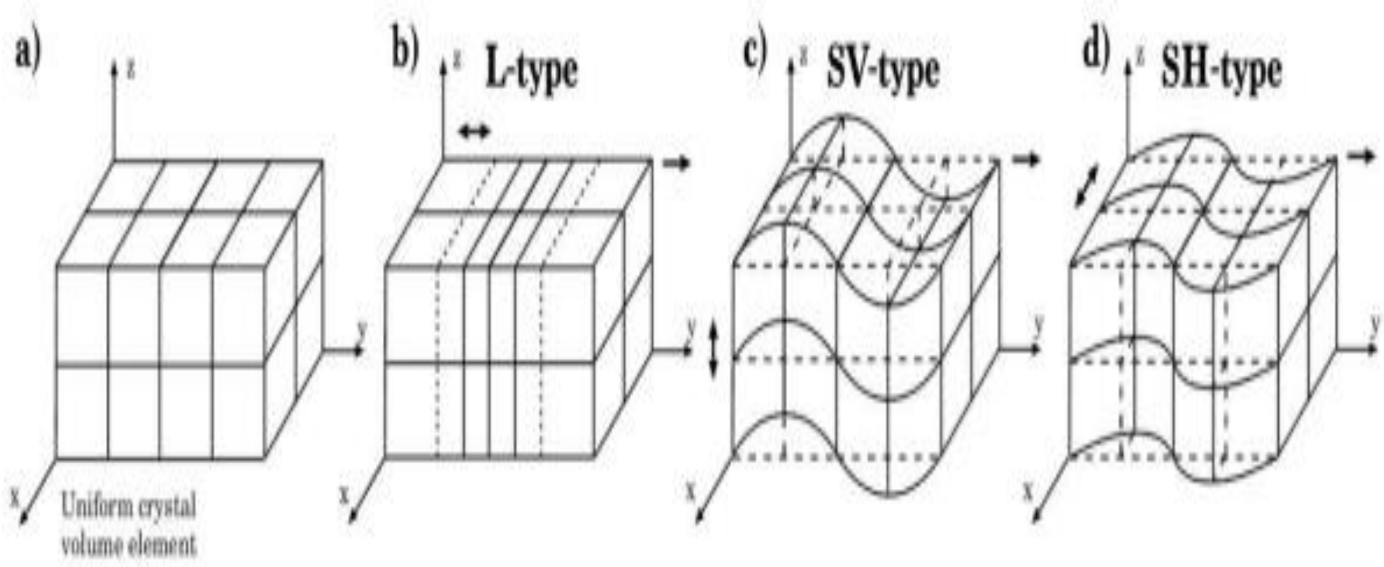



Figure 2. Various types of bulk plane acoustic waves. Black arrows indicate the direction of displacement. **a)** depicts a uniform crystal volume element; **b)** longitudinal wave; **c)** wave with shear-vertical polarization; **d)** wave with shear-horizontal polarization. [33]

# *Plane wave in piezo electric solids:*

All acoustic wave devices rely on piezoelectric materials to generate the acoustic wave [34]. Piezoelectricity is the appearance of electrical charges in a certain type of solids when they are subjected to mechanical stress. This phenomenon is a reversible process, i.e., application of an electrical field will result in a mechanical strain.

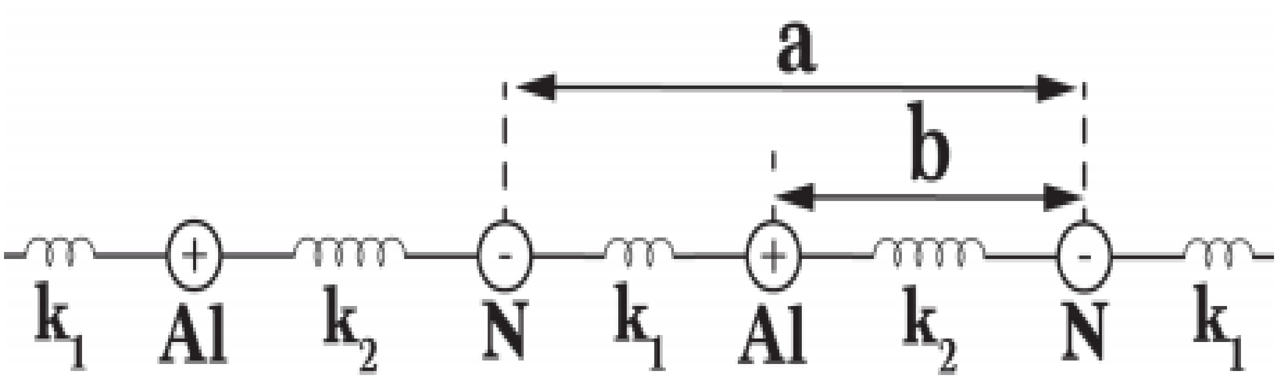
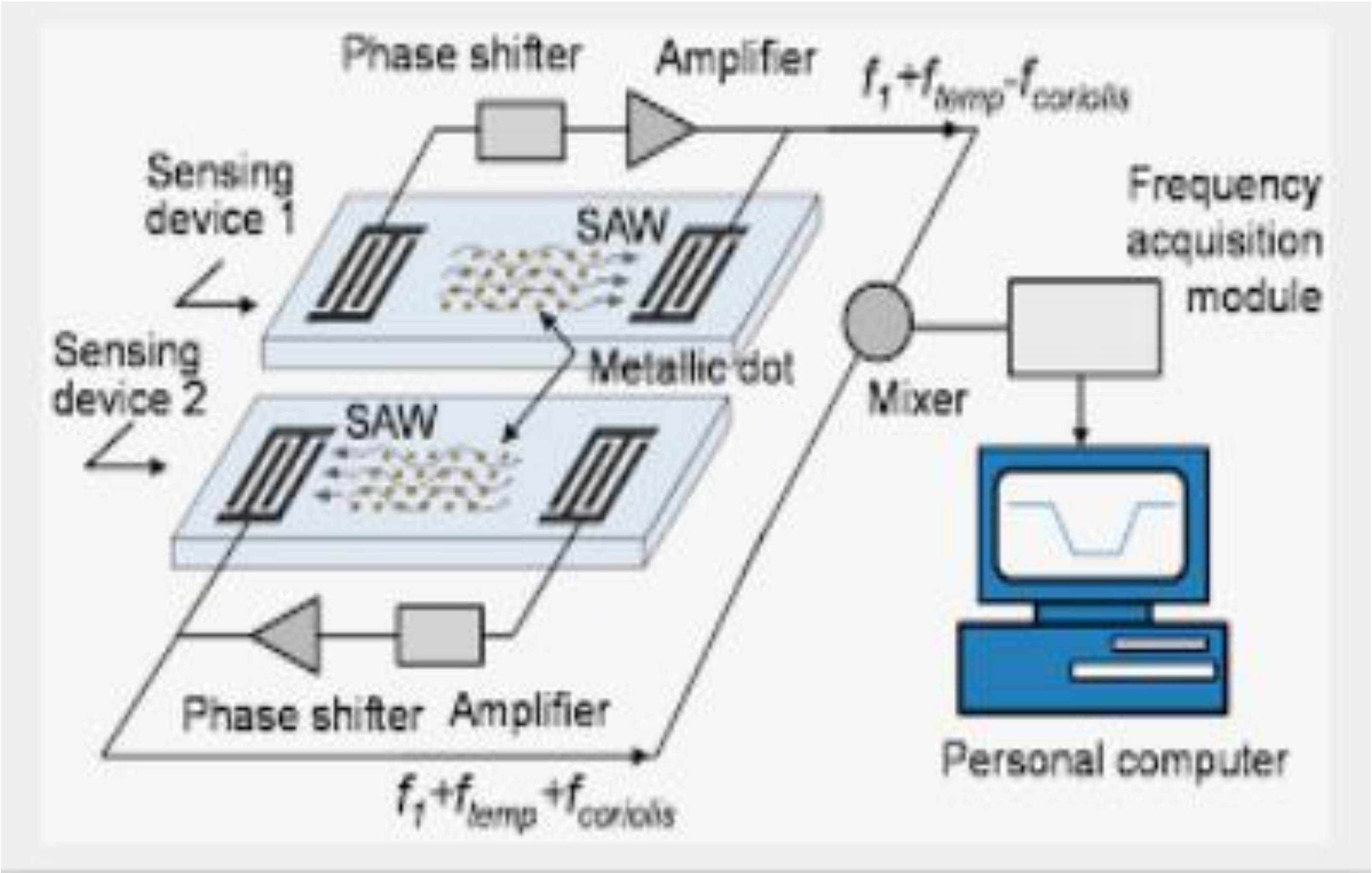
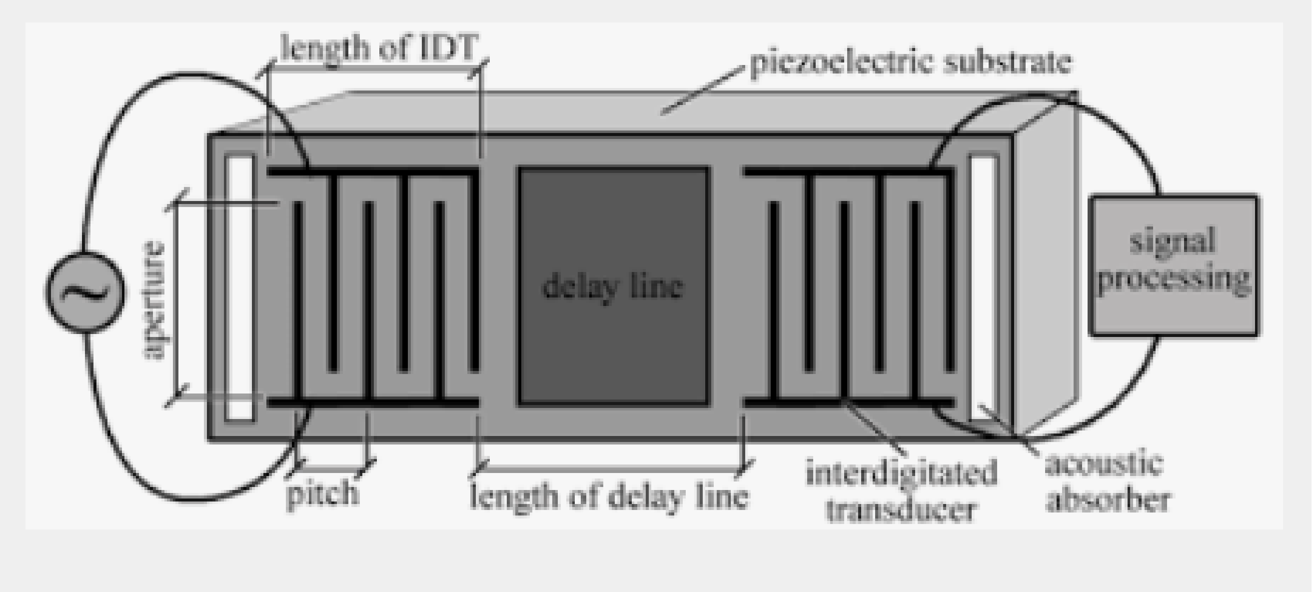
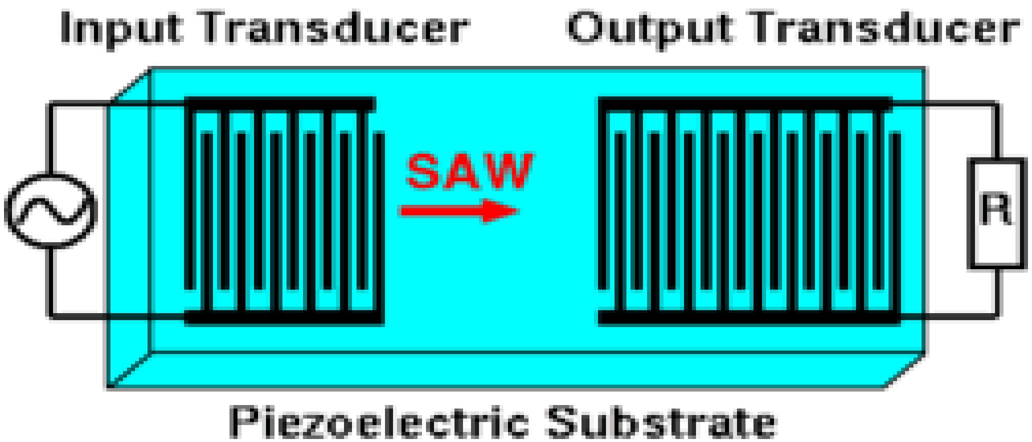



**Figure 3**. Schematic diagram of a simplified mechanical model of the AlN ion crystal.

# Surface Acoustic Wave Sensor




length of IDT
piezoelectric substrate
aperture
delay line
signal processing
pitch
length of delay line
interdigitated transducer
acoustic absorber


Input Transducer
Output Transducer
SAW
R
Piezoelectric Substrate

- Rayleigh waves move vertically in a direction normal to the surface plane of a surface acoustic wave (SAW) sensor. SAW waves are very sensitive to surface changes, but do not work well for most liquid sensing applications.
- Rayleigh waves have a **longitudinal and a vertical shear component that can couple with a medium in contact with the device's surface.**
- Such coupling **strongly affects the amplitude and velocity of the wave**. This feature enables SAW sensors to **directly sense mass and mechanical properties**. The **surface motion also allows the devices to be used as microactuators.**

# Sensor Applications

- All acoustic wave sensors are sensitive, to varying degrees, to perturbations from many different physical parameters.
- These sensors become pressure, torque, shock, and force detectors under an applied stress that changes the dynamics of the propagating medium.
- They become mass, or gravimetric, sensors when particles are allowed to contact the propagation medium, changing the stress on it. They become vapor sensors when a coating is applied that absorbs only specific chemical vapors. These devices work by effectively measuring the mass of the absorbed vapor.
- If the coating absorbs specific biological chemicals in liquids, the detector becomes a biosensor.