ULTRASOUND EQUIPMENT TECHNIQUES

(Ultrasound waves)

LECTURE [4]

Diagnostic Ultrasound

Today, ultrasound (US) is one of the most commonly used imaging technologies in medicine. Sounds in the range 2 and 18 megahertz (MHz) are typically used for diagnostic ultrasound. The accuracy of ultrasound diagnosis based on computerized analysis of reflected ultrasound waves, which non-invasively build up fine images of internal body structures. The best resolution can be achieved is by using shorter wavelengths, with a wavelength that is inversely proportional to the frequency. However, the use of high frequencies is limited due to the increased attenuation (loss of signal strength) in various tissues and so easily absorbed and thus shorter than the depth of penetration. For this reason, specific probes are used for different frequency ranges to examine different parts of the body:

- *3–5 MHz for abdominal areas*
- *5–10 MHz for small and superficial parts and*
- *10–30 MHz for the skin or the eyes*

Because of the heterogeneity of the different tissues within the body with different densities, the ultrasonic waves penetrate varies accordingly. Bones absorb ultrasound much more than soft tissue, so that, in general, ultrasound is suitable for examining only the surfaces of the bone. For this reason, ultrasound images show a black zone behind the bones due to the inability of ultrasound energy to reach those areas. If the high frequencies used, called acoustic shadow.

2.5 Piezoelectric Materials

The word piezoelectricity means the ability of some materials (notably crystals and certain ceramics, including bone) to generate an electric charge or of electric polarity in dielectric crystals in response to applied mechanical stress in such crystals subjected to an applied voltage. The piezo is derived from the **Greek** word 'piezein' (πιέζειν), which means to squeeze or press, and electric or electron (ήλεκτρον), which stands for amber, an ancient source of electric charge. The piezoelectric effect was first discovered in 1880 by brothers Pierre Curie and Jacques Curie (French physicists). The Curie brothers only found that piezoelectric materials can produce electricity. The next development was the discovery by Gabriel Lippmann that electricity can deform piezoelectric materials. It was not until the early twentieth century that practical devices began to appear. Today, it is known that many materials such as quartz, topaz, cane sugar, Rochelle salt, and bone have this effect.

In summary;

1. Piezoelectricity discovered by the Curies in 1880 using natural quartz
2. SONAR (originally an acronym for **SO**und **N**avigation **A**nd **R**anging) is a technique that uses sound propagation (usually underwater, as in submarine navigation) was first used in 1940’s war-time
3. Diagnostic Medical applications in use since late 1950’s

Piezoelectric crystals or materials generate an electrical voltage from separation of positive and negative charges when they are squeezed or stretched. In other words, it is the charge that accumulates in certain solid materials (notably crystals, certain ceramics, and biological matter such as bone, DNA and various proteins) in response to applied mechanical stress. We can view each SiO2 unit as a sphere that has a positively charged core (lawn green) and a negatively charged shell (light pink), as depicted in Figure 8.2. Figure 8.2 explains what happens if the SiO2 is put under mechanical stress (symbolized by yellow arrows). The overall formula of quartz is SiO2, and since every oxygen atom carries the same extra amount of negative charge taken from silicon atom, the central silicon atoms carry 2 positive charges and the oxygen just one negative charge.

Under mechanical stress the crystal all tetrahedral are affected, with their central silicon atom pushed downwards. The whole structure (All SiO_2 units) is electrically polarized in the same way, in this case being more negative on the top and more positive on the bottom, as depicted in Figure 2 to the right. The voltage built up in each SiO_2 unit is very small, but since millions of them line up in the crystal structure, their voltage adds up to a measurable amount.

Piezoelectric crystals have the property a change of polarization density within the material's volume when a voltage is applied. Thus, applying an alternating current (AC) across the materials causes them to oscillate at very high frequencies, thus producing very high frequency sound waves. For good examples of piezoelectric material, **Lead** (from Latin: **plumbum**) **Zirconate Titanate** – more commonly known as PZT – crystals. PZT is an inorganic compound with the chemical formula Pb $[Zr_xTi_{1-x}]$ O_3 $0 \le x \le 1$) that shows a marked piezoelectric effect, which finds practical applications in the area of electro-ceramics. PZT is a white solid that is insoluble in all solvents. PZT crystals are the most widely-used piezoelectric material used for energy harvesting. PZT will generate measurable piezoelectricity when their static structure is deformed by about 0.1% of the original dimension. Conversely, those same crystals will change about 0.1% of their static dimension when an external electric field is applied to the material. A key advantage of PZT materials is that they can be optimized to suit specific applications through their ability to be manufactured in any shape or size. Moreover, PZT materials characterized by their ability to resilient, and resistance to high temperatures and various air pressures and chemically inert.

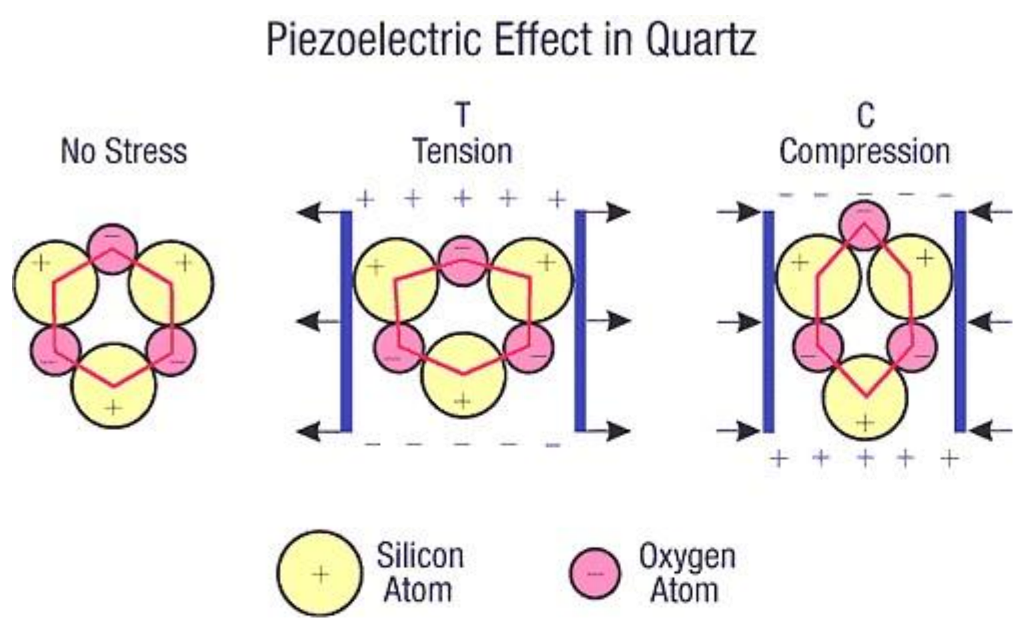

Figure 2: A piezoelectric disk generates a voltage when deformed (change in shape is greatly exaggerated) Quartz (SiO_2): Effect of deformation on charge distribution.

Quartz is an electrical insulator but have a number of unique physical properties that are very different from that of other solid substances, like plastic, wood, concrete, bone, or glass. For example, may show some interesting behavior when exposed to electric fields or get electrically charged when put under stress. This is one of the most important properties of quartz technically and it has many applications. This property can be found in certain types of crystals, but not in amorphous substances, which reacts differently depending on the direction of external forces which is called **anisotropic**. To explain this, we have to look at individual molecules of crystal that is made up of an ordered repeating pattern of the same atom or molecule. Each molecule is polarized since one end is more negatively charged and the other end is positively charged, and is called a dipole as a result of the atoms that make up the molecule and the way the molecules are shaped.

2.6 Piezoelectric Effect

The piezoelectric effect is the ability of certain non-conducting materials, such as quartz crystals and ceramics, to generate electric current when they are exposed to mechanical stress (such as pressure or vibration). It also works in the opposite direction, mechanical deformation slightly (the substance shrinks or expands) may be produced or the generation of vibrations in such materials when subjected to an AC voltage, or both. This vibration or oscillation caused by applied AC transmitted as ultrasonic waves into the surrounding medium. The piezoelectric crystal, therefore, serves as a transducer, which converts electrical energy into mechanical energy and vice versa.

The piezoelectric effect occurs only in crystals with a special crystal structure which they **lack** of **center** of **symmetry**. All piezoelectric classes lack a center of symmetry. Under an applied force the centers of mass for positive and negative ions are shifted which results in a net dipole moment. When the force is along a different direction, there may not be a resulting net dipole moment in that direction though there may be a net dipole moment along a different direction. In the **absence** of an **applied force**, the **center** of **mass** of the **positive** ions **coincides** with that of the **negative ions** and there is no resulting dipole moment or polarization.

In summary

Ultrasound waves are generated by **piezoelectric crystals**. Piezoelectric means "pressure electric" effect. When electric current applied on quartz crystal produces a mechanical deformation of the shape and change polarity. Thus, applying an alternating current (AC) across the materials causes expansion and contraction that in turn leads to the production of compression and rarefaction of sound waves. It also works in the opposite direction; an electrical current is generated on exposure to returning echoes that are processed to generate a display. Hence the **piezoelectric crystals** are both transmitter (small proportion of the time) and receiver (most of the time). It is known that many materials have **piezoelectric** effect (e.g., topaz, cane sugar, Rochelle salt, and bone) and the frequency of the generated wave is a specific feature of the crystal used.

2.7 Detection of Ultrasound

Normally the transmitting and receiving crystals are built into the same hand-held unit, which is called an ultrasonic transducer (generally, a transducer is any device to convert energy from one form to another, usually to or from electrical energy. May come to mind a question what is the material used by doctors and placed on the skin prior to the examination:

Ultrasound gel is a type of conductive medium that is used in ultrasound diagnostic techniques and treatment therapies. It is placed on the patient’s skin at the beginning of the ultrasound examination or therapy. The transducer, which is the device used to send and receive sound waves, is then placed on top of it. Ultrasound gel is also used with a fetal Doppler, which can be employed to allow parents and doctors to listen to the heart beat of an unborn child.

Many doctors, hospitals, clinics, and other facilities use ultrasound technology for diagnostic purposes. It works by passing sound waves into a person’s body. Once there, they don’t remain for long. Instead, they bounce off the organ or other part of the body the doctors are trying to view. The sound waves then move back through the transducer, and they are ultimately analyzed by a computer, which allows the analyzed sound waves to be viewed on a monitor or even printed out for doctor or patient use.