University Of Technology- Iraq
Department of Materials Engineering
General Materials Branch
Fourth class

Smart Materials

Lecture 8 : Piezoelectric Materials

Class Code on Google Classroom :2shhens

Piezoelectric Effect

- Discovered in 1880 by French physicists **Jacques** and Pierre Curie in quartz crystals.
- The word originates from the greek word “piezein”, which means “to press”.
- If certain crystals were subjected to mechanical strain, they became electrically polarized and the degree of polarization was proportional to the applied strain.
- Examples -- Quartz, Barium titanate, tourmaline e.t.c.

Piezoelectric Effect

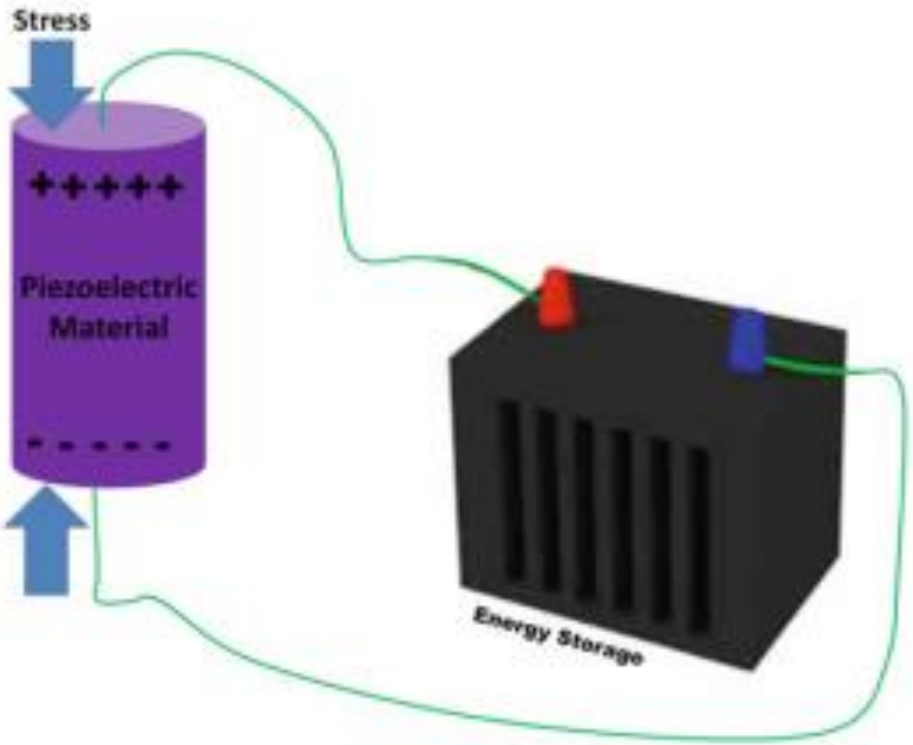


Fig. 2.3 Energy storage by piezoelectric material by stress

Mechanism and Working of Piezoelectric Effect

- elastic compliance, s, is the strain produced in a piezoelectric material per unit of stress applied and, for the 11 and 33 directions, is the reciprocal of the modulus of elasticity (Young's modulus, Y).
- sD is the compliance under a constant electric displacement;
- sE is the compliance under a constant electric field.
- The first subscript indicates the direction of strain, the second is the direction of stress

Types Of Piezoelectricity

- Piezoelectric behaviour can be manifested in
- *two* distinct ways-
- 1. ‘Direct’ piezoelectric effect
- 2. ‘Converse’ piezoelectric effect

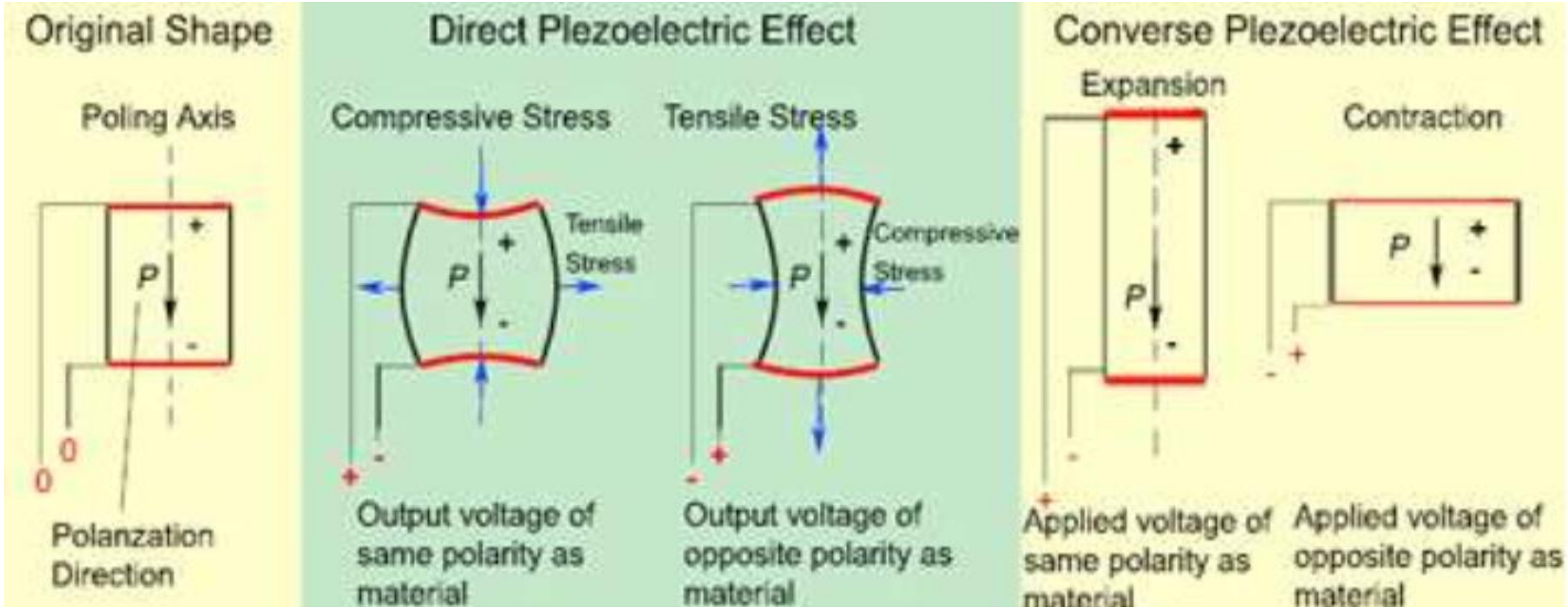
Direct piezoelectric effect

- The electrical response to mechanical stimulation is called the direct piezoelectric effect.
- The devices based on this effect can be used to detect strain, movement, force, pressure or vibration by developing appropriate electrical responses, as in the case of force and acoustic or ultrasonic sensors.

Converse Piezoelectric Effect

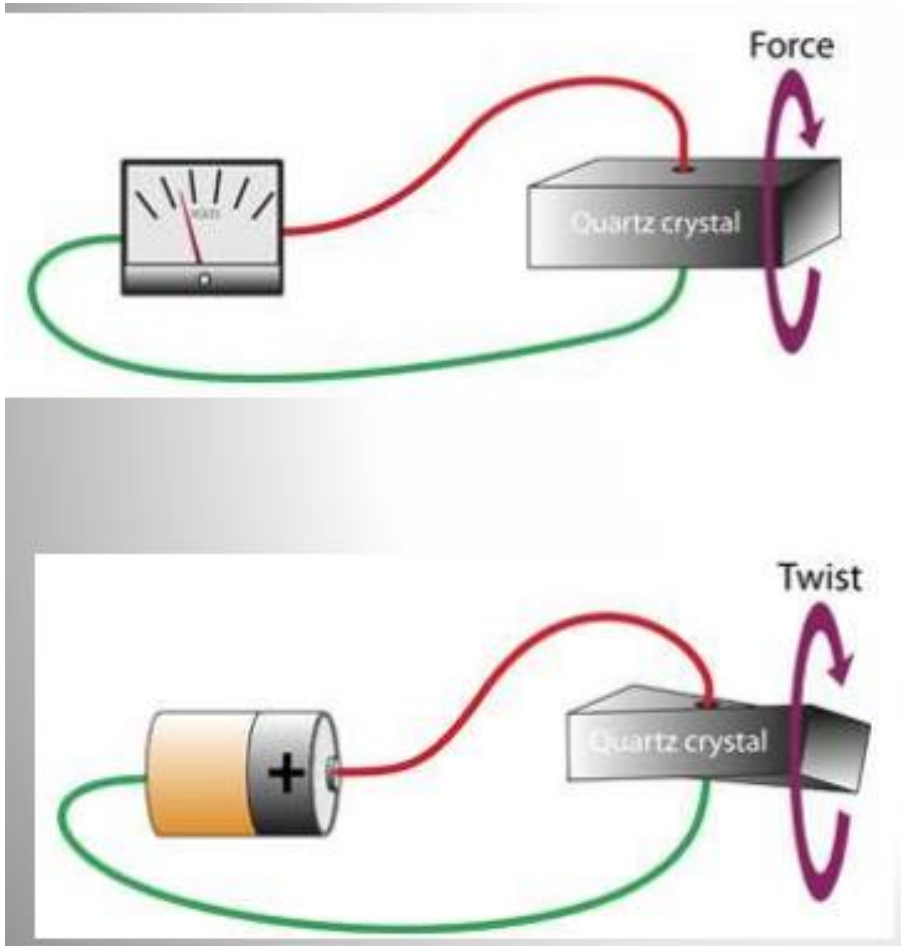
- The mechanical response to electrical stimulation is called the converse piezoelectric effect i.e. when the piezoelectric material placed in an electric field they becomes strained.
- This property can be used to generate strain, movement, force, pressure or vibration through the application of suitable electric field on piezoelectric material

Types Of Piezoelectricity



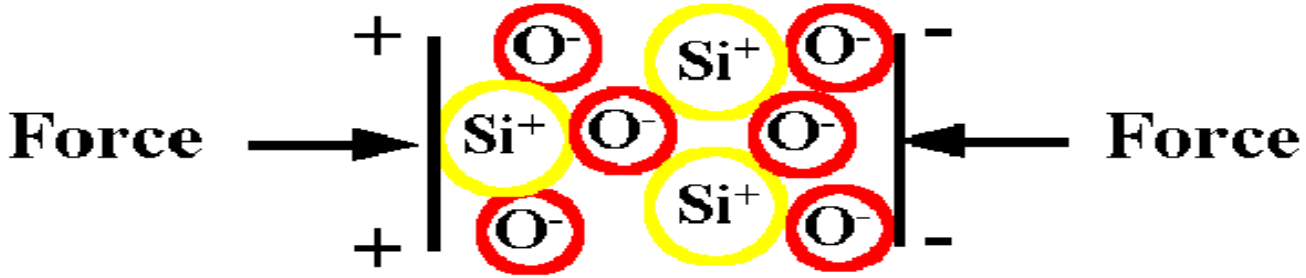
Piezoelectricity

- Piezoelectricity is the ability of certain materials (piezoelectric materials) to produce a voltage when subjected to mechanical stress.
- Piezoelectric materials also show the opposite effect, where application of an electrical field creates mechanical stress (size modification) in the crystal.



INTERNAL WORKING

- The effect is explained by the displacement of ions in crystals that have a nonsymmetrical unit cell.
- When the crystal is compressed, the ions in each unit cell are displaced, causing the electric polarization of the unit cell.



- Because of the regularity of crystalline structure, these effects accumulate, causing the appearance of an electric potential difference between certain faces of the crystal.
- When an external electric field is applied to the crystal, the ions in each unit cell are displaced by electrostatic forces, resulting in the mechanical deformation of the whole crystal.

Piezoelectric Material

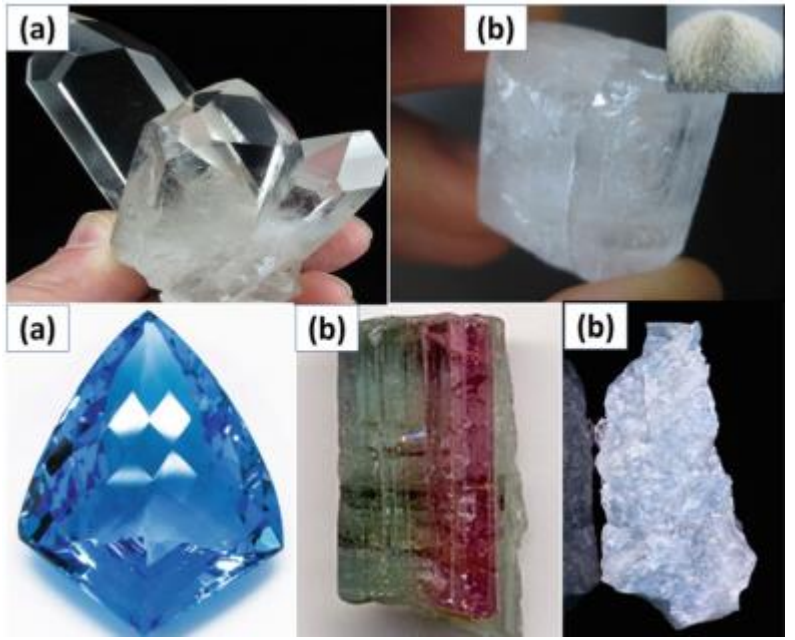
- To exhibit piezoelectricity two main necessary conditions are -
- 1. Crystal should have Ionic or partially Ionic bonds.
- 2. Its structure should have no centre of symmetry.
- Piezoelectric materials are usually divided into two groups

I. Hard Piezoelectric Materials

II. Soft Piezoelectric Materials

- The antonyms “hard” and “soft” doped piezoelectric materials refer to the ferroelectric properties, i.e. the mobility of the dipoles or domains and hence also to the polarization/depolarization behaviour.

Some naturally occurring crystals



1. Quartz
2. Sucrose (table sugar)
3. Tourmaline-group minerals
4. Rochelle salt
5. Berlinite ($AlPO_4$), a rare phosphate mineral that is structurally identical to quartz
6. Topaz
7. Lead titanate ($PbTiO_3$). Although it occurs in nature as mineral macedonite, it is synthesized for research and applications.

Some synthetic crystals

1. Barium titanate ($BaTiO_3$)—Barium titanate was the *first piezoelectric ceramic* discovered.
2. Lead zirconate titanate ($Pb[Zr_xTi_{1-x}]O_3$, $0 \leq x \leq 1$)—more commonly known as ***PZT***, *the most common piezoelectric ceramic in use today.*
3. Gallium orthophosphate ($GaPO_4$)
4. Langasite ($La_3Ga_5SiO_{14}$)
5. Potassium niobate ($KNbO_3$)
6. Lithium niobate ($LiNbO_3$)

Some synthetic crystals

7. Lithium tantalate ($LiTaO_3$)
8. Sodium tungstate (Na_2WO_3)
9. $Ba_2NaNb_5O_5$
10. $Pb_2KNb_5O_{15}$
11. Zinc oxide (ZnO) , Ceramics and Polycrystalline thin film.

Biological materials exhibiting piezoelectric properties include

1. Tendon
2. Silk
3. Wood (due to piezoelectric texture)
4. Enamel
5. Dentin
6. DNA
7. Dry Bone
8. Viral proteins, including those from bacteriophage.

Principles of Application

- **1. Energy Conversion Mechanism -** An externally applied electric field causes a change in the dielectric polarization in the material which in turn causes an elastic strain. The generating action takes place when an elastic strain causes a change in the polarization that induces a charge on the electrodes.
- **2. Transducer Operating Environment -** The acoustic properties of the medium (air, water or ice) are very important in the design of transducers. Transducers must also withstand the severe effects of sea water, biological activity, hydrostatic pressure, and extreme temperature conditions.

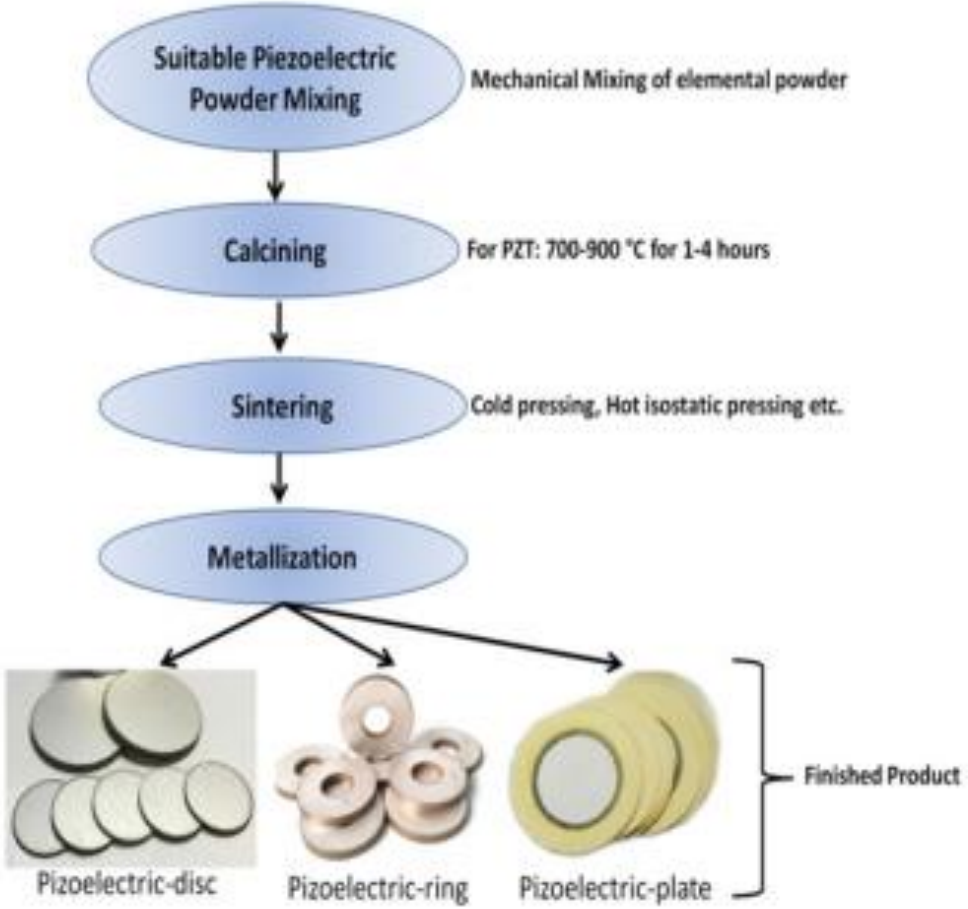
Piezoelectric Material Parameters

1. Temperature
2. Accuracy/Linearity
3. Resolution
4. Stiffness
5. Resonant Frequency
6. Mechanical Amplification

Piezoelectric Material Parameter

7. Quality Factor
8. Bandwidth
9. Frequency Constant
10. Humidity
11. Load Ratings

Manufacturing of Piezoelectric Components



- Piezoelectric components are used in wide variety of applications. According to the application, piezoelectric structural materials are manufactured as

1. bulk ceramics: disks, rings, plates;
2. benders: unimorphs and bimorphsactuators and sensors; multilayer actuators and multilayer benders;

- thin films for piezo-MEMS.

Commercially, the focus will be on PZT based ceramics

Application Of Piezoelectric Material

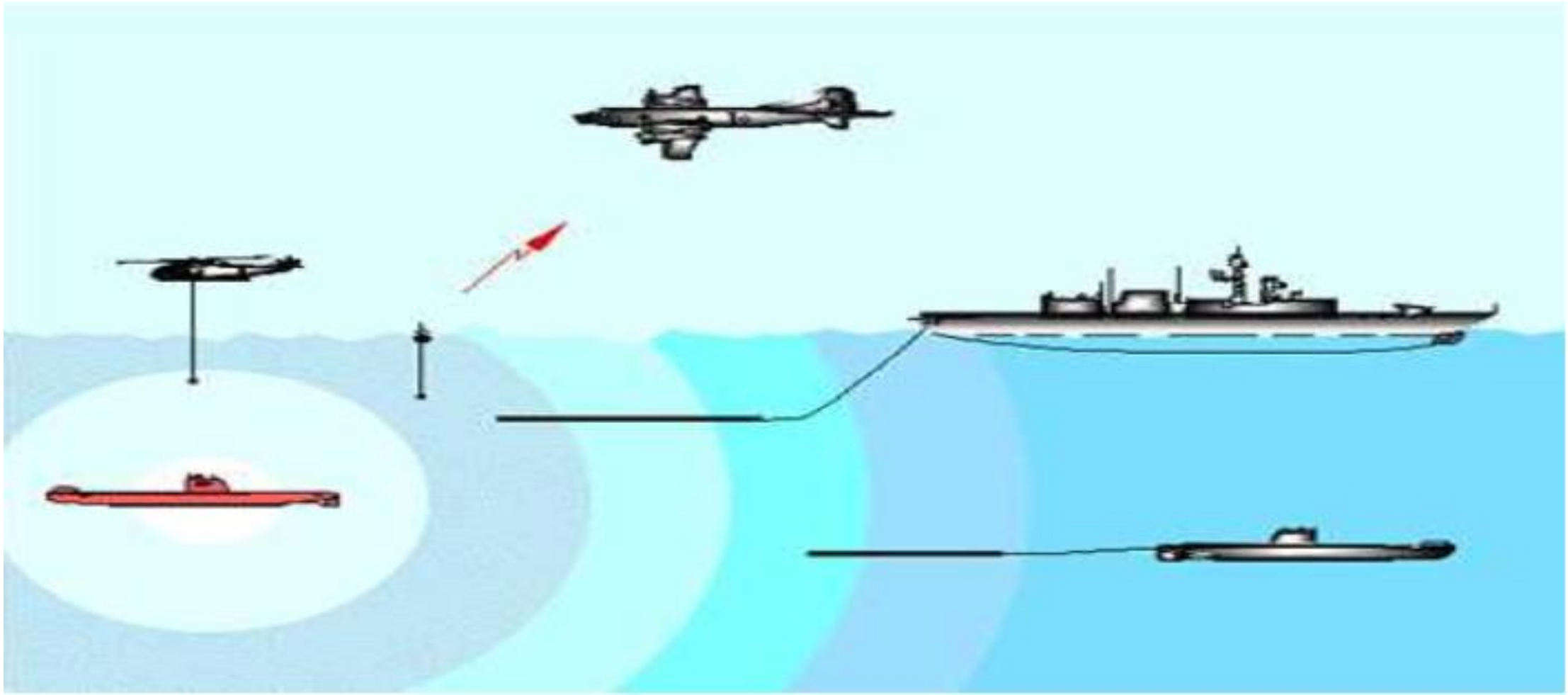
Mechanical to Electrical Conversion

- 1. Phonograph cartridges
- 2. Microphones
- 3. Vibration sensors
- 4. Accelerometers
- 5. Photoflash actuators
- 6. Gas igniters
- 7. Fuses

Electrical to Mechanical Conversion

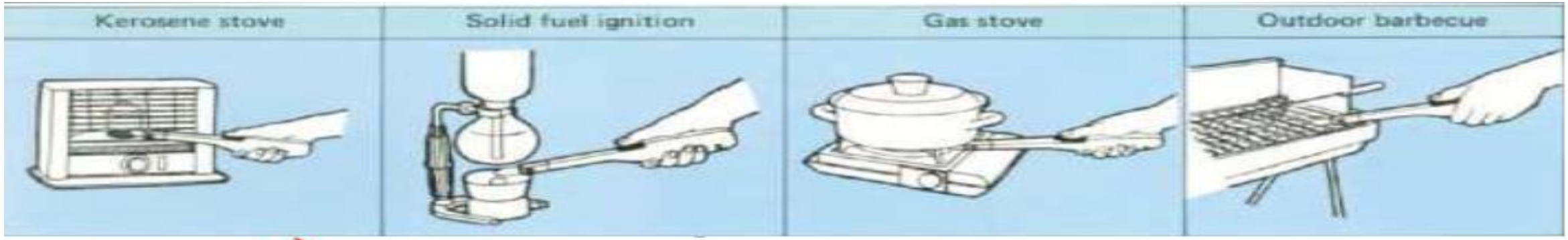
- 1. Valves
- 2. Micropumps
- 3. Earphones and speakers
- 4. Ultrasonic cleaners
- 5. Emulsifiers
- 6. Sonic transducers

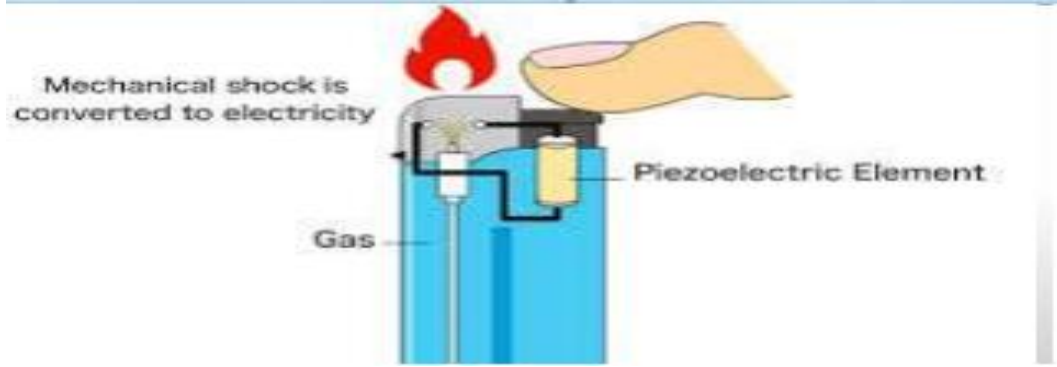
Sonar was First practical application of Piezoelectric devices used during WORLD WAR 2 in 1940

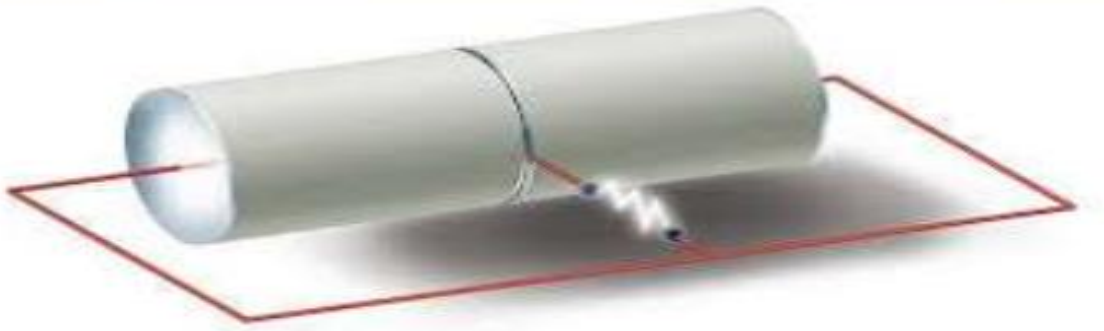


Daily use of piezoelectric device

- **Piezoelectric Igniters -** Commercially, most common use is as gas lighters. These are capable of producing a spark.

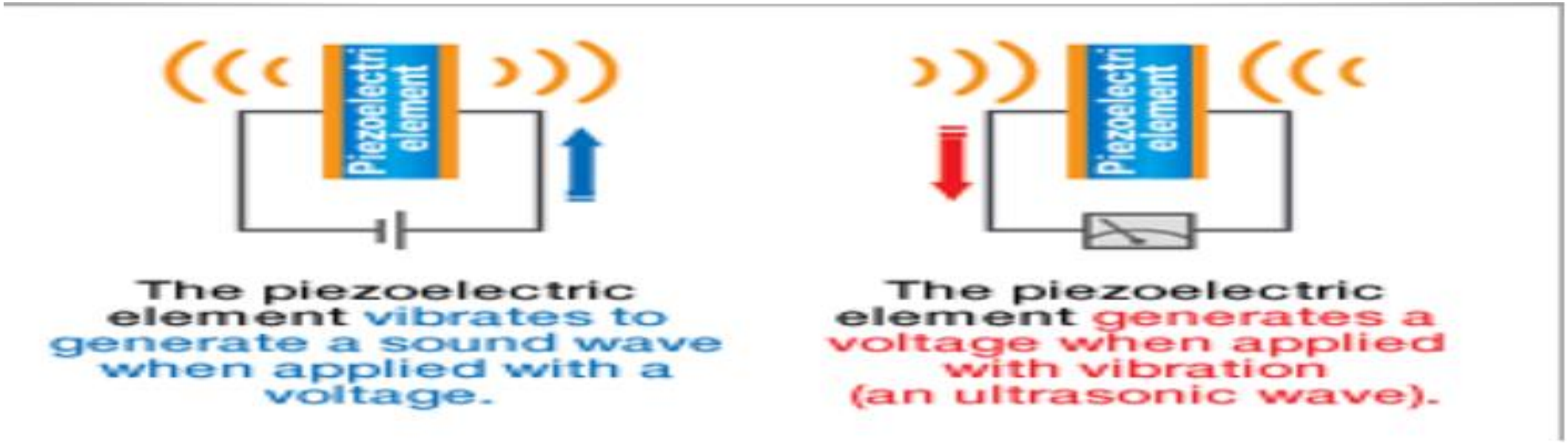






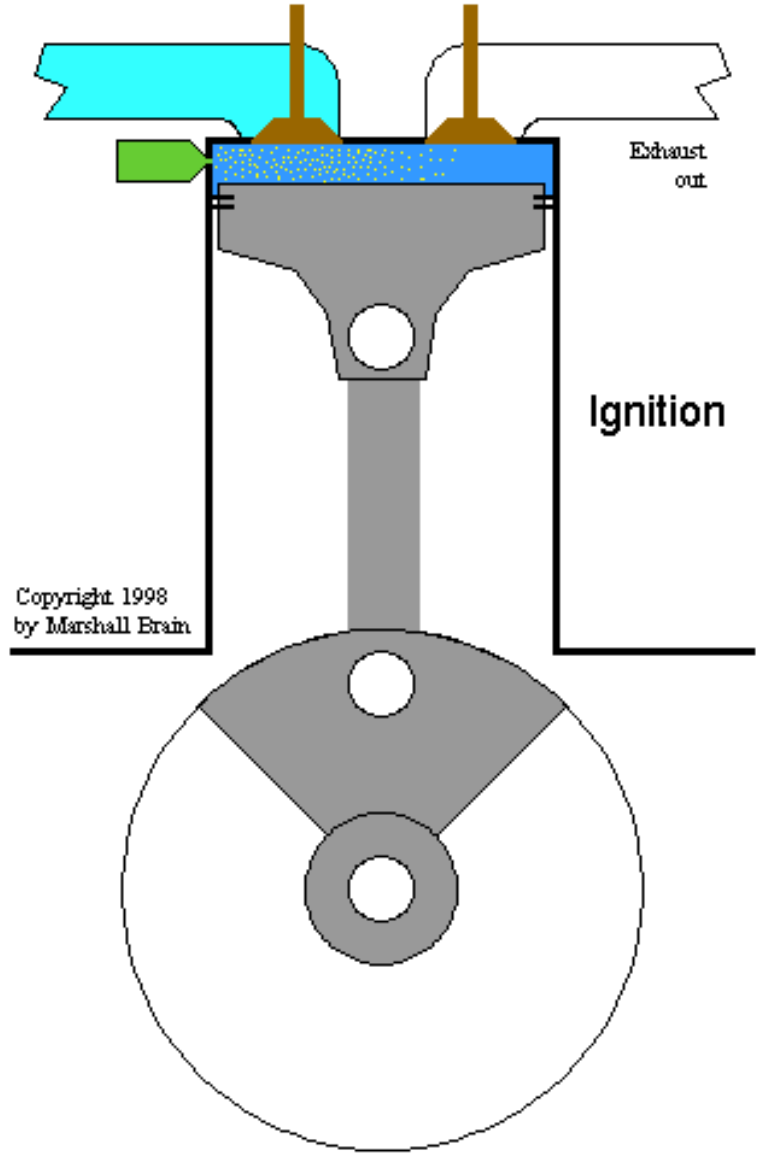
Medical Application

- Industrially, piezoelectric devices are mainly used for imaging, mostly in medicine. They are used to produce ultrasound, which is used to check on unborn babies. In a non-medicinal manner, it can be used to detect cracks.



Typical Application-Combustion Monitoring

- Pressures developed during the combustion process is continuously measured by sensors mounted on the cylinder heads.
- Continuous Pressure monitor(CPM) systems are the basic data acquisition and data reduction software and hardware units.



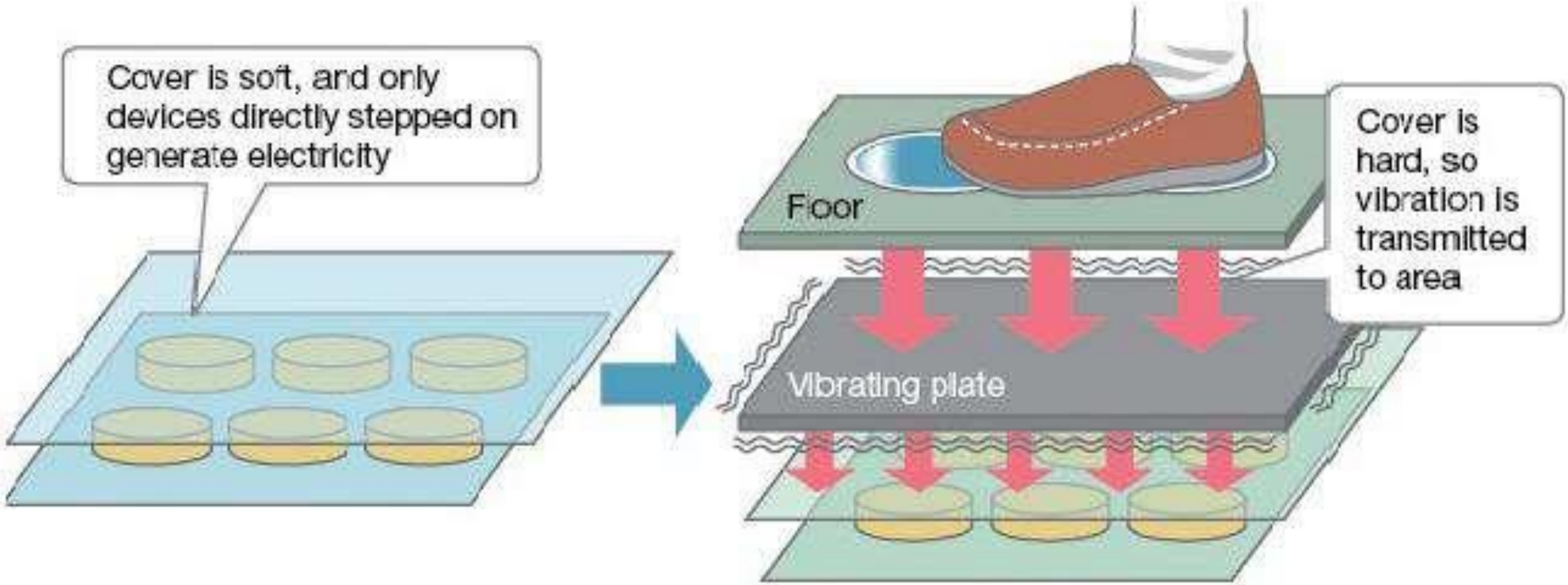
Recent Advances of Piezoelectric Material in Medical

- recent application of piezoelectric ultrasound sources is piezoelectric surgery, also known as piezosurgery.
- Piezosurgery is a minimally invasive technique that aims to cut a target tissue with little damage to neighboring tissues.
- For example -*its used in* hand surgery for the cutting of bone, using frequencies in the range 25–29 kHz, causing microvibrations of 60–210 µm.
- It has the ability to cut mineralized tissue without cutting neurovascular tissue and other soft tissue, thereby maintaining a blood-free operating area, better visibility and greater precision.

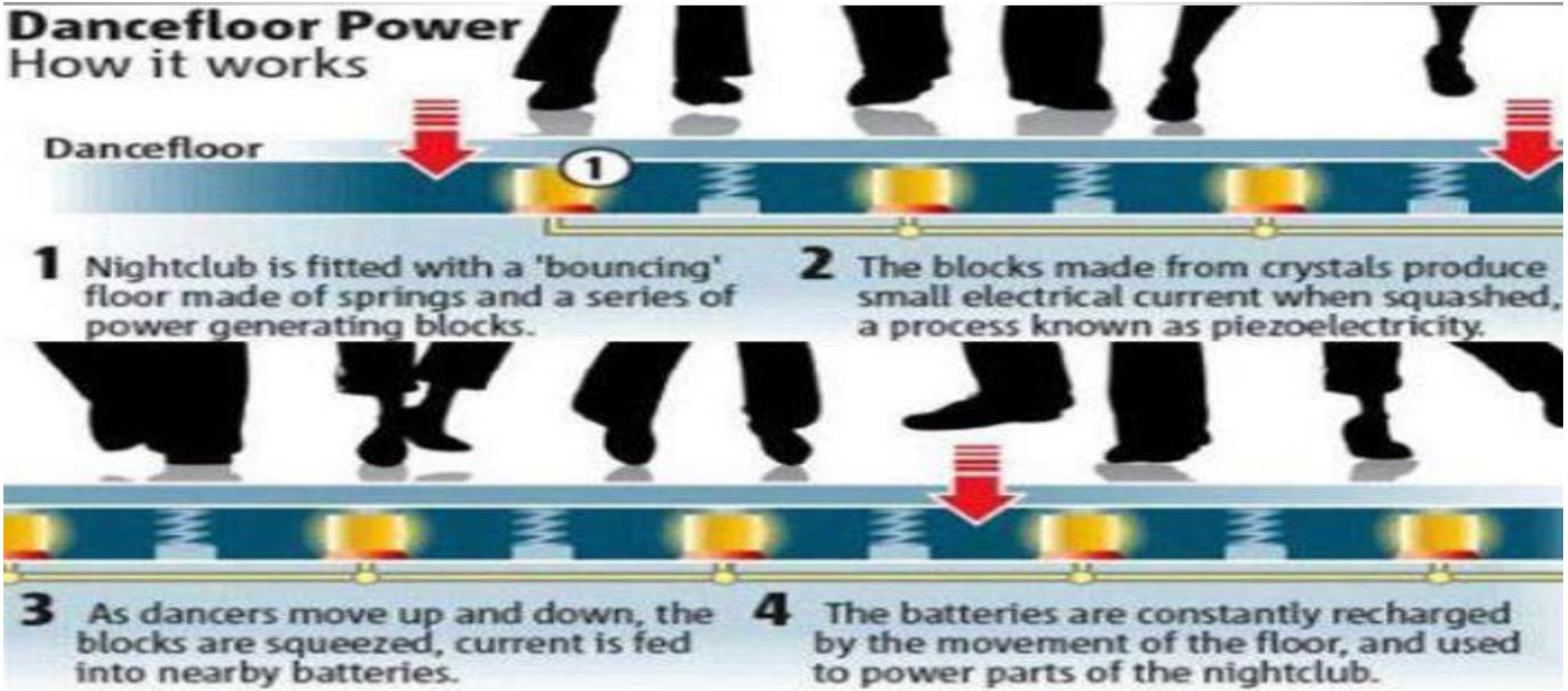
HARVESTING ENERGY FROM HUMANS (*Present use of technology*)

- With the increase in energy consumption due to ever growing number of electronic devices, the concept of harvesting renewable energy in human surrounding arouses a renewed interest.
- Piezoelectric effect can be used to generate electricity using such body energies to run smaller gadgets which consume less power. With further advancement in field of electronics, better synthesized piezoelectric crystals and better selection of place of installations, more electricity can be generated and it can be viewed as a next promising source of generating electricity

Special flooring tiles with piezoelectric crystals to generate electricity



Dance floors with piezoelectric crystals installed to produce electricity



Specially designed road which generates electricity