An Introduction to Piezoelectric Materials and Components

Published by:

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The cover picture on the front shows a schematic representation of the perovskite structure.

The cover picture on the back shows various typical piezoelectric components and products as well as a ‘piezoelectric active lens mount’ used for active vibration control in microlithography.

This book was written as part of the dissemination activities of the SmartPie research program.
www.smartpie.nl

The SmartPie consortium gratefully acknowledges the support of the Smart Mix Programme of the Dutch Ministry of Economic Affairs and the Ministry of Education, Culture and Science.

First published June 2012

ISBN 978-90-819361-0-1
NUR 971

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1 Introduction

In this chapter, we
- *briefly sketch the history of piezoelectricity;*
- *give a glance of everyday life applications of piezoelectricity;*
- *present the scope of this book.*

1.1 Piezoelectricity in everyday life

Materials always have had a large influence on society. This was obvious in the Stone Age, Bronze Age, and Iron Age. We have named these eras by the most advanced material in that period, since these materials determine and limit the state of technology at the time.

Also in modern society, the influence of materials is still present. However, nowadays the materials as such are not as visible anymore as they used to be. They are more and more embedded in complex devices and high tech systems that make whole economies exist and function in an efficient way.

Piezoelectric materials are among these 'invisible' materials that are widespread around us, although they are unknown to the public at large. Mobile phones, automotive electronics, medical technology, and industrial systems are only a few areas where *piezoelectric components* are indispensable. Echoes to capture the image of an unborn baby in a womb make use of piezoelectricity. Even in a parking sensor at the back of our car, piezoelectric material is present.

piezoelectric materials

piezoelectric components

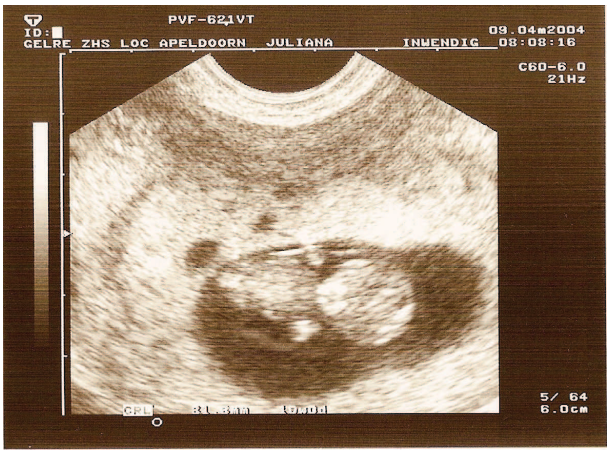

FIGURE 1.1 Echoscopy image of an unborn baby in a womb

1.2 Piezoelectric effect

What's the reason for piezoelectric materials to be applicable so abundantly? Well, its the nature of the material itself: it has the ability to convert mechanical energy into electric energy and vice versa.

direct effect

inverse effect

The *direct* piezoelectric effect is that these materials, when subjected to mechanical stress, generate an electric charge proportional to that stress. The *inverse* piezoelectric effect is that these materials become strained when an electric field is applied, the strain again being proportional to the applied field. Clever use of piezoelectric materials enables the realization of a wide variety of technical functions.

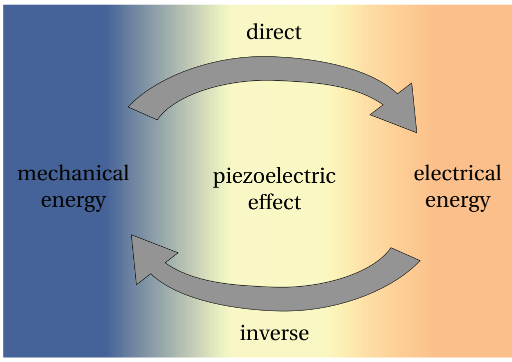

FIGURE 1.2 Piezoelectricity enables conversion from mechanical energy into electric energy and vice versa

1.3 History of piezoelectrics

tourmaline

pyroelectricity

The history of piezoelectricity – as a physical phenomenon to be used intentionally – goes back to the beginning of the 18th century. At that time the Dutch brought a precious stone called tourmaline from the East Indies to Europe. Tourmaline had a peculiar feature: while being heated, the material attracted other materials such as ashes. Almost half a century later the Swedish botanist and physician Carl Linneaus – also famous as developer of biological nomenclature – had a hunch that this phenomenon might have something to do with electricity. And indeed, within a decade, the German physicist Franz Aepinus confirmed that this 'peculiar feature' was electric. This phenomenon was later known as *pyroelectricity*: the ability of a material to generate a temporary voltage when it is being cooled or heated.

Pyroelectricity lead to the discovery of piezoelectricity, which was to a large extent a French affair. When Charles-Augustin de Coulomb assumed that electric charge might be produced by pressure, René-Just Haüy and later also Antoine César Becquerel tried to apply their knowledge of pyroelectricity to perform experiments to investigate Coulomb's assumption. However, they were not very successful.

discovery of piezoelectricity

In 1880 the brothers Pierre and Jacques Curie finally discovered the direct piezoelectric effect, also with pyroelectricity as a basis. They observed that by pressing in a certain direction on crystals of tourmaline, quartz, cane sugar and Rochelle salt (also known as Seignette's salt), these crystals were able to generate charge on certain positions of their surfaces. The German physicist Wilhelm G. Hankel gave this phenomenon the name 'piezoelectricity' – named after the ancient Greek *piezein* that means to press or to squeeze, and *elektron* meaning amber, describing substances that (like amber) attract other substances when rubbed. One year later, the French-Luxembourgian physicist Gabriel Lippmann predicted the inverse piezoelectric effect, which was experimentally verified by the Curie brothers in that same year.

etymology of 'piezoelectricity'

Practical applications

So far the 'founding fathers' and the scientific history. This interesting phenomenon of materials that can convert mechanical energy into electric energy – and vice versa – cried out for practical applications. And they came. During World War I, in 1917 Paul Langevin developed the predecessor of sonar, a device to detect other objects under water. He managed to make a quartz-based transducer to send ultrasonic waves, and a receiver to detect the returning echo. By measuring the time span between the emitted wave and the wave that returned after bouncing off an object, a submarine should be able to determine the distance to that object. To date, sonar is still a major application of piezo technology, were modern (ceramic) materials are being used.

sonar

quartz

Sonar as a successful application of a piezoelectric material stimulated others to discover new piezoelectric materials and to develop new devices. An eye-catching example is the use of Rochelle salt as a single crystal needle in the pick-up part of early electronic phonographs, starting in 1935. Around 1950 Rochelle salt was replaced by piezoelectric ceramics , and in turn they were replaced by magnetic cartridges in the 1970's. It took about ten years before compact disk players massively replaced phonographs.

piezoelectric ceramics

The second World War had a large influence on the development of new piezoelectric materials. Independent from each other – due to World War II – Japanese, Russian and American research groups discovered the so-called ferroelectrics, a new kind of man-made materials with much better piezoelectric properties than their natural counterparts. Barium titanate ceramics were the first materials in this

ferroelectrics

barium titanate

FIGURE 1.3 Quartz crystal