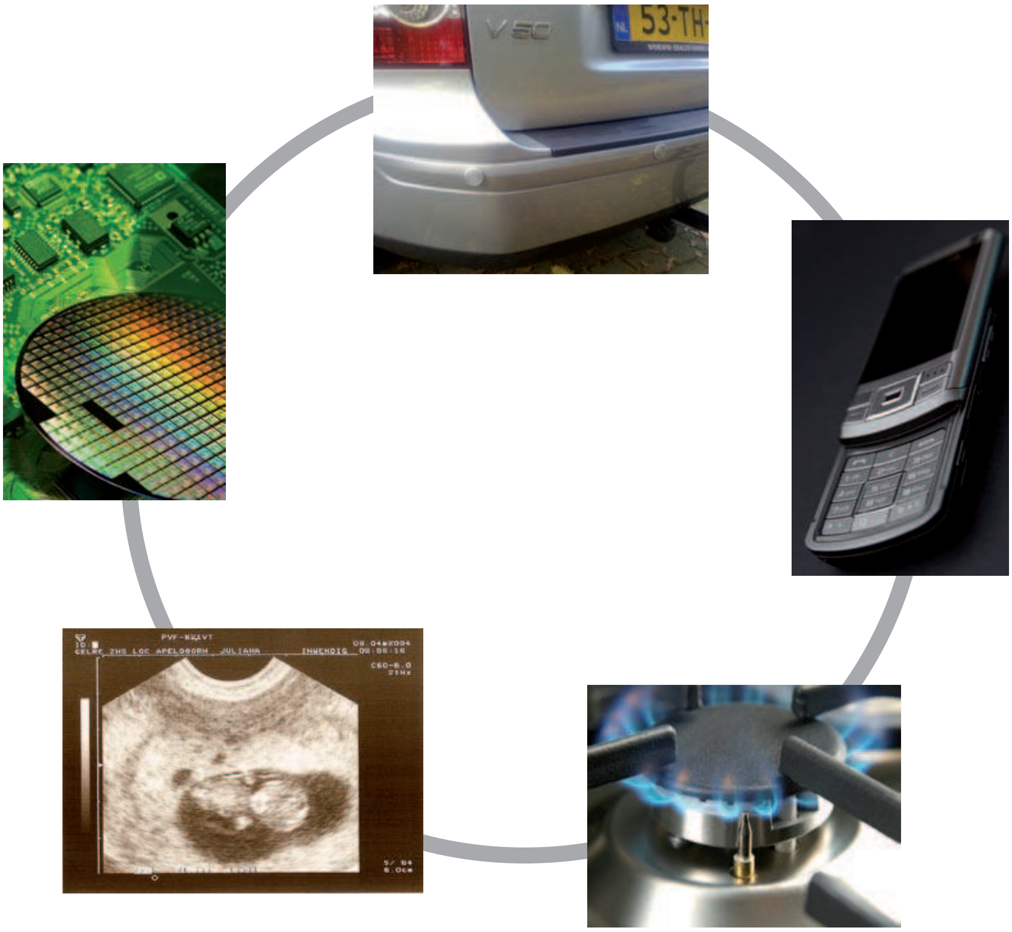
applied PIEZO

The hidden use of piezo technology in applications all around us



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The hidden use of piezo technology in applications all around us

Stichting Applied Piezo

Contents

This book gives you an insight in the ubiquitous use of piezo technology. Through everyday examples we show you that often without realising, you make use of piezo technology several times each day. This is what we call "the hidden use of piezo technology in applications all around us".

Applied Piezo and its affiliated organisations are working on new piezo technology and applications everyday. With this book we hope to give you an insight in the contribution of our work on modern day society. We hope that you may benefit from our work and enjoy this book.

Jan Peters, Chairman Applied Piezo

Piezoelectric materials have the capability to convert electrical energy into mechanical energy, and vice versa.

Introduction - piezo in a nutshell

Materials have always had a large influence on society. This was obvious in the Stone Age, Bronze Age or 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 ‘piezo’ is indispensable. Echos to capture the image of an unborn baby in a womb make use of piezo. Even in a parking sensor at the back of our car piezo is present.

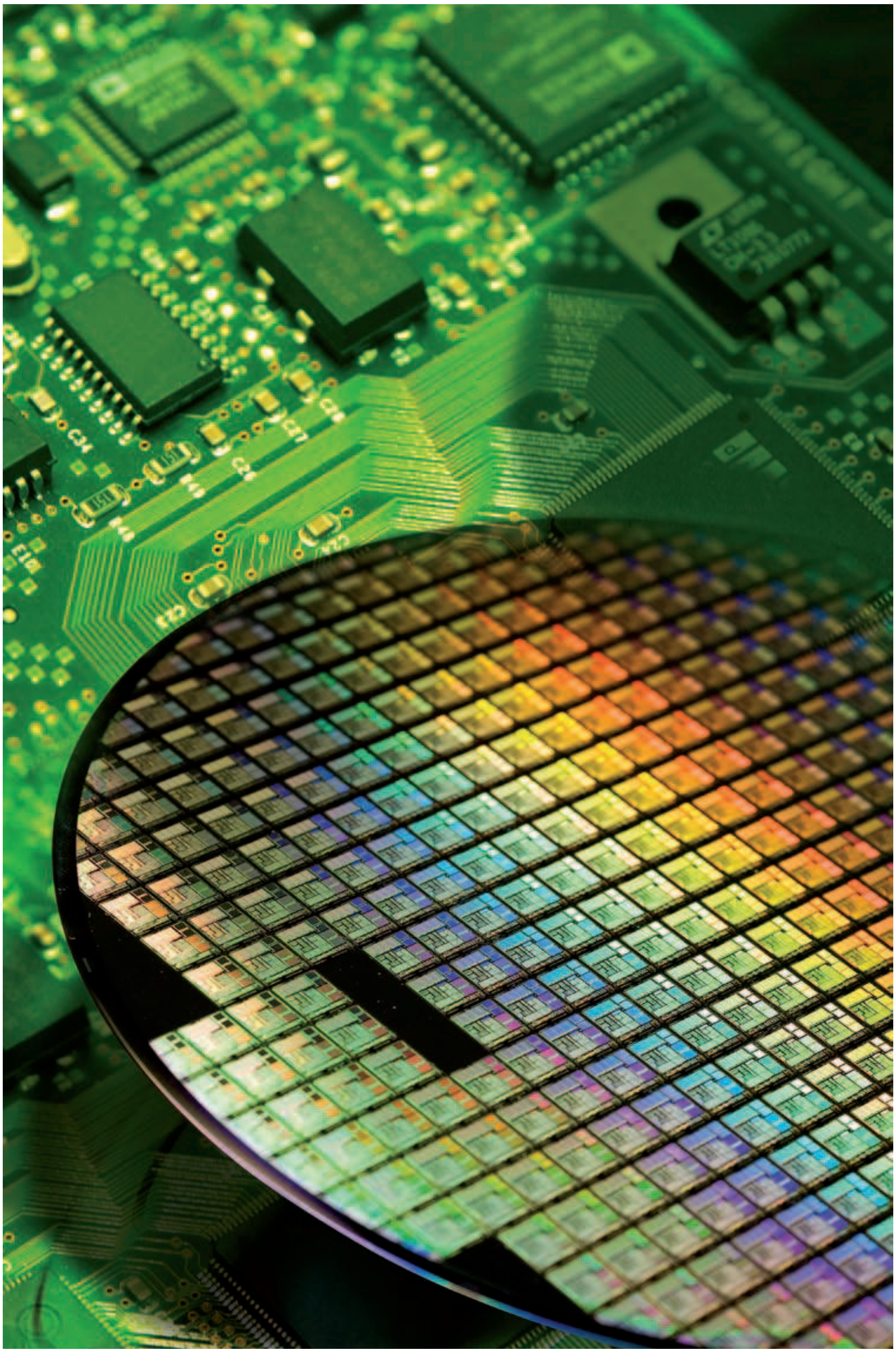
What makes ‘piezo’ a phenomenon that can be applied so abundantly? Well, it is the nature of the material itself: it has the capability to change shape - for example become shorter or wider - by applying an electric voltage over it. This change in shape is not very big - generally in the micron range - but it occurs very fast, within milliseconds. Furthermore it is highly reproducible, and accurate in the nanometer range. Piezo also works the other way around: compressing or otherwise deforming the material generates an electric charge. So the piezo material is a smart system in itself.

Piezo stems from the ancient Greek πιέζειν (piezein), which means ‘to press’ or ‘to squeeze’.

Piezoelectric actuators - devices that convert an electrical signal into an 'action' such as a physical displacement - play an important role in high tech systems, and also in high tech manufacturing technology. As do piezoelectric sensors - devices that convert a mechanical action into an electrical signal.

Due to the fact that piezoelectric materials are able to change in size very accurately, they can be found in various applications. Not only in inkjet printers, but also in loudspeakers, for example. Furthermore, since piezoelectric materials can position objects in an extremely accurate way, they are applied in scanning tunneling microscopes (STM) to keep the needle close to the sample, or in wafer steppers for making integrated circuits (ICs).

This book 'Applied Piezo' shows the huge variety of applications that rely on piezoelectricity. Maybe they will inspire you to use piezo materials in your own line of work. Have fun reading this book!



Piezo motors for lens positioning

As has been shown in the previous pages, piezo actuators and motors are being used to keep the lens in a wafer stepper in precisely the right place to print an IC pattern on a silicon wafer. However, piezo motors are also used in a comparable but more accessible application: to zoom or focus the lenses of the camera in your own mobile phone.

Traditional electric motors convert electrical energy into mechanical energy via the movement of a rotor in a magnetic field. Piezo motors make this energy conversion in another way using the inverse piezo-electric effect, where the ultrasonic vibrations of the piezo material generate a rotary or linear motion. Whereas traditional electric motors consist of many moving parts, their less complex piezo counterparts are composed of only a few parts.

In a piezo version of a stepper motor, piezo elements change shape in the same way that a caterpillar moves when walking on a branch of a tree. In fact, the branch is in this example a slider - a rod or a plate - that is pushed away by the repeatedly shrinking or stretching piezo elements, resulting in a linear motion.

A different type of linear piezo motor consists of piezo elements that are connected to an internally threaded nut. Inside this nut a screw is placed that can move back and forth when the piezo elements change shape by ultrasonic vibrations, and convert rotary motion into linear motion.

Surface acoustic wave (SAW) motion forms another basis for piezo-electric motors. At the surface of a piezo element travelling waves are being generated, and a slider on top of these waves can be moved in a certain direction, just like a surfboard on a sea wave.

A piezo motor can be considered as a highly accurate replacement for the traditional stepper motor due to the displacement accuracy in the nanometer range and response time that is less than a microsecond.

Other applications where piezo motors are used

Piezoelectric motors are also applied in precision manufacturing for machining, milling and grinding on a micro scale. Electron microscopes use piezo motors to position samples without generating an interfering magnetic field as traditional electric motors do. In medical technology piezo motors are used in robotic surgery.

The future of piezo

Lead-free piezo ceramics

Lead-zirconate-titanate or PZT is to date the most common piezoelectric material. The European Restriction of Hazardous Substances Directive or RoHS restricts the use of lead in the manufacture of various types of electronic and electrical equipment. However, this Directive makes an exception for PZT, as no useful alternatives are available yet. Are there any compounds that might replace PZT in the future? Investigations are in progress in this field.

In 2004 a Japanese research group compared the piezoelectric properties of a newly discovered sodium-potassium-niobate composition with the properties of PZT. Although the properties of this niobate composition are close to those of PZT, it seems that the occurrence of lithium, sodium and potassium in the composition is a disadvantage with respect to manufacturing. Furthermore, it is still uncertain what high poling voltages will do with the material, and how stable the material will be in the long run. In 2009 an American research group claimed that a comparable material, $(K_{0.5}Na_{0.5})_{0.97}Li_{0.03}(Nb_{0.9}Ta_{0.1})O_3$, may be suitable for high-frequency ultrasonic transducer applications. Recently, in 2010, English researchers claim that a potassium-sodium-bismuth-titanate composition is useful as a piezoelectric ceramic material.

At the moment there is no positive confirmation on the long-term stability of these compositions. However, one day one of these compositions might be just as successful in piezoelectric applications as PZT is now.

As we have seen in the previous pages, piezoelectric materials are present - and indispensable - in a lot of applications nowadays. But how about the future?

Piezo and MEMS

An intrinsic shortcoming of piezoelectric devices is due to the (brittle) ceramic nature of the piezo material itself, and on the technology that is required to make these devices. So in order to make a big step in piezo device performance it seems highly attractive to combine silicon technology for making integrated circuits with piezo technology. For example by using novel laser-based deposition techniques for locally depositing piezo films. In this way MEMS - micro electro mechanical systems - can be created with exceptional functionality in a single device.

By combining silicon and piezo technology we will get the best of both worlds. The integration of piezo in MEMS makes very small devices possible that have electronic, mechanical and chemical components, but that communicate now by sensing and actuating with the surroundings.

Composite sensors for airplanes

For many aerospace applications current piezoelectric materials have inadequate properties to be used as a reliable sensor. Transducers for vibration sensing and damping, acceleration sensors, sensors for impact detection of hail and birds, and sensors for non-destructive testing of fibre breakage in fibre-reinforced plastics in airplanes should meet certain demands. For these applications, current PZT materials are not ductile enough, whereas the thermal stability of PVDF is too poor. An ideal material for these applications acts like PZT, but can be shaped with single or double curvatures. As it is hard to combine this in one material, a composite with the desired properties has to be developed.

PZT-polymer composite sensors

Besides ceramic materials such as PZT, there are polymers as polyvinylidene difluoride (PVDF) that exhibit piezoelectric behaviour. Here the intertwined long-chain molecules attract and repel each other when an electric field is applied. Due to the structure of the polymer, such polymeric piezo materials have high flexibility and excellent ductility, but rather low sensitivity and temperature stability. Being a polymer, they can easily be shaped into films or 3D structures.

The properties of *ceramic* piezo materials are completely different: they have high stiffness and are brittle, they have a high sensitivity and can be used up to high temperatures. Because of their ceramic nature, they can not easily be formed into films or complex shapes.

An obvious and potentially interesting compromise can be reached by making a composite consisting of a polymer matrix and PZT particles. Earlier attempts to make such composites yielded rather poor results as the poling and the piezo-actuation and sensing efficiencies are rather low. It can be shown that the poor properties are not due to processing but follow directly from physical models. Only at rather high loading fractions of 40 % and higher the PZT-polymer composites have adequate sensorial sensitivity. For such high loading fractions the material becomes rather brittle and hard to process and most of the advantages of a composite are gone. Hence, only a few experimental applications consist in which PZT-polymer composites are used in devices such as impact sensors and simple switches.

Very recently, research in the Netherlands in the context of the Smart-Pie research program resulted in a breakthrough as scientists discovered a route to align the PZT particles as 'chains' within the polymer matrix during curing. By this alignment, suddenly the material has quite good sensorial properties even at a low PZT loading fraction of about 15 %. Now, the material combines the desired properties of high flexibility, good sensorial behaviour, easy processing and most importantly a potentially low cost price. At this moment research focuses on both the optimisation of the polymer chemistry and PZT alignment, and industrial trials are expected. The new polymer composites have great potential not only as sensor materials, but also as energy harvesting films in tyres.

SmartPie

SmartPie is a scientific research program on piezo technology. SmartPie is an acronym for "**SMART** systems based on integrated **PIE**zo". The aim of the SMARTPIE research is to strengthen the innovative position and perception of the Dutch high tech industry by providing it with new piezo-based technology. The research will provide new piezo materials and applications, in order to accomplish a total paradigm shift in the type of base technologies being used. By its very nature the program fits perfectly in the Dutch national focal area for innovation, i.e. High Tech Systems and Materials.

Website: www.smartpie.nl

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

Stichting Applied Piezo

The Stichting (Foundation) Applied Piezo is a group of cooperating industrial companies with supplemental expertise in the field of piezo technology. They offer "one stop shopping" for piezo applications. Applied Piezo facilitates the access of industry to utilization of piezo technology. Applied Piezo will help you evaluate and benefit from the advantages of piezo technology and support you from idea to production. There is a close relation with universities and several (international) organisations that are active in the field of piezo technology.

The aim of Applied Piezo is to define and execute new projects together, to promote piezo technology, to stimulate knowledge development and innovation and to provide a network where knowledge, expertise and products can be exchanged.

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