A possible paradigm shift within piezoelectricity

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Piezoelectricity is used everywhere: Watches, cars, alarms, headphones, pickups for instruments, electric lighters and gas burners. One of the most common examples is probably the quartz watch, where the piezoelectric material quartz is a prerequisite for the watch's function.

Piezoelectric materials have the particular property that their shape changes when applying an electrical voltage to the material. It also works the other way around: Exposing them to a mechanical impact will create an electrical voltage.

Piezoelectricity is often used in sensors, actuators, and resonators. In small devices, they are known as MEMS (micro-electromechanical systems). Here, materials other than quartz must be used. These materials, however, often contain lead in the form of lead zirconate titanate (PZT).

This may prove to be a barrier to the spread of technology in, for example, the biomedical field, as lead is harmful to the body. However, researchers assess an excellent potential for utilizing the piezoelectric effect in a wider range of diagnostics, prognosis and therapy technologies if lead could be removed.

In a new article in the journal *Science*, Professor Nini Pryds and Professor Vincenzo Esposito from DTU Energy show that it is possible to create piezoelectric effects in materials where this is not ordinarily possible. It paves the way for designing piezoelectric materials that are lead-free and far more environmentally friendly. The research was conducted with colleagues from EPFL (École Polytechnique Fédérale de Lausanne), Tel Aviv University and the University of Antwerp.

More environmentally friendly materials

The work stems from the DTU-coordinated EU project Biowings, where several European partners are researching the development of new biomedical MEMS made with thin, lead-free films based on Gadolinium-doped oxide materials that are non-toxic and environmentally friendly. It is a great challenge, but the potential within, e.g. blood cell sorting, bacterial separation, and estimation of hematocrit levels are high.

"Many micro-electromechanical systems already exist, but they often contain lead-containing materials that are harmful for human implantation. The BioWings project aims to develop biocompatible materials with properties similar to common lead-containing materials that do not contain lead or the other harmful materials," says Nini Pryds, adding:

"The new development will provide a fundamental step towards environmentally friendly piezoelectric materials with high performance for use, e.g. in car technology and medical applications," says Nini Pryds.

As a fundamental premise, piezoelectric materials depend on crystal symmetry. Typical piezoelectric materials have a so-called non-centrosymmetric crystal lattice. This means, for example, that when one presses on the material, an electrical voltage naturally arises across the material due to the movement of positive and negative ions relative to each other. This results in the symmetry of the crystal being broken. For over a century, this has been a significant obstacle to finding new piezoelectric materials because piezoelectricity can only be created with a non-centrosymmetric crystal lattice.

Possible paradigm shift

One of the startling results of the new study is that a sizeable piezoelectric effect can be achieved with materials that do not usually allow it—i.e. centrosymmetric materials. Induction of piezoelectricity in centrosymmetric oxides can be achieved by using alternating current (AC) and direct current (DC) simultaneously. The field leads to the movement of positive and negative ion defects in the material relative to each other resulting in electric dipole or polarization. It breaks the crystal symmetry of the material, thereby achieving piezoelectricity in centrosymmetric crystals.

According to Nini Pryds, this concept will also be possible with other materials with similar atomic defects. It can thus help pave the way for non-lead-based piezoelectricity in, for example, actuators and sensors.

"For the time being, piezoelectric materials are limited to the non-centrosymmetric crystal structure. This entails a significant limitation in the number of materials that may be used. Our new results provide a paradigm shift towards inducing piezoelectricity in centrosymmetric crystals, thereby expanding the number of possible materials used. I expect it will have a significant effect on the design of new electromechanical devices with new biocompatible materials," says Nini Pryds.

More information: D.-S. Park et al, Induced giant piezoelectricity in centrosymmetric oxides, *Science* (2022). DOI: 10.1126/science.abm7497

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