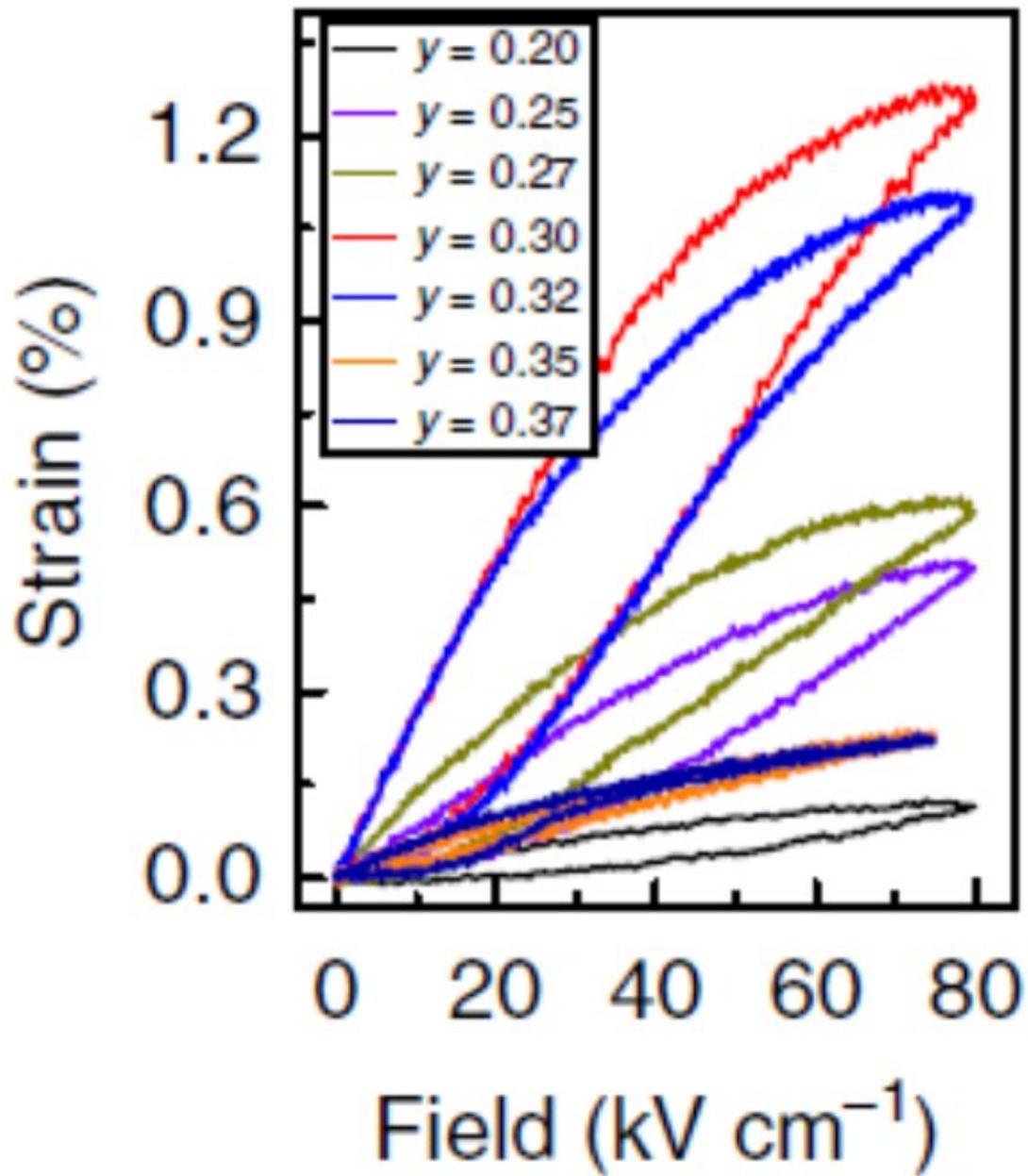


New ceramic material could cut down cost of piezoelectric devices

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$0.55\text{Bi}_{1-y}\text{La}_y\text{FeO}_3-0.45\text{PbTiO}_3$



Credit: Indian Institute of Science

Piezoelectrics are materials that change their shape when an electric field is applied, with wide-ranging applications including printing ink onto paper and precisely moving the tip of a scanning tunnelling microscope. Currently, the most effective piezoelectrics are those in single crystal form, because they have a large electrostrain value (> 1 percent), which is a mark of how much the material can change its shape when the electric field is applied. However, they are very expensive and difficult to manufacture. Ceramic piezoelectrics, made up of multiple tiny crystals, are at least a hundred times cheaper and easy to mass-produce, but they usually have very low electrostrain values.

For the first time, researchers at the Indian institute of Science (IISc) have designed a ceramic material capable of achieving an electrostrain value of 1.3 percent—the highest for a ceramic to date and the closest to the record set by single crystals.

"The process of making ceramics is similar to that of making bricks," says Rajeev Ranjan, Associate Professor, Department of Materials Engineering, IISc, who led the study. "This may allow the actuator and transducer industry the option to choose [materials](#) that are much cheaper than single crystals for high-end applications."

The study was published in *Nature Materials*.

Natural materials such as quartz, when cut as single crystals, can compress or expand automatically when voltage is applied. However, their fabrication is costly and complicated. Since the 1950s, the focus has shifted towards cheaper ferroelectric-based ceramic mixed-metal oxides. These ceramics does not show piezoelectricity in their prepared form, but can be made to by applying a strong voltage.

When an [electric field](#) is applied to a piezoelectric material—crystal or ceramic—it develops a strain, a quality that is measured by how much its

length changes in proportion to its original dimension. The greater the strain that can be induced in the material, the better, especially for applications such as ultrasound generation in medical imaging equipment. The highest value of this electrostrain achieved to date is 1.7 percent in [single crystals](#) of a special type of lead-based materials called relaxor ferroelectrics. So far, researchers have been unable to design ceramics with similar or close electrostrain values.

A ceramic material is generally an assorted mass of tiny, randomly oriented metal oxide crystals called grains. When voltage is applied, local regions called domains within each grain try to orient themselves in the direction of the applied field, prompting the grain to change its shape. The extent to which a grain changes shape depends on an inherent property called "spontaneous lattice strain". The larger this spontaneous strain, the more the grain can deform under an electric field. The electrostrain seen in a ceramic piezoelectric material represents the sum total of the elongations of all the several thousand grains.

However, most piezoelectric ceramics have a drawback: when the voltage is turned off, the domains remain stuck in their new configuration, pinned by defects in the material, and are unable to return to their original state. This means that when voltage is applied for a second or third time, the electrostrain reduces drastically.

Therefore, an ideal piezoceramic material should not only have a large spontaneous lattice strain, but also a reversible movement of domains.

To develop such a material, Ranjan and his team first prepared a solid solution of the compounds BiFeO_3 and PbTiO_3 that had a large spontaneous lattice strain. Because the domains in this material were immobile, they chemically modified it by adding varying amounts of the element lanthanum to make the domains move. At a certain critical concentration of lanthanum, the domains were able to switch back to

their original state when the voltage was turned off.

"Our material can therefore be likened to a rubber which can be elongated repeatedly each time we stretch," says Ranjan.

At this concentration of lanthanum, the material also showed an electrostrain value of 1.3 percent, almost double the highest value reported for a ceramic so far. The value remained the same every time [voltage](#) was applied. On closer examination, the material showed nanoscale properties that were similar to the high-performance relaxor ferroelectrics.

"Our demonstration that electrostrain of such large magnitude can be realized even in ceramics is likely to stimulate scientists to look for more new materials," says Ranjan.

More information: Bastola Narayan et al, Electrostrain in excess of 1% in polycrystalline piezoelectrics, *Nature Materials* (2018). [DOI: 10.1038/s41563-018-0060-2](#)

Provided by Indian Institute of Science

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