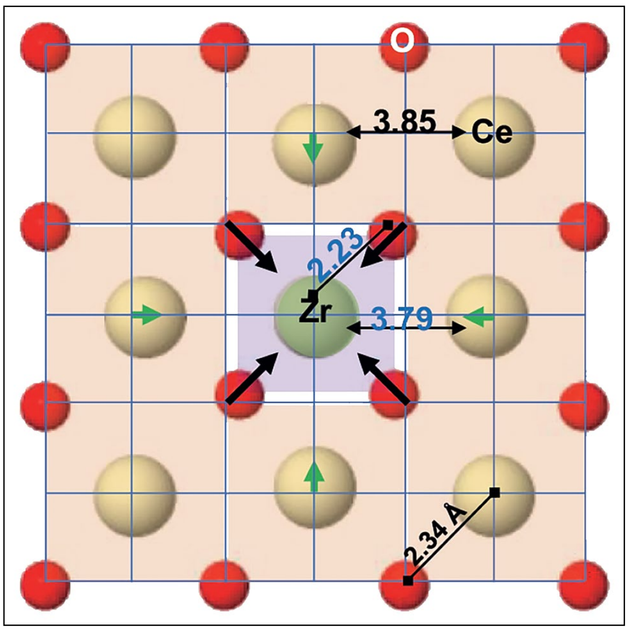
Lead-free, low-permittivity electrostrictor could be an alternative to lead-based materials

Electrostrictors, which are materials that develop mechanical strain in proportion to the square of an applied electric field, are a key building block of devices like actuators, transducers, and sensors. But common electrostrictor materials often include lead and have high dielectric permittivities, rendering them both toxic and impractical.

In an article recently published in *Nature Communications* (https://doi.org/https://doi.org/10.1038/s41467-023-43032-5), Maxim Varenik of the Weizmann Institute of Science, Israel, and colleagues address both scientific issues with one material. Their zirconium-doped ceria ceramic is lead-free, has a low permittivity, and has properties comparable to lead-containing $PbMg_{1/3}Nb_{2/3}O_3$-$PbTiO_3$ (PMN-PT), which is the best commercially available electrostrictor. This new compound, the researchers believe, can be the first of a new generation of electrostrictors.

"This work was successful because theoretical concepts, characterization, and functional behavior all combined to solve the puzzle of the nature of the electrostriction in this material," says Anatoly I. Frenkel, a materials scientist at Stony Brook University, The State University of New York, and one of the authors.

Ceria-based ceramic materials—doped, typically with lanthanides—are known to have electrostrictive properties, especially at low frequencies. But no ceria-based material had ever matched PMN-PT as an electrostrictor at high frequencies. Previous experiments had told the researchers that swapping cerium atoms with atoms of a different oxidation state could generate local elastic dipoles, which could give rise to anharmonic motion—which encourages electrostriction.



The addition of Zr atoms creates mismatched bond lengths. Cations are in yellow; oxygens are in red. Credit: *Nature Communications.*

The researchers advanced that concept by using zirconium as the dopant. When they measured the electrostriction of a doped ceria with 10% zirconium, they found that the new material matched PMN-PT. Moreover, the new material performed well as an electrostrictor across a range of frequencies, avoiding the problem that its fellow lead-free electrostrictors previously faced.

Further studies showed that the material's zirconium-oxygen bonds were noticeably shorter than the more common cerium-oxygen bonds. The researchers believe that this bond length mismatch, in addition to the dynamic anharmonicity, form the electrostrictor's two key structural descriptors.

"The most significant discovery, besides the material itself, is our successful explanation of the effect in terms of the structural descriptors," says co-author Yue Qi, a physicist at Brown University.

In fact, these two descriptors could be characteristic of more electrostrictors than just this one. "This, we believe, is the general rule for a potentially large class of other materials that feature these descriptors, including, importantly, not lead-based ones," says co-researcher Igor Lubomirsky, a materials scientist at the Weizmann Institute of Science.

Rahul Rao