Non-classical Electrostriction in Fluorites and Perovskites: Current understanding and Future Prospects

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In our 2012 report[1] on large, non-classical (non-Newnham) electrostriction in thin film Gd-doped ceria (CGO), one of the most studied oxygen conductors, we posed the question of whether such unusual electromechanical activity is limited to this material or that CGO represents but one example of a more general phenomenon. In order to answer this question, we expanded our investigation to include four other polycrystalline ceramics with a large concentration of point defects, oxygen vacancies or proton interstitials: Gd and Eu doped ceria; (Y,Nb)-stabilized cubic Bi_2O_3 [2]; partially hydrated, Y-doped barium zirconate; (Sr,Mg) doped $LaGaO_3$.

We found that, depending on dopant type and concentration, all these ceramics exhibit electrostrictive strain considerably in excess of that expected on the basis of the classical theory scaling law[3]. The electrostrictive strain coefficient (M_{33}) of ~99% dense 10 mol% Gd-doped ceria (10CGO) reaches 3×10^{-16} m^2/V^2 at frequencies below a few Hz, but drops 100-fold above. Replacing Gd with Lu reduces M_{33} by an order of magnitude. The electrostrictive strain coefficient of 30CGO was found to be < 10^{-18} m^2/V^2, close to that expected from classical electrostriction. (Y,Nb)-stabilized cubic Bi_2O_3, partially hydrated[2] Y-doped barium zirconate and (Sr,Mg)-doped $LaGaO_3$ exhibit values of M_{33} within the range 10^{-18}-10^{-17} m^2/V^2 at 10-100 Hz without marked frequency-dependence. Interestingly, the electrostriction in cubic Bi_2O_3 scales with oxygen vacancy concentration. Taken together, these data indicate a correlation between mobility of point defects at elevated temperature and non-classical electrostriction at room temperature.

EXAFS and high-energy resolution fluorescence detection (HERFD) measurements on 10CGO provide evidence for local lattice distortions in the vicinity of oxygen vacancies, reaching a few% of the normal Ce-O bond length. These distortions weaken under electric field. Comparison of the local strain (4.7% for 10CGO), the concentration of distorted units (≈3.5%) and the macroscopic strain (10^{-3}-10^{-4}), suggested that the macroscopic electrostrictive strain results from a spatial average of the sparsely distributed local strains. This is very different from classical electrostriction. Electrostriction in doped ceria persists until at least 200 °C, the temperature at which no permanent local lattice distortions can be detected.

Comparison of all four materials implies the existence of a wide class of materials displaying non-classical electrostriction. The common feature for these materials is a large concentration of point defects that become mobile at moderately elevated temperatures.

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3. Newnham, R. E.; Sundar, V.; Yimnirun, R.; Su, J.; Zhang, Q. M., Electrostriction: Nonlinear electromechanical coupling in solid dielectrics. J Phys Chem B 1997, 101, 10141-10150.