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Changing Dielectrics into Multiferroics—Alchemy Enabled by Strain

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Ferroelectric ferromagnets are exceedingly rare, fundamentally interesting multiferroic materials. The properties of what few compounds simultaneously exhibit these phenomena pale in comparison to useful ferroelectrics or ferromagnets: their spontaneous polarizations (P_s) or magnetizations (M_s) are smaller by a factor of 1000 or more. The same holds for (magnetic or electric) field-induced multiferroics. Recently, however, Fennie and Rabe proposed a new route to ferroelectric ferromagnets[1]—transforming magnetically ordered insulators that are neither ferroelectric nor ferromagnetic, of which there are many, into ferroelectric ferromagnets using a single control parameter: strain. The system targeted, $EuTiO_3$, was predicted to simultaneously exhibit strong ferromagnetism ($M_s \sim 7\ \mu_B$/Eu) and strong ferroelectricity ($P_s \sim 10\ \mu C/cm^2$) under large biaxial compressive strain. These values are orders of magnitude higher than any known ferroelectric ferromagnet and rival the best materials that are solely ferroelectric or ferromagnetic. Hindered by the absence of an appropriate substrate to provide the desired compression, we show[3] both experimentally and theoretically the emergence of a multiferroic state under biaxial *tension* with the unexpected benefit that even lower misfits are required, thereby enabling higher quality crystalline films. The resulting genesis of a strong ferromagnetic ferroelectric points the way to high temperature manifestations of this spin-phonon coupling mechanism.[2] Our work[3] demonstrates that a single experimental parameter, strain, simultaneously controls multiple order parameters and is a viable alternative tuning parameter to composition for creating multiferroics.

[1]C.J. Fennie and K.M. Rabe, *Phys. Rev. Lett.* **97** (2006) 267602.
[2]J.H. Lee and K.M. Rabe, *Phys. Rev. Lett.* **104** (2010) 207204.
[3]J.H. Lee, L. Fang, E. Vlahos, X. Ke, Y.W. Jung, L. Fitting Kourkoutis, J-W. Kim, P.J. Ryan, T. Heeg, M. Roeckerath, V. Goian, M. Bernhagen, R. Uecker, P.C. Hammel, K.M. Rabe, S. Kamba, J. Schubert, J.W. Freeland, D.A. Muller, C.J. Fennie, P. Schiffer, V. Gopalan, E. Johnston-Halperin, and D.G. Schlom, *Nature* **466** (2010) 954-958.