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## Crystal Chemistry and Symmetry based approaches to multiferroics : controlling properties through chemistry

15 Oct 2014, 2pm, Ingram Lecture Theatre

Substitution into crystalline solids can be controlled to afford materials with valuable properties such as transparent conductors for displays and photovoltaics, and battery and fuel cell electrodes and electrolytes. However, it is desirable in many cases to combine properties, current materials synthesis lacks approaches and understanding to achieve this level of structure-property-composition control. This problem is particularly marked when the properties have antagonistic chemical requirements. For example, the synthesis of a phase combining electrical polarisation **P** and spontaneous magnetisation **M** is hard because of the distinct electronic structure requirements for the main mechanisms producing each property *e.g.,* the closed-shell $d^0$ $Ti^{4+}$ and $s^2$ $Pb^{2+}$cations which produce polarisation in the ferroelectric perovskite oxide $PbZr_{1-x}Ti_xO_3$ do not have the unpaired electrons needed for magnetisation. In addition to this fundamental scientific challenge to the control of properties by designed substitution, it is technologically important to efficiently combine these two long-range orders: multiferroic or magnetoelectric information storage offers the possibility to overcome the drawbacks of ferroelectric memory (slow writing) and magnetic random access memory (high power density) and opens the possibility of four state memory with reduced energy consumption.

The control of symmetry braking by using crystal chemistry and symmetry arguments will be introduced and exemplified by two practical examples, which overcome the difficulties discussed above:

(i) Suitable doping of the RP phase $SrLn_2Fe_2O_7$ can induce a polar tilted ground state where weak ferromagnetism and magnetocelecricity are induced by the appearance of the polar tilted state. The transition temperatures and phase sucession is dependant on the degree of doping.

(ii) The oxide heterostructure $[(YFeO_3)_5(LaFeO_3)_5]_{40}$,which is magnetically ordered and piezoelectric at room temperature, has been constructed from two weak ferromagnetic $AFeO_3$ perovskites with different A cations using RHEED-monitored pulsed laser deposition.