Revival of the magnetoelectric effect

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Abstract: Recent research activities on the linear magnetoelectric (ME) effect-induction of magnetization by an electric field or of polarization by a magnetic field-are reviewed. Beginning with a brief summary of the history of the ME effect since its prediction in 1894, the paper focuses on the present revival of the effect. Two major sources for 'large' ME effects are identified, (i) In composite materials the ME effect is generated as a product property of a magnetostrictive and a piezoelectric compound. A linear ME polarization is induced by a weak ac magnetic field oscillating in the presence of a strong dc bias field. The ME effect is large if the ME coefficient coupling the magnetic and electric fields is large. Experiments on sintered granular composites and on laminated layers of the constituents as well as theories on the interaction between the constituents are described. In the vicinity of electromechanical resonances a ME voltage coefficient of up to 90 V cm-1 Oe -1 is achieved, which exceeds the ME response of single-phase compounds by 3-5 orders of magnitude. Microwave devices, sensors, transducers and heterogeneous read/write devices are among the suggested technical implementations of the composite ME effect, (ii) In multiferroics the internal magnetic and/or electric fields are enhanced by the presence of multiple long-range ordering. The ME effect is strong enough to trigger magnetic or electrical phase transitions. ME effects in multiferroics are thus 'large' if the corresponding contribution to the free energy is large. Clamped ME switching of electrical and magnetic domains, ferroelectric reorientation induced by applied magnetic fields and induction of ferromagnetic ordering in applied electric fields were observed. Mechanisms favouring multiferroicity are summarized, and multiferroics in reduced dimensions are discussed. In addition to composites and multiferroics, novel and exotic manifestations of ME behaviour are investigated. This includes (i) optical second harmonic generation as a tool to study magnetic, electrical and ME properties in one setup and with access to domain structures; (ii) ME effects in colossal magnetoresistive manganites, superconductors and phosphates of the LiMPO4 type; (iii) the concept of the toroidal moment as manifestation of a ME dipole moment; (iv) pronounced ME effects in photonic crystals with a possibility of electromagnetic unidirectionality. The review concludes with a summary and an outlook to the future development of magnetoelectrics research. © 2005 IOP Publishing Ltd.

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