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Multiferroic materials and heterostructures / Matériaux et hétérostructures multiferroïques

Foreword

The term multiferroic was first introduced by Hans Schmid in 1994. His original definition referred to multiferroics as single-phase materials that simultaneously possess two or more primary ferroic properties, among which ferroelectricity, ferromagnetism, ferroelasticity, or ferrotoroidicity. Ferroelectric materials possess a stable spontaneous polarization that can be switched hysteretically by an applied electric field, ferromagnetic compounds exhibit a stable spontaneous magnetization hysteretically switchable by an applied magnetic field, while ferroelastic materials display a stable spontaneous deformation that can be reversed hysteretically by an applied stress. Ferrotoroidic materials possess the curl of a magnetization or polarization as a stable and spontaneous order parameter. This definition is nowadays extended to include other long-range orders, such as antiferromagnetism.

After the pioneering work on bulk compounds in 1950–1960s, it was already clear that single-phase materials that exhibit both ferromagnetism and ferroelectricity are very scarce. Even rarer are compounds that present a magnetoelectric coupling between the magnetic and ferroelectric orders allowing a magnetic control of the polarization or an electric control of the magnetic orders at room temperature, the most exciting feature of these compounds from the point of view of the applications. This magnetoelectric coupling may arise directly between the two order parameters, or indirectly via strain. It motivates a lot of theoretical and experimental efforts. New device concepts emerge from these researches, such as magnetoelectric random access memories (MeRAM) in which the information is stored magnetically and written electrically. Such an opportunity takes the advantages of magnetic random access memories (MRAM) and ferroelectric random access memories (FeRAM) without their drawbacks, such as the large power needed to write information in MRAMs.

These materials have seen an important revival in the early 2000s after the observation of a large ferroelectric polarization at room temperature in thin films of the antiferromagnetic–ferroelectric compound $BiFeO_3$ [Wang et al., Science 299 (2003)] and the presence of a large magnetoelectric coupling in bulk $TbMnO_3$ [Kimura et al., Nature 426 (2003)] allowing a magnetic control of the polarization in 2003. Those observations triggered huge theoretical and experimental efforts in order to understand the mechanism at the origin of the magnetoelectric coupling and find or design new multiferroics. In this volume, we present a review of the fundamental mechanisms at the origin of multiferroicity and summarize the recent work performed on the most-studied compound families, namely the Bi-based multiferroics and rare-earth hexagonal and orthorhombic $RMnO_3$.

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