Multiferroics

Guest Editors

Alois Loidl
Augsburg University, Germany

Hilbert von Loehneysen
Karlsruhe University, Germany

G Michael Kalvius
Munich Technical University, Germany

This special issue deals with the simultaneous occurrence of at least two primary ferroic properties, namely of ferroelectricity, ferromagnetism, ferrotoroidicity or ferroelasticity in one single homogeneous phase. The question of how different ferroic states can coexist in a single-phase material is an important issue and is outlined in detail using symmetry arguments and Landau theory for continuous phase transitions, which shows that the spin structure alone can break spatial inversion symmetry leading to ferroelectric order. The main focus of this special issue lies on single-phase materials that are magnetic and ferroelectric. They promise control of electric properties by magnetic fields and the control of magnetic properties by electric fields. The magnetoelectric coupling will allow the design of materials with novel electronic properties and in selected cases bring them to application.

Ferromagnetic ferroelectrics are scarce in nature. This is because the conventional mechanism for ferroelectricity, namely an off-centering of the cations, which can be achieved best in ions with empty d shells, contradicts the formation of magnetic order in materials with partly filled d shells [1, 2]. Ferroelectricity in specific cases is achieved via the stereochemical activity of lone pairs in magnetic oxides. But in these cases the coupling between ferroelectricty and magnetism is weak. There have been a number of studies on multiferroics, especially in the 1960s and 1970s, particularly in the former Soviet Union [3, 4], but these activities faded away, most probably due to the lack of materials with strong magnetoelectric coupling and high ordering temperature, although the enormous potential of multiferroics for technological important applications was recognized early on [5].

An intense revival and the return of multiferroicity to the forefront of condensed matter research has been triggered by the invention of a number of frustrated magnets, like manganite rare earths, i.e., $RMnO_3$ [6], RMn_2O_5 [7], or $Ni_3V_2O_8$ [8], which are characterized by strong spin frustration due to competing exchange interactions. In fact, they reveal transitions into magnetic phases with complex non-collinear spin order, thereby breaking inversion symmetry and concomitantly inducing ferroelectricity. This renaissance of multiferroics was made possible because developments in sample growth and sample characterization allowed the production of high quality single crystals and thin films. In addition, computational methods helped to design new materials with outstanding properties.

To explore the complex physics of multiferroics, outstanding laboratories with novel instrumentation and exceptional theoretical tools were involved. Most of the scientists responsible for this enormous revival in the synthesis, characterization, and modeling of these new classes of multiferroics have contributed to this special issue. Hence, it provides an impressive survey of the state of the art and documents key experiments in this area of condensed matter research: dielectric spectroscopy as a function of temperature and external magnetic field, neutron-scattering experiments to unravel the complex magnetic phase diagrams including spin order and magnetic excitations and also to explore possible induced lattice deformations, as well as optical experiments to search for new classes of excitations, like electromagnons. In addition, intense modeling of the underlying physics of multiferroics and fascinating theoretical concepts—these issues are all documented in this issue on multiferroics, as well as possible applications in modern optics or in spintronics. Furthermore, new routes to multiferroicity are also tackled, like charge order or electronic ferroelectricity as prototypical and important examples.

This special issue provides an inspiring overview of the ongoing research in the field of magnetoelectric effects, multiferroicity and ferrotoroidicity. We hope it will stimulate and trigger further important contributions in experimental exploration and theoretical concepts.

References

[1] Hill N A 2000 *J. Phys. Chem.* B **104** 6694–709

[2] Khomskii D I and Bull A 2001 *Phys. Soc.* C **21** 2
Khomskii D I 2006 *J. Magn. Magn. Mater.* **306** 1

[3] Smoleskii G A, Agranovskaia A I, Popov S N and Isupov V A 1958 *Sov. Phys. Tech. Phys.* **3** 1981

[4] Smolenskii G A and Chupis I E 1974 *Sov. Phys. Usp.* **25** 475

[5] Wood V E and Austin A E 1974 *Int. J. Magnetism* **5** 303

[6] Kimura T, Goto T, Shintani H, Ishizaka K, Arima T and Tokura Y 2003 *Nature* **426** 55

[7] Hur N, Park S, Sharma P A, Ahn J S, Guha S, Cheong S-W 2004 *Nature* **429** 392

[8] Lawes G, Harris A B, Kimura T, Rogado N, Cava R J, Aharony A, Entin-Wohlmann O, Yildirim T, Kenzelmann M, Broholm C and Ramirez A P 2005 *Phys. Rev. Lett.* **95** 087205