Handbook of Magnetic Materials

Edited by

K.H.J. Buschow

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VOLUME

19

VOLUME NINETEEN

HANDBOOK OF MAGNETIC MATERIALS

Editor

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Preface to Volume 19

The Handbook series Magnetic Materials is a continuation of the Handbook series Ferromagnetic Materials. When Peter Wohlfarth started the latter series, his original aim was to combine new developments in magnetism with the achievements of earlier compilations of monographs, producing a worthy successor to Bozorth's classical and monumental book *Ferromagnetism*. This is the main reason why *Ferromagnetic Materials* was initially chosen as the title for the Handbook series, although the latter aimed at giving a more complete cross section of magnetism than Bozorth's book. In the last few decades, magnetism has seen an enormous expansion into a variety of different areas of research, comprising the magnetism of several classes of novel materials that share with truly ferromagnetic materials only the presence of magnetic moments. For this reason, the Editor and Publisher of this Handbook series have carefully reconsidered the title of the Handbook series and changed it into *Magnetic Materials*. It is with much pleasure that I am now introducing Volume 19 of this Handbook series to you.

The areal density of magnetic recording systems has dramatically increased over the last several decades. In 1970, the same area required to store one bit of information stores more than 5 million bits in 2010. A concise description of modern magnetic recording heads, their operation and the underlying physics and advanced materials is presented in Chapter 1 of this Handbook volume.

In the introduction of their chapter, the authors briefly review how the historical evolution to lower and lower areal densities was driven by quite a number of important factors. These include shrinking recording head dimensions and increasing sensitivity of read sensors going hand in hand with the development of low-noise high-resolution recording media, advanced signal detection channels and decreasing head-medium spacing. In this chapter, the authors concentrate on how the development of nanometer-scale recording head geometries and highly sensitive magnetoresistive read sensors had a major impact on recording density evolution. Following the introduction, the authors concentrate on magnetic write head, including perpendicular-recording heads and energy-assisted write heads, considering thermal-assisted recording and microwave-assisted recording. The second part of the chapter is devoted to magnetic read sensors. Special emphasis is given to the anisotropic magnetoresistive (AMR) and giant magnetoresistive (GMR) effects and the underlying physical principles. Important topics described in this part include tunnel junctions, noise in magnetic sensors and finally, sensor characterization.

The chapter is presented in a tutorial way and will be of interest to those working in the field of magnetic recording and also to those who wish to be introduced to this important field.

Spinelectronics, shortly spintronics, is a very rapidly expanding field exploiting both charge and spin in electron transport. After the discovery of the giant magnetoresistance (discussed in the first section of Volume 12 of this Handbook), several breakthroughs that have opened up new research directions in this field have occurred. These include spin-valves dealt with in the first chapter of Volume 15, tunnel magnetoresistance, treated in the first chapter of Volume 17, spin transfer and voltage-controlled magnetic properties discussed in the second chapter of the latter volume. The phenomenon of spin transfer is particularly attractive both from the fundamental and applied point of view since it provides a new way to manipulate the magnetization of magnetic nanostructures by a spin-polarized current. Spinelectronics has found applications in hard disk drives and more recently in non-volatile standalone memories, the so-called magnetic random access memories (MRAMs). In the second chapter of the present volume, the authors show how the spin-transfer phenomenon provides a new write scheme in MRAMs, yielding a much better scalability of these devices towards the 22-nm node. The authors also discuss how, besides MRAMs, hybrid CMOS/magnetic technology can yield a totally new approach in the way electronic devices are designed. Most CMOS devices such as microprocessors are based on the so-called Von Neumann architecture in which logic and memories are separate components. The unique set of characteristics combined within magnetic tunnel junctions: cyclability, switching speed and scalability make it possible to conceive novel electronic systems in which logic and memory are intimately combined in non-volatile logic components (concept of non-volatile CPU).

Chapter 3 of this volume deals with magnetoelectricity, with separate sections dealing with fundamentals and measurement techniques. Generally, magnetoelectricity means the interaction between the magnetic and the electric subsystems in a given material. Although field-induced changes in the dielectric constant or the electrical resistivity are sometimes considered as magnetoelectricity, the authors of the present chapter concentrate on changes in the electric polarization induced by magnetic fields, or on the inverse, that is, on linear changes in magnetization induced by electric fields. Currently, hundreds of single-phase and composite materials are being investigated in the search for large magnetoelectric responses. Composites generally show orders of magnitude larger effects. Research on single-phase materials offers, however, the opportunity to fundamentally better understand and improve magnetoelectricity in the various types of materials. Generally, one speaks of multiferroicity when two or more of the primary ferroic properties, that is, ferroelectric, ferromagnetic, ferrotoroidic, and ferroelastic, are combined in the same phase. However, also ferri-, anti-ferro- and weakly-ferro- ordering schemes tend to be included. As shown by the authors, the overwhelming majority of materials regarded today as multiferroics are ferroelectric-antiferromagnetic. The magnetoelectric response in single-phase materials is generally weak and requires low temperatures. For this reason, the authors have devoted a separate section to magnetoelectric composites in which the response is much larger. In the last section of their chapter, the authors discuss possible applications of ferroelectric materials.

The most prominent position in the series of Ferromagnetic Transition Metal Intermetallics is taken by the Heusler alloys, as described already in Chapter 4 of Volume 4 of this Handbook. Owing to their proliferation and the concomitant large mutual differences in magnetic properties of these compounds, they have formed the playing ground for many theoretical models. This is the reason that, over the years, they have contributed much to the present understanding of magnetism in metallic transition metal systems. Of particular interest is the occurrence of half-metallicity in some of the Heusler alloys, a property that has played an important role in the field of spintronics. Of equal interest is the fact that some Heusler-based alloys, apart from ferromagnetism, give rise to a martensitic transformation. As described in Chapter 1 of Volume 17 of this Handbook, the compound Ni_2MnGa is a Heusler alloy that shows a martensitic transformation and exhibits a magnetic-field-induced strain of the order of 10%, forming a breakthrough in the field of magnetic-field driven actuators. The origin of this large magnetostriction is a twin-related variant reorientation caused by field-induced twin-boundary motion. In the last few years, the field of magnetic shape-memory effects has seen a rapid growth, and many other alloys showing this interesting property have been discovered. Today, it is known that almost any Ni–Mn-based Heusler alloy will show a martensitic transformation, provided it is given a suitable off-stoichiometric composition. Chapter 4 in the present volume of the Handbook deals to a large extent with these new alloys, for which the properties are compared to those of Ni–Mn–Ga, considered as reference material. In this chapter, the authors emphasize that contrary to systems displaying field-induced variant-reorientations characterized by high magnetocrystalline anisotropy in the martensite phase, magnetic superelasticity essentially relies on a large change of magnetization at the transition. They stress that apart from large deformations, the advantage of the superelastic deformation mechanism is the concomitant large work output which can be of importance for future applications. In their chapter, the authors provide an overview of magnetic-field-induced structural effects at mesoscopic and microscopic scales where features related to the magnetostructural transition that manifest themselves in the mesoscopic scale are discussed in the framework of twin-boundary motion. The chapter provides an overview of the contemporary state of research on structural and magnetic properties of martensitic Heusler alloys with emphasis on the nature of the magnetic coupling in the austenite and martensite states. Also, reviews on phase diagrams are presented. Furthermore, field-induced structural effects at the microscopic scale are discussed in relation to lattice dynamics probed through phonon and ultrasonic attenuation investigations. The final section of the chapter deals with field-driven effects and collects together the various effects that take place when a magnetic field is applied to these alloys.

In Chapter 5 of this volume, Fe–Pt alloys are reviewed. These alloys have found many applications due to their unique combination of excellent intrinsic magnetic properties and good corrosion resistance. Fe–Pt thin films and nanoparticles are promising candidates for ultra-high-density magnetic storage media. Fe–Pt nanoparticles are also considered for bio-medical applications such as contrast agents in magnetic resonance imaging and for catalysis. As bulk alloys, Fe–Pt-based alloys are known as excellent permanent magnets, although high costs limit these permanent magnets to very specialized applications such as in magnetic microelectromechanical systems, magnetic MEMS or to applications in aggressive environments, for instance, in dentistry, where they are used as magnetic attachments to fix dental prostheses in the oral cavity. In Chapter 5, the authors of the last chapter of this volume present a comprehensive review of the magnetic properties of the various forms of Fe–Pt alloys. Because the magnetic properties in all these forms are intimately connected with the corresponding methods of preparation, the authors have devoted a substantial part of their chapter to synthesis methods which are presented along with phase relationships, atomic scale structures and transformation kinetics. Bulk alloys, nanocrystalline alloys and thin films are discussed in separate sections, the last section of their chapter being mainly devoted to magnetic data storage applications.

Volume 19 of the *Handbook on the Properties of Magnetic Materials*, as the preceding volumes, has a dual purpose. As a textbook, it is intended to be of assistance to those who wish to be introduced to a given topic in the field of magnetism without the need to read the vast amount of literature published. As a work of reference, it is intended for scientists active in magnetism research. To this dual purpose, Volume 19 of the Handbook is composed of topical review articles written by leading authorities. In each of these articles, an extensive description is given in graphical as well as in tabular form, much emphasis being placed on the discussion of the experimental material in the framework of physics, chemistry and material science. The task to provide the readership with novel trends and achievements in magnetism would have been extremely difficult without the professionalism of the North Holland Physics Division of Elsevier Science B.V.

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