Preface

Intensive investigations on nanoscale magnetism have promoted remarkable progress in technological applications of magnetism in various areas. The technical progress of recent years in the preparations of multilayer thin films and nanowires led to the discovery of Giant Magnetoresistance (GMR), implying an extraordinary change in the resistivity of the material by varying the applied external magnetic field. The Nobel Prize for Physics in 2007 was awarded to Albert Fert and Peter Grünberg for their discovery of GMR. Applications of this phenomenon have revolutionized techniques for retrieving data from hard disks. The discovery also plays a major role in various magnetic sensors as well as the development of a new generation of electronics. The use of GMR can be regarded as one of the first major applications of nanotechnology.

The GMR materials have already found applications as sensors of low magnetic field, a key component of computer hard disk heads, magnetoresistive RAM chips etc. The "read" heads for magnetic hard disk drives have allowed us to increase the storage density on a disk drive from 1 to 20 Gbit per square inch, merely by the incorporation of the new GMR materials. On the other hand, recently discovered giant magneto-impedance (GMI) materials look very promising in the development of a new generation of microwave band electronic devices (such as switches, attenuators, and antennas) which could be managed electrically.

Magnetic data storage is one of the most promising applications of nanomagnetism. The physical size of the recording bits of hard disk drives is already in the nanometer regime, and continues decreasing due to the ever increasing demand for higher recording densities. Soon the dimension of the recording bit will reach the sub-10 nm regime. At this level, both the writing and reading processes will become extremely challenging, if not impossible. This is because the sensor must be made smaller or at least comparable to the bit size, and at the same time, its sensitivity must be improved continuously so as to compensate the loss in signal-to-noise ratio due to the decrease in the bit size. The former has to rely heavily on the advance of nanotechnology, and the latter on an emerging field called spintronics. The combination of these two fields has played an important role in advancing the areal density of magnetic recording from a few gigabits/in^2 to the current level of more than 100 Gbits/in^2. In addition to hard disk drives, the developed technologies have also been applied to magnetic random access memories (MRAMs). Further advance in these fields is the key to realizing terabits/in^2 hard disk drives and gigabit nonvolatile memories within this decade.

Spintronics in its broader sense contains all types of electronics that make use of both charges and spins. It is a new and rapidly developing branch of commercial electronics, which utilizes spin degrees of freedom of the carriers to control an electric current. One may say that spintronics accumulates or synthesizes the frontier knowledge of the physics of spin and magnetism, electronics and optics, putting them together in the nanoscale range and realizing them in new multifunctional devices. The first generation of devices combines standard microelectronics with spin-dependent effects that arise from the interaction between the spin of the carrier and the magnetic properties of the material. Therefore, by controlling the spin alignment one can add an extra parameter to adjust the device characteristics. The magneto-optical effect is another important phenomenon for spin injection, detection and manipulation to bring electron-spin and photon in a single component of an electronic device. The ultimate goal is to use the collaborative effects of the magnetic, electric and optical nature to improve the performance of the devices. The magnetoresistive read heads for the computer hard disk drives give us the first example of successful long-term innovation, which resulted in total reorientation of the computer hard-disk industry on the magnetoresistive read heads.

These metal-based spintronic devices are based primarily on the spatial modulation of electron spins through using layered structures of magnetic and non-magnetic materials. The lack of capability in charge modulation in these types of structures may eventually limit their ultimate performances in terms of both the magnetoresistance and other functionalities. To address this issue, recently, a great deal of effort has been devoted to the developments of magnetic semiconductors which allow the modulation of both the spins and charges. The advances in this field may eventually lead to spintronic devices with performances superior to their metal-based counterparts. In addition to pure metal-based or semiconductor-based spintronic devices, hybrid devices making use of both technologies also have been explored actively in recent years.

The magnetic semiconductors are usually made by adding magnetic impurities to host semiconductors. It is not sufficient, however, that every semiconductor can be made magnetic using this approach because some of them still do not exhibit any magnetic properties even after they are doped with a substantial amount of magnetic impurities. Some of them, though magnetic, show a very low Curie temperature. However, the situation has changed drastically in recent years due to the intensive efforts made by researchers in this field in many research organizations. Several different types of magnetic semiconductors having a Curie temperature higher than room temperature have already been found. It should be noted, however, that all these are based on preliminary experimental results; further experiments are required to verify the results. The progress was made not only in materials themselves, but also in the applications of these materials in creating new functional devices such as semiconductor-based magnetic tunnel junctions and spin-injection devices. Although the current technology for a read sensor is based on metallic spintronics, semiconductor-based spintronics has the potential to provide sensors or storage elements with superior performances for next-generation data storage devices.

Although the read sensor for magnetic recording and storage cells for magnetic memory are based on spintronics, the storage of information in disk media is still based on classic physics, and it does not involve spintronics. However, as the bit size continues decreasing, it will approach atomic size in the near future. At this stage, a fundamental change in the information storage principle will be required. One of the possible scenarios is to store information in the reciprocal space or energy domain. In this case, the spin of electrons and nuclei instead of the magnetization of magnetic grains will play an important role. This is closely related to another emerging field called quantum information storage.

At the present time the small-scale magnetic materials are used both in new recording media and, in particular, in the most critical elements of recording systems, in recording heads. Magnetic layers serving as recording medium in a storage media are becoming increasingly complex with increasing areal density of recording. The size of a single recorded bit in most recent hard disks is now in nanometric scale. Magnetic recording density is increasing close to 100 per cent every year. So, recording technology has already demonstrated recording density over 100 Gbit per square inch at the present time. However, even if all the technological problems could be solved there is still a theoretical limit for recording density. With the decreasing size of recorded bits, these magnetic particles have already been entering the superparamagnetic regime. The thermal agitation energy becomes comparable to the effective magnetic anisotropy (including the shape anisotropy) energy of a single particle. Then, magnetic moments start to flip within a finite time and therefore the recorded data are partly washed out. The stability of the bit exponentially depends both on the barrier energy (anisotropy energy) and on the particle volume.

The superparamagnetic limit for some typical materials is of the order of 10 nm, which corresponds to a recording density of the order of Terabits per square inch. The important parameters are anisotropy, coercivity, size, preferential orientation and the density of magnetic particles. The density can be improved further by using perpendicular recording. In this case very thin and long enough magnetic wires are ordered perpendicular to the surface of the media. Even an individual wire or particle can be used as a bit unit in the near future. Production of magnetic fine particles with uniform physical properties can be achieved by some lithography techniques. Dimensions of magnetic components used as sensor and writer elements in recording heads are in nanometric scale and smaller than the limit of optical lithography.

Thus, the sensitivity and the resolution of reading are going to increase drastically as the size of the particles is decreased down to nanometer scale. The sensitivity of magneto-restive device is defined as relative change of resistivity per Oersted. In a recording head, magneto-resistive elements based on GMR or spin tunneling effect are used. By using the spin tunneling effect, sensitivity can be an order of magnitude higher compared to conventional magneto-resistive Ni-Fe sensor. High sensitivity has been achieved by GMR materials. In order to enhance the sensitivity further, the current perpendicular to the surface mode is going to be implemented.

Of late, magnetic and semiconducting elements are being combined into a chip (MRAM) in order to avoid the mechanical part from our lives (Speed of data transfer in hard disks is now close to 1 Gbit/s). Moreover, logic devices based on nano-magnetism are under investigation. Magnetic transistors have recently been demonstrated. The basic principles of this device depend on the injection of spin-polarized current between magnetic-nonmagnetic layers. Also, some researchers are trying to use magneto-optic, magneto-elastic, and other material properties to develop novel devices.

This book is intended to provide a review of the latest developments and the fundamental concepts in the field of nanomagnetism, with an emphasis on the research and application of nanoscaled magnetic materials in high-density magnetic data storage and MRAMs and recent achievements in the emerging field of spintronics. The idea for this book was born at the Fourth International Conference on Nanoscale Magnetism (ICNM-2007) held in Istanbul (Turkey) from June 25-29, 2007. The contributions are focused on the magnetic properties of nanoscale magnetic materials, especially on fabrication and characterization as well as the physics behind the behavior of these structures.

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