Chapter 1
Introduction

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Electrochemical nanotechnology utilizes electrochemical processes and techniques. We have been publishing several books in series, on electrochemical nanotechnologies. [1–6] This book deals mainly with applications of electrochemical nanotechnology in the fields of magnetic recording, ULSI interconnection, energy devices, bio-analysis, and bio-electrochemistry.

Nanotechnologies, in general, are concerned not only with downsizing and miniaturization of products, but also with ideas for creating new systems and new materials involving the scale of nanometers. A typical example is the invention of GMR, for which Fert and Gruenberg received the 2007 Nobel Prize in Physics. The system is based exactly on the nano-order combination of magnetic materials with thin films.

Figure 1.1 shows the change in areal density of magnetic recording device with time, in which the areal density of hard disk drive (HDD) is plotted against the calendar year. The areal density of 1 terabit/in^2 was thought to be the achievable limit in view of the physical limitation of super paramagnetism. However, recent assessment assumes the possibility of achieving higher densities on new systems of DTR (discrete track recording), BPR (bit patterned recording), and TAMR (thermal-assisted magnetic recording). This example shows that nano-order arrangements and relevant ideas are becoming increasingly important in recent years.

Needless to say, highly functional magnetic film is a key component of future magnetic recording devices, and the development of new magnetic films will contribute to the fabrication of new magnetic devices, as has been demonstrated in the past. For example, the growth rate of the areal density in the past was controlled mainly by the development of head core material of soft magnetic film with a high-saturation magnetic flux density. To meet the demand for the GHz response, it was necessary for the soft magnetic film to possess properties of low magnetostriction, high electrical resistivity, high thermal stability, low film stress, and high corrosion resistance.

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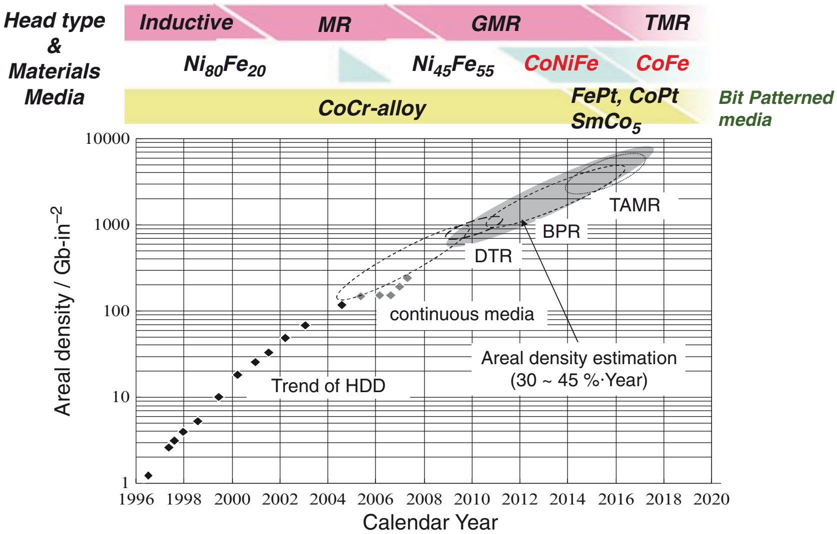

Fig. 1.1 Trend of increasing areal density of hard-disk drives (HDD) with time

One approach to meet these requirements was to prepare the film with the structure composed of nanocrystal domains dispersed in an amorphous matrix. This structure is called "nanocrystalline soft/hard magnetic material". Although the preparation method using a heating-quenching technique was reported, it was not suitable as a magnetic head manufacturing process because of the damage caused in other head components. We proposed an electrochemical method consisting of a new concept that is different from the thermal method. The electrodeposited CoNiFe film led to the development of an ultra small GMR head. In this section, we first introduce the new concept based on electrochemical nanotechnology, which was developed through research on electro- and electroless-deposited CoNiFe alloy films. Subsequently we introduce its application to the fabrication of cusp-field single-pole type (CF-SPT) head, which is considered to be promising as a next generation magnetic head, and recent research on the enhanced concept for the magnetic domain control of films.

The energy density of portable batteries will be considered next. The changing trend of energy devices is illustrated in Fig. 1.2 with portable battery energy devices in mind. The idea of electrochemical nanotechnology has been adopted for developing energy systems for portable electric devices to enhance their energy density. Currently, Li ion battery is used for high-end electric devices such as cellular phones, portable computers, and PDAs. The demand for higher capacity and higher power for the energy systems comes from the requirement for future enhanced IT technologies and for the welfare of our society. While the energy density of a battery pack is limited primarily by the materials used in the battery, the nanometer-scale design of the electrode leads to an improved capacity and power output of the battery. The conventional electrode materials are prepared at a high temperature.

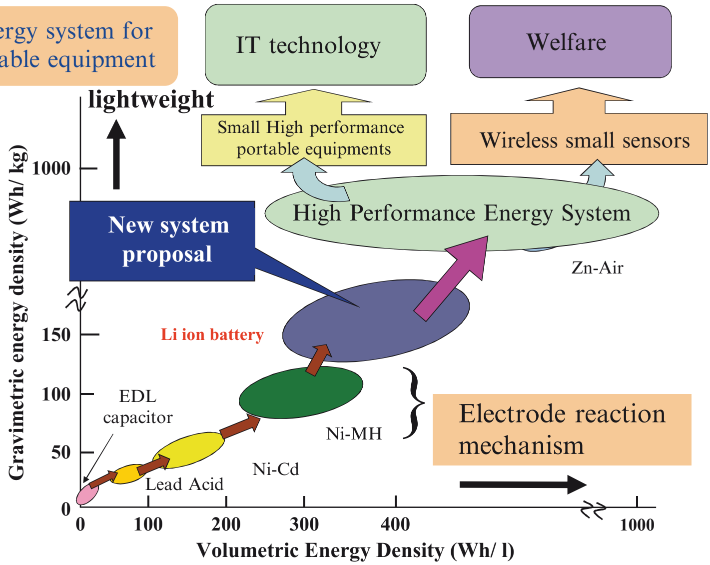

Fig. 1.2 Trend of energy devices

The homogeneity in structure and composition of those materials are advantageous for mass production of the batteries. On the other hand, electrochemical methods for the preparation of new electrode materials permit the control of the phase, the amount of impurities/additives, and the nanometer-scale structure of the product. Controlling those aspects of materials led to the development of Sn–Sx, Ni–Sn, and mesoporous Sn as new candidates for the electrode material of future Li batteries. With these technologies, it is anticipated that further progress will be made in the performance of batteries in the future. Electrochemical nanotechnology is also powerful for developing fuel cells. New materials and new processes for synthesizing catalysts by wet procedures based on electrochemical nanotechnology have been proposed. Furthermore, with MEMS technologies, the construction and operation of miniaturized fuel cells have been demonstrated.

Finally, we describe results of studies of bioanalysis and bioelectrochemistry based on nanotechnology. For example, magnetic nanoparticles offer some attractive possibilities for applications in the fields of bioanalysis and biomedicine as shown in Fig. 1.3 [7]. Magnetic nanoparticles can be used as a magnetic marker for the detection of biorelevant materials such as a cell (10–100 μm), a virus (20–450 nm), a protein (5–50 nm), or a gene (2 nm wide and 10–100 nm long). These materials are comparable in size to magnetic nanoparticles. Also, iron-oxide nanoparticles of magnetite (Fe_3O_4) and maghemite (γ-Fe_2O_3), which are reported to be nontoxic to the human body, are applied as a magnetic carrier for drug delivery systems (DDS), as a heating element in hypothermia, and as a contrasting agent for magnetic resonance imaging (MRI). In these cases, magnetic properties of iron-oxide nanoparticles, which are very different from those of the bulk material, are utilized for

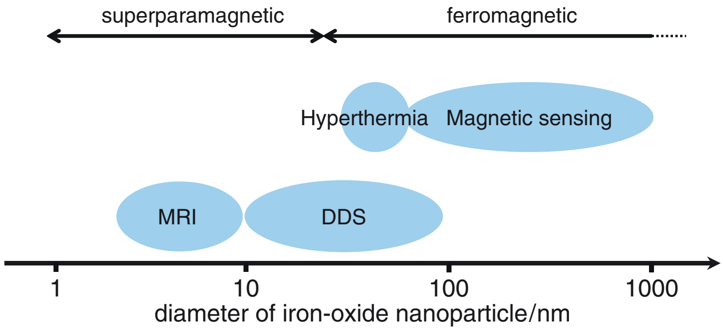

Fig. 1.3 Bioapplications of iron-oxide nanoparticles

biomedical treatment. Thus, special magnetic properties in addition to the biologically advantageous size of magnetic nanoparticles are utilized in their bioanalytical and medical applications such as bioassays, biomedicine, ultrasensitive biodetection, and bioimaging. This book introduces the present status of nanotechnologies for bio-chip applications, electrochemical field effect transistor (FET) micro pH and biosensors, electrochemical and magnetic technologies for bioapplications, and nano bioelectrochemical interfacing.

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