Materials for Magnetic Data Storage: The Ongoing Quest for Superior Magnetic Materials

Hans Coufal, Lisa Dhar, and C. Denis Mee, Guest Editors

Abstract

From its inception until today, and for the foreseeable future, magnetic data storage on disks and tape has provided constantly increased storage density. This has required not only constant innovation, but also major breakthroughs in magnetic materials, both for the media and the read head. Today's disk and tape drives take advantage of novel nanoengineered composite magnetic materials and quantum mechanical processes. In this issue of *MRS Bulletin*, we present a number of review articles by some of the leaders in this rapidly moving field that highlight the key materials science accomplishments that have enabled the tremendous progress in hard disk drive and magnetic tape technologies. Individual articles describe the materials involved in state-of-the-art magnetic recording, advanced media for perpendicular magnetic recording, the materials challenges of achieving high performance in flexible media such as magnetic tape, the materials issues of read heads, and future avenues for magnetic storage beyond magnetic recording, such as nanowires and spintronics.

Keywords: *magnetic, magnetoresistance, memory, nanoscale, spintronic.*

Half a century of progress in magnetic data storage has changed the world. Almost 50 years ago, on September 13, 1956, IBM announced the 305 RAMAC (random access method of accounting and control) computer system with the IBM 350, the world's first disk drive. This novel way to store and retrieve data with a rotating disk enabled rapid "random" access to the data. The high cost of one recording and read head and the associated racks of electronics was amortized over 50 24-in. disks with a total of ~5 Mbyte of storage capacity, resulting in an acceptable cost per bit. As shown in Figure 1, the storage density of hard disk drives (HDDs) has since then increased by eight orders of magnitude from these humble beginnings, first at a compounded growth rate of 25% per year, then 60%, followed by several years of 100%, to finally slow down a little bit in the last couple of years. At the same time, the cost has been declining exponentially (see Figure 2); today, storing data on a hard disk is substantially cheaper than storing the same information on paper.

Disk drive design, while basically unchanged from its inception, required breakthroughs in magnetic materials to enable the low-cost, large-capacity disk drives that have moved computers from the "glass houses" of the early days, which proudly showcased a company's most prized possession behind a wall of windows, to portable applications such as laptops or iPods. Some of the drastic changes in the areal density curve of Figure 1 are due to breakthroughs in materials science that allowed the introduction of new technologies such as the thin-film head, the magnetoresistance head, and, finally, giant magnetoresistance and magnetic tunnel junction heads and the corresponding magnetic recording media. The development of nanoengineered composite magnetic multilayers based on spintronics and other quantum mechanical processes enabled the most recent density advances.

Magnetic tape drives, which were developed well before the magnetic HDD, have also improved in storage density over a long period, but at a slower rate than HDDs. Progress in the areal density of HDDs has been slow to trickle down to removable flexible media, which has lagged the areal density of hard disks by typically 2–3 orders of magnitude. Nevertheless, due to the removability feature of the media and the well-understood long-term behavior of magnetic tape, it is still the archival storage material of choice for the information technology industry and has for many years dominated information storage in the consumer market, first in the form of audio cassettes and later as the ubiquitous VHS cartridge for video recording. More recently, optical storage (CDs and DVDs) and flash memory have come to dominate the consumer market.

In this issue, we have collected reviews of the state of the art in materials for magnetic recording devices, plus some of the developments that are in progress, and we address the perennial question of why magnetic tape has been lagging disk drives in areal density and what it would take to change that fact.

The fundamentals of magnetic recording and the arguments summarized in this introduction, scaling over the last 50 years in particular, are discussed in more detail by McFadyen et al. This article includes a thorough discussion of conventional longitudinal recording and advances in spin-exchange coupled media and giant magnetoresistance read heads.

Richter and Harkness take us to the next step—magnetic recording media with densities above 100 Gbit/square inch. At these densities, HDD technology may transition from longitudinal to perpendicular media; that is, the magnetiza-

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tion would no longer be parallel to the surface of the media but perpendicular to it instead. The principles and the advantages of patterned media are explained, and the material science implications and challenges are discussed.

Parkin, who has made major contributions to the progress in magnetic recording over the years, focuses on the use of the magnetic tunnel effect for read heads in his article. Given the decreasing size of the magnetic bits and a minimum safe distance between the read head and the rapidly spinning magnetic media, the sensitivity of the magnetic sensor to the fields that are present in a disk drive has to increase ever more. The underlying physics and preliminary results of this novel detection scheme are discussed.

Allenspach and Jubert, and Wolf et al., take us further into the future of magnetic storage. Magnetic domains in nanowires and more sophisticated applications of spintronics, along with giant magnetoresistance read heads and antiferromagnetically coupled media discussed in the other articles, may provide the breakthroughs that will allow future improvements in areal density. Looking back to the beginnings of magnetic recording, the rotating disk allowed "random" access to the stored data and kept the cost per bit reasonably low. Now, nanoelectronics—and spintronics in particular—may enable data storage in an all-solid-state device at a competitive cost and provide truly random access at the speeds of modern computers. Products employing nanoelectronics and spintronics are now in development.

In addition, with cheap and reliable archival storage still being one key priority for the operators of data centers as well as film and broadcast studios, it is only natural to ask the question, how will these breakthroughs in magnetic recording be reflected in future magnetic tape systems? Dee analyzes the similarities and the differences between magnetic storage on a rigid, spinning disk and on flexible tape, and points out the hurdles that have to be overcome to enable a convergence of the two recording technologies.

In this issue of the *MRS Bulletin*, we have sought to cover areas in materials science research and engineering that span the field of current and future magnetic data storage. From state-of-the-art disk drives, with advanced read heads and media, we cover composite media and read heads that take full advantage of the relevant quantum mechanical processes, such as spin exchange and tunneling. We hope that the articles on magnetic recording in this issue and on optical media in the April 2006 issue[1] will draw attention to the exciting materials science challenges involved in advancing data storage.

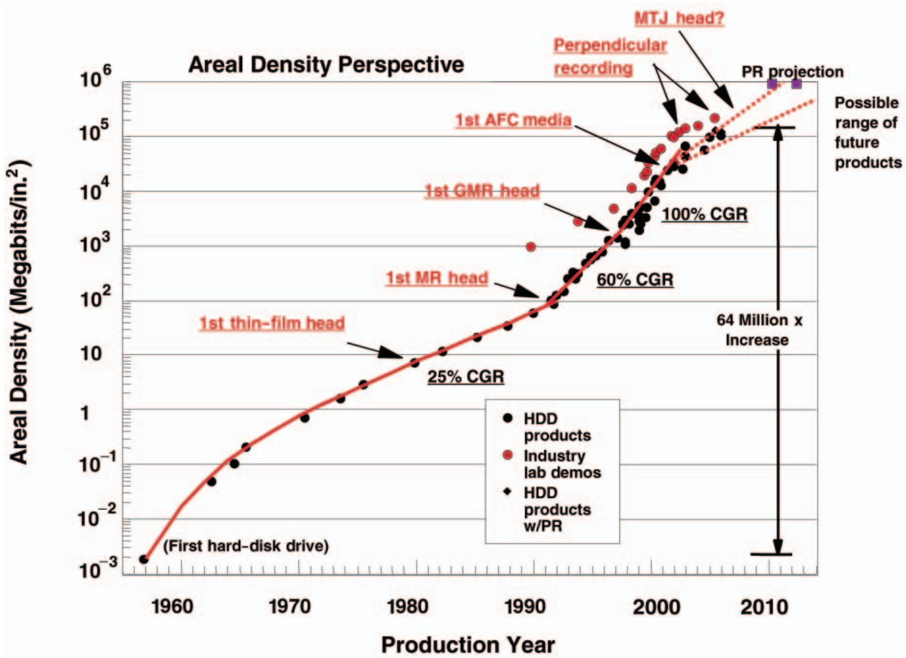

Figure 1. Areal density of magnetic hard disk drives as a function of calendar year, from the first disk drive to today's products. The compounded growth rate (CGR) for some of the periods are indicated, as well as the technical breakthroughs that allowed changes in the slope. MR stands for the introduction of the magnetoresistance head, GMR the introduction of the giant magnetoresistance head, AFC the introduction of antiferromagnetically coupled media, and PR the introduction of perpendicular recording into the manufacturing of hard disk drives (HDDs).

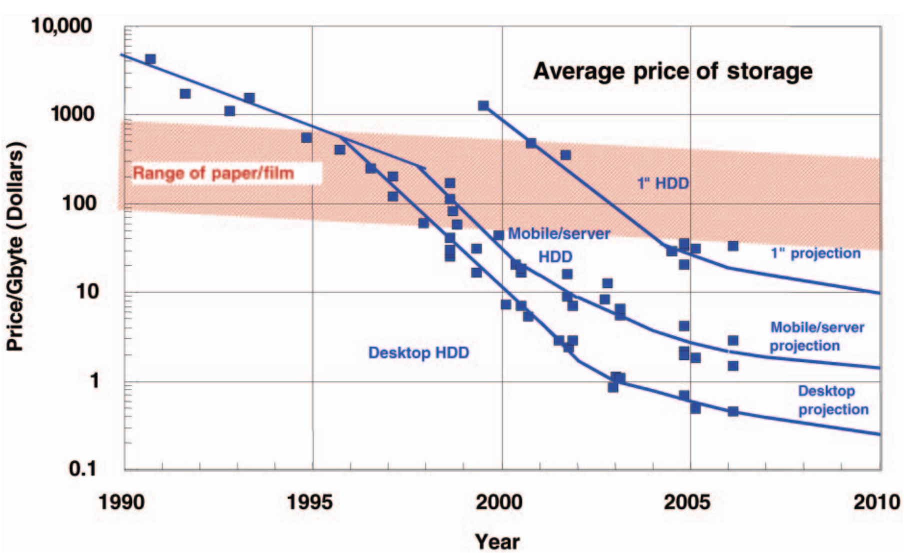

Figure 2. Price per gigabyte of data stored on a hard disk drive as a function of calendar year, with projections to the year 2010.

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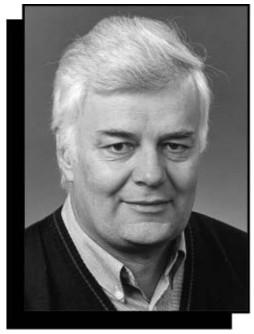

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His career in magnetic recording spans 23 years at Storage Technology Corp., where he worked on the design and development of thin-film multi-element magnetic recording heads for high-density tape applications and associated magnetic recording physics. His contribution to high-density magnetic tape systems at StorageTek led to his appointment to the position of StorageTek Fellow.

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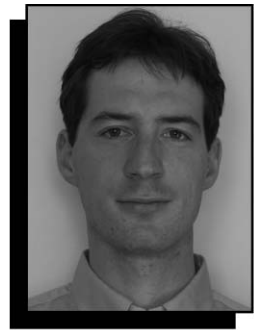
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