A HISTORY OF PERPENDICULAR MAGNETIC RECORDING IN THE UNITED STATES

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ABSTRACT

After the classic paper by Iwasaki and Nakamura¹ in 1977, a number of commercial efforts were begun in the United States, all intended to provide higher performance data recording systems and media. This paper reviews these efforts and discusses the current status of perpendicular magnetic recording ("PMR") in the U.S.

HISTORY

Perpendicular magnetic recording (PMR) had its genesis in the United States in 1977 following the astonishing paper by Iwasaki and Nakamura on circular mode magnetization. A number of companies immediately began research on PMR, several new companies were formed to commercialize the technology, and many PhD theses developed theories to explain the experimental results. Yet here we are, 12 years later, having spent many hundreds of millions of dollars (some would say close to a billion dollars), with commercialization just beginning. Why has commercialization required so much time and money, and what are the expectations that PMR-based products can recover this massive investment?

There was little guidance to researchers working with PMR from the previous highly successful work in increasing the areal density of **longitudinal** magnetic recording. PMR heads were different, signal processing was different, and the head-media interface and tribology were certainly different.

Two of the earliest companies to undertake the commercial development of PMR in the U.S. were **Vertimag Systems Corporation** of Minneapolis, MN and **Lanx, Inc.** of San Jose, CA.

The Vertimag Effort

The Vertimag effort was based directly on the research at Tohoku University, in that it utilized a double-layer flexible floppy disk medium designed to work with single-pole heads. The Lanx effort, on the other hand, was a single-layer **rigid** disk that was to be a direct replacement for existing hard disk systems using conventional ring heads. Both companies employed experienced researchers who had already expended considerable effort in understanding the physics of PMR.

Both companies experienced a number of developmental challenges. The promise of higher linear densities required either higher data-rate handling capabilities, or a reduction in disk angular velocity (with its concomitant increase in latency time and lower signal output). It became clear to the Vertimag researchers that a systems approach was required. This meant that a complete redesign of the floppy disk drive itself was required. While the tantalizing promise of increased storage capacity should have enticed a number of U.S. floppy drive manufacturers to consider manufacturing PMR-based drives, the timing was all wrong. The Vertimag effort took place at a time when most U.S. floppy drive manufacturers were either closing up

shop, or moving their production offshore. The last thing they wanted to consider at that critical time was development of a radically different drive suitable for PMR media.

Single-pole head design proved to be a major obstacle for the Vertimag development team. In order to obtain sufficiently high SNR at the higher bandwidth required by the higher density media employed, lower noise single-pole heads were needed, heads whose pole pieces had to have very high initial permeability. Vertimag, after some 18 months of work, perfected an annealing recipe for fabricating very low noise amorphous cobalt-zirconium-niobium heads.

The substrate of choice for PMR floppy disks was a polyimide film. Polyimide films can successfully resist the high sputtering deposition temperatures required in the CoCr coating process, but in the early 1980s, suitable films with very smooth, uniform surfaces were almost impossible to obtain. Surface imperfections in the film substrate degraded head-medium contact, resulting in data losses. Ultimately, super-smooth polyimide films were developed, but much too late for use in the Vertimag effort. Vertimag, however, pioneered this work, and its needs led to the now successful development of film substrates specifically designed for PMR applications.

The Vertimag team implemented a number of other features into their drive, such as constant linear velocity recording. In the Vertimag drive, the speed was adjusted proportionally to the head radius. This led to varying sectors per track, which were identified by headers indexed in RAM. A separate disk track carried information on the disk's defective sectors so that they could be reassigned.

Finally, a real-time error-correction scheme was incorporated so that single bit errors in any sector could be corrected on the fly. Many of these features, now common on disk drives, were quite novel at the time.

In the end, tribological problems proved to be the killer. Vertimag was unable to get repeatable, error-free, long-life results from its head/medium interface. Innumerable slider materials were tried. The usual method, used in particulate media, of incorporating a lubricant into the magnetic layer itself, is inapplicable with metallic films. Long-chain fluoro-carbon materials coated over the metallic films proved to be inadequate, as they could not be permanently attached to the film surface.

The Lanx Effort

Lanx approached the PMR opportunity via rigid media. Its founders were experts in sputtering technology and built their own in-line sputtering system. However, by relying on the drive manufacturer to make flying-height modifications along with significant changes in the read-write electronics, Lanx found it difficult to market its PMR disks, even though they provided definite advantages. The improvement in performance obtained by standard ring heads and PMR media was not sufficient to induce drive manufacturers to change their designs and accept PMR as a viable alternative to conventional oxide-based rigid media.

The changes required were considerable: a lower flying height to compensate for the reduction in signal level brought about by the higher linear density; modification of the detection electronics resulting from a radically different readback waveform; and an increase in the signal processing chain bandwidth required to accommodate the increased data rate. No effort was made to reduce the rotational velocity of the disk drive itself to help achieve these changes.

Interestingly, one of Lanx' great strengths --- its sputtering technology --- served to found today's longitudinal thin-film media industry. The modular design employed by Lanx in its multi-chamber disk sputtering device, in which the sputtering parameters of each chamber

can be independently controlled, are widely used now to manufacture conventional longitudinal sputtered rigid media.

Barium Ferrite Media

Barium ferrite has been promoted for some time as a particulate alternative to CoCr for PMR media. Its easy magnetic axis is perpendicular to its flat, hexagonal shaped surface. Thus, when the particles are completely dispersed and oriented with their flat surfaces in the plane of the medium, at least some of the improvements inherent in PMR are realized. The formulation conditions mentioned above are not easy to meet, and the actual manufacture of suitable BaFe particles has been a vexing and expensive proposition. Several companies now offer barium ferrite pigments on a commercial basis.

Nashua Corporation currently has an active development program in place aimed at producing high performance BaFe rigid disk media. Sample lots are now being delivered to drive manufacturers, and test results indicate improvements in D_{50} comparable to the best CoNi thin-film longitudinal media now available. **Iomega** offers commercially available BaFe-coated "Bernoulli Disks" which have recordable densities well above those possible with standard CoFe coatings. **Eastman Kodak**, **3M**, **Xidex** and several other U.S. companies now can provide BaFe floppy disks, although none is available commercially, and these coatings are more truly isotropic than perpendicularly oriented. To date, no one in the U.S. has attempted to use the barium ferrite coating in a true PMR mode.

Anodized Aluminum Media

In the late 1970's, while the Iwasaki group at Tohoku University focused on sputtered cobalt-chromium films that exhibited perpendicular anisotropy, **Dr. S. Kawai** of the **Pilot Pen Company** was working on an aluminum anodizing process in which a high density of microscopic

pores are etched into aluminum and then filled with an appropriate magnetic material such as cobalt, nickel, iron or the alloys thereof, using electroplating techniques.

These pores can be extremely small, with diameters in the range of 400 Angstroms and length-to-diameter ratios of perhaps 10, thus creating a magnetic material which is filamentary and of high coercivity. Further, these filaments exhibit a strongly preferred crystallographic orientation.

This anodizing method of fabricating PMR media has recently been reactivated after a hiatus of several years by a group at the University of Toronto. Not only have they been able to decrease pore size and increase density, but they have developed a method of depositing a high-permeability underlayer to provide the return magnetic path required by single-pole heads.

A novel implementation by the Toronto researchers is the use of photoresist to control the electroplated areas. In this way, narrow tracks can be established **mechanically** --- as narrow as 0.5 micron tracks have been produced experimentally --- thereby permitting easier track-following and reducing adjacent track crosstalk.

The current revitalization of anodized aluminum substrate media is being actively supported by a number of government agencies for use in high-reliability and extreme environment applications, such as aircraft flight recorders, missile data gathering and the like. Present flight recorders use a nickel foil medium operating at very low storage densities; thus the use of a high permeability magnetic material that would be both the substrate and the return path layer in a dual-layer PMR medium is not a large step. In this process, the aluminum layer is plated onto the etched nickel carrier, anodized to form the necessary microscopic pores, and these are then filled with magnetic material. This process shows considerable promise.

Censtor's Efforts

There remains one U.S. "startup" company still active in PMR. Often jokingly referred to as "the world's oldest startup company" because it was founded in 1981, **Censtor Corporation** (San Jose, CA) is now delivering several hundred 130mm and 200mm PMR disks monthly to selected customers. The company is also delivering its proprietary "monopole" heads, which are matched to the special PMR media. **Northern Telecom**, a prominent U.S./Canadian company manufacturing high performance disk drives, intends to use these Censtor heads and media in a drive offering well over 1,000MB of storage capacity.

The Censtor media are dual-layer types, but the underlayer is **not** the usual NiFe high permeability layer cited in the literature. Company researchers have found that the performance of the active magnetic layer is highly dependent on the structure of the underlayer, and that this structure is a function of its composition and the deposition method used. Censtor media and heads made on a semi-commercial basis show improvements in areal density of at least five times current high performance longitudinal media/ring head combinations.

Censtor has already spent close to **\$40 million** in PMR research and development, and is just now, after eight years, able to supply evaluation samples. How much more time, and how much more money, will be needed to bring its heads and media into full production, remain very good questions!

Longitudinal Vs Perpendicular Recording

While intensive development work was underway in PMR, huge improvements in longitudinal recording media, heads and systems have been made. Thin-film coatings and metal-in-gap (MIG) heads make possible the use of longitudinal media with coercivities above 1500 Oe, and smoother surfaces allow lower flying heights, some as low as

four microinches. Linear densities in the best longitudinal media are already approaching those considered theoretically attainable by PMR. Except for barium ferrite media, the use of PMR technology in Winchester applications may be too late to become commercially significant.

Meanwhile, in **flexible** PMR media, barium ferrite is finally coming onto the marketplace. However, better control of head-media spacing, and the opportunity to match the heads, disks, and electronics into an integrated subsystem, hold out the promise of a commercially viable superior **CoCr** thin-film flexible PMR medium. **Sony** has been able to commercialize an evaporated thin-metal film tape for 8mm video applications. The wear, tribology and uniformity characteristics of this tape are similar to those of sputtered PMR media. Can PMR thin-film flexible disks and tapes be far behind?

Future Requirements

The need for increased storage density continues unabated. With the development of the digital video systems that are required for high-definition television (HDTV), the need for digital VCRs for consumer use is apparent. Digital VCRs currently require large quantities of tape, and this should motivate the media engineer to increase still further areal storage density in order to reduce the amount of tape required to record a program of 90 or 120 minutes duration. Fully compressed HDTV requires a data rate of about 60Mb/second, or about **50 GBytes** for a two-hour program! PMR technology could well make such capacities in a small cartridge practicable.

References:

1. S. Iwasaki and Y. Nakamura, IEEE Trans. Mag., Vol. Mag-13, 1272 (1977).
2. S. Kawai, Electrochemical Technology in Electronics, Proc. of The Electrochemical Society, Vol. 88-23, 389, 1987.