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RIGID DISK MEDIA

COMPETITIVE TECHNOLOGY REPORT
RIGID DISK FILES

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1.0 ACKNOWLEDGEMENTS

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A more complete account of the LOW END activity may be found in Tom W. Glaser's report "DASD TECHNOLOGY COMPETITIVE ANALYSIS DISK TRENDS - LOW END", August 19, 1989. Much of Tom's work is used verbatim in this report.

2.0 RIGID DASD ENVIRONMENT

In the external environment, Low End files using standard interfaces and standard form factors are rapidly evolving to become very high performance, high capacity devices. Newer drives are being designed around extensions to the SCSI interface, promising data rates in excess of 4 MB/sec. Seek times are now in the 12 ms range, and dropping. Capacities for announced 5.25" drives are already in excess of 1 GB. The IBM LIGHTNING 3.5" file is just beginning to ship with a 320 MB capacity and 12 ms seek time. The Rochester CSL DABB prototype 2.5" file has a 7 ms seek time and 3 ms average latency.

The manufacturing costs for these drives, including associated electronics, is well under $1000, with a development cycle of 18 months to two years. In a number of areas, the technology used for the low end files is quite different from that used for the high end files. Those differences help to make fast development and low cost possible. With small diameter drives, the differences do not carry the same performance penalties which they carried with larger drives. This shift in the Low End market, combined with the emergence of new, aggressive technologies such as the MR and MIG heads have important implications for High End DASD.

At the same time, High End HDA's are shrinking toward the Low End size, and in fact have met at 5.25". Thus a collision between High End and the high range of Low End DASD may occur within six (6) years. This implies that, with a different control unit and data management, the same HDA may serve both Low and High End files. Even as this report was being written, Imprimis Technology announced a new 5.25" drive 'ELITE'. A comparison of 'ELITE' with IBM's IPI/SUTTER (3Q90) shows the trend of this collision.

		ELITE	IPI/SUTTER
CAPACITY	GB	1.2 1.5 (zone)	1.5
AVE SEEK TIME	msec	12	12
LATENCY	msec	5.6	5.6
DATA RATE	MB/sec	3 (4 SCSI)	4.4
MTBF	Khours	100	400+

HIGH END RIGID DISKS

3.0 HIGH END ENVIRONMENT

HDA - Trends are for smaller diameter disk stacks with increased areal density to obtain large capacities in smaller HDA's. Fujitsu first introduced the High End smaller disk with the 10.5" Eagle HDA in 1982. JCM companies followed with 9.5", 9", 8.8", 8.3" and 8" diameter disks. We will join the trend with the IBM 3390 at 10.8", and extend it with Sutter at 5.25".

The movement toward smaller disks brings with it many HDA improvements. Power required to drive the spindles and actuator drops rapidly with reduced disk diameter. Thus, these designs consume less power and generate less heat while offering greater packing density. In addition, the mechanical resonant frequencies are increased. Use of small disks has also led to higher performance, with decreased latencies and lower average access times.

Of particular note in the move toward smaller diameter disks is the elimination of the performance advantage of linear actuators that was realized in larger files. Small size brings with it small data bands and increased mechanical resonant frequencies which make possible the use of rotary actuators in High End DASD. JCM companies have made impressive use of rotary actuators with smaller disk HDA's. The simpler bearing structure of rotary actuators can be manufactured less expensively than a linear actuator. In addition, linear actuator ball bearings generate particulate debris at the rolling surfaces. Debris generation is minimal with rotary actuators. Also, at the 5.25" disk size, it is easier to fit the rotary actuator within the OEM industry standard form factor.

IBM San Jose has minimal experience and no activity with rotary actuators. We recommend a joint development activity between Research, Rochester, and San Jose to explore the use of rotary actuators in High End DASD for HDA's with disks between 5.25 and 3.5". The use of composite and ceramic materials should be studied in addition to conventional materials.

The subsystem is using buffering, caching, intelligent interfaces, faster channels and serial optics, to improve performance. Higher MTBF's are being proclaimed in device specifications, and remote diagnostic/maintenance strategies are being used to provide high availabilities.

3.1 COST/MB

Cost/MB continues to drive most key design decisions for High End files. Unlike the Low End, with its broad product range, High End DASD tends to be centered on one or two products, both with S/MB as the main goal.

Conservative designs and components used in IBM High End files have been used to obtain greater product reliability. The challenge facing IBM High End is to provide increased reliability at greatly reduced cost.

3.2 AREAL DENSITY

PCM competitors have responded to IBM's capacity with products 12-15 months later using lower areal densities. In the case of competitive 3380K's the areal densities range is 75-96% of IBM products. Hitachi's Standard and "E" equivalents used ferrite heads and obtained densities of 9 and 14 Mb/sq.in. Using thin film heads they jumped to 34.5 Mb/sq.in. and coupled with dense modular packing shipped with twice our capacity (15GB) only one year after the IBM 3380K. Hitachi continues to lead the PCM with an announcement this year of 64.4 Mb/sq.in. (DK312C-25 at 1660 TPI and 38.8K BPI). The IBM 3390 has 62 Mb/sq.in. and Sutter (GA 3Q90) 107 Mb/sq.in.

The use of MR heads to extend areal density creates a number of new issues if used for the servo PES. The PES linearity and stability under variations of current and external fields are not well understood for MR heads. Read-to-write offsets can be a new source of TMR, especially when used with rotary actuators. These issues need to be studied if the MR head is to be used in PES functions.

3.3 PERFORMANCE

High End customers continue to demand faster response times with increased throughput rates. Seek time, latency and data rate enhancements will be a high priority over the next decade. High End DASD with its count-key-data architecture has been dependent upon channel speeds as an upper limit to data transfer rates. Thus the IBM 3380 family was limited to 3MB/s data rate. With faster channels (4.5MB/s) the IBM 3390 will attain 4.22 MB/s data rate. Both Fujitsu and Hitachi have already announced system channel speeds of 9MB/s and 6MB/s respectively and are introducing serial fiber optic links. Competitors with higher data rates than IBM include NEC's GEMMY file of 8.8GB with 4.4 MB/s and Hitachi's 2GB DK816-20 at 4.5 MB/s. Internal IBM activity is high to provide increased data rate for the future.

Average access times for both IBM and PCM's have remained in the 15-17ms range with the exception of the Hitachi "K" at 12.5ms. The IBM 3390 will match that time.

3.4 SERVO

Digital servos were introduced into the DASD market with the low end CONNER and MAXTOR drives. GPD followed these simple early products with a substantially different, high performance digital servo in the 3380 J and K. High end PCM's have continued using analog servo systems, with GPD digital products demonstrating leadership in track arrival quality but only breaking even in overall performance.

The servo situation cannot be viewed from just high end competition. The rapidly moving low end market has resulted in significant advances to the servo control art. In the past, high end DASD dominated servo performance. Now, low end drives have equalled the high end in performance, and prototypes (Rochester's DABB sector servo with an average seek time of 7 msec.) have exceeded it. Samples of the patent, publication, and aggressive concepts used by the low end to improve performance are:

- Hewlett-Packard patented (1987) a method to contain HDA vibration effects in small, light weight drives using base plate acceleration feedback. (SUTTER will use this method).

- The Vermont Research model 7030 used an augmented state estimator to adaptively adjust for changes in the elastomer of the shock mounts and other HDA materials. (GPD is pursuing this control method for future products.)

- The IBM Rochester LIGHTNING drive features thermal compensation to reduce TMR for every head.

- The Rochester 2.5 inch DABB prototype uses sector servo to reduce TMR. (High end DASD has been frustrated attempting to use sector servo with the count-key-data and cylinder mode demands.)

As the high end disk size becomes smaller, the competition facing the servo area expands from the high end PCM's to include many of the low end competitors. These companies have a wide range of low cost, high performance digital signal processing components available to them. The Texas Instruments TMS320 family is widely used. Analog Devices, Inc. has advertised their ADSP-2101 as "...well suited to handle digital servo control system tasks..." with a reference to IBM's digital servo patent.

In general IBM has a leadership position in servo systems and pattern/demodulators. However, with low cost components and a wealth of control system knowledge readily available, the competition is ready to move into the high end digital control field. Pressure to maintain IBM's high end leadership position will be significant.

3.5 DISK ARRAYS

A concept that may reshape High End storage is the use of disk arrays. Large groups of small disk files (3.5 - 5.25") provide large amounts of data, are potentially faster, cheaper and occupy less floor space than the large High End DASD. By adding parity information in either a dedicated HDA or distributed within the array, a large increase in MTBF may be attained. Maximum Strategy has announced an array controller, while Micropolis has test marketed an array of 5.25" drives with limited success. Imprimis Technology has introduced "Arraymaster" and is shattering existing data-transfer rates by posting speeds of 22 MB/s. Combining parallel transfer drives and disk arrays the Imprimis offering allows users to transfer files at speeds ranging from 16 MB/s with parity to short burst rate of 25 MB/s. In addition, Auspex Systems announced plans to introduce a disk array for midrange computers in January, 1990, with the claim that, for the first time in history, smaller drives are cheaper per byte than larger drives. They plan to replace a $100K 7.5 GB file with an array of ten 780 MB drives for $35K. IBM is planning to provide an array to SSI based on the 5.25" Placer product.

3.6 RELIABILITY

High End file reliability has always been in a state of improvement thru each generation. This results from need, as the box capacities increase, and from pressures brought about by Reliability Plus (R+) comparisons. Unlike the Low

End files with 'advertised' MTBF as the main comparison, High End files face the measurement of machines operating in customer environments.

The Hitachi version of '3380 E' has established an outstanding record in Reliability Plus, and now their 'K' is considered best-of-breed because of its superior R+ performance. With the fastest average access time of 12.5 ms, high packaging density of 15 GB/box, and lowest power and cooling requirements, this JCM product is our major competitor.

The use of disk arrays to enhance reliability is in the forefront of outside activity. Adding parity information in a dedicated or distributed system will greatly increase the MTBF. Randy Katz, a Berkeley computer scientist, claims to have found ways to reduce the number of extra drives in an array, while insuring against loss of data. While not everyone agrees that arrays will help reliability, it is an area of study where IBM should place greater resources.

3.7 CONCLUSIONS

HDA size will continue to shrink, with 5.25" the dominant leader thru the early 90's. 3.5" devices will emerge, perhaps from the high range of the 'Low End' products.

All key metrices will continue to improve aggressively, being pushed from both PCM's and Rochester.

The use of disk arrays is expected to grow and become a part of the 'High End' family.

Fujitsu, forecasting trends, presented its projections in a general review session of IEICE in February, 1988. The comparison is between current capability of the industry vs. what is likely to develop in 4-6 years.

DRIVE PARAMETER	CURRENT CAPABILITY	NEXT STEP
Linear density (bPI)	30K	80K
Track density (TPI)	2K	3K
Areal density (Mb/sq.in)	60	240
Access time (msec)	15	10
Data rate (MB/sec)	4.5	9.0
Rotating speed (RPM)	3600	5400
Cost of file ($/MB)	8	2.4
Cost of media (cents/MB)	40	12

4.0 LOW END ENVIRONMENT

The general arena encompassed by low end storage is actually very broad in scope. It spans the very low cost, low performance entry products that in the next several years will include portable applications, thru medium capacity (1 GB and higher per spindle), to high performance drives for powerful mid-range systems. With this breadth, it is difficult in all of the technology areas to make sweeping conclusions.

For example, in the area of heads used in low end drives, the span is from the least expensive, low performance 'street' ferrite heads to the planned use of the highest technology MR heads known in the industry. A like span of technologies exists in the other key technology areas of low end DASD. In fact, this breadth of technology usage is perhaps one of the more interesting attributes of low end files.

Perhaps the key conclusion for the general nature of the low end business is the intensity of the competition, with numerous, competent, competitive companies participating in this industry.

For the next two years, two clear trends emerge: substantial growth in number of units shipped and the rapid assumption of the 3.5" form factor as the volume leader in the low end business. This is not meant to imply that the profit $ follow this trend, but this substantial volume swing will have some effect in the resultant cost of components, thus further reducing the gap in cost/MB between 3.5" and the larger drive sizes.

Clearly, as one looks into the future of low end files, continued growth in areal density, volumetric density and other key measurement parameters will occur. Several additional key trends are also developing.

First is the relatively new arena of clusters of small drives configured to emulate the characteristics of large files. Several firms have, or are, marketing such arrays. One of the simpler products is the MICROPOLIS cluster of 5.25" drives (product now withdrawn). These products are beginning to proliferate, claiming key advantages of lower cost for the performance and improved data integrity through the use of several different redundancy schemes. We expect continued rapid growth in this area over the next several years, resulting in low end devices infiltrating applications and product areas generally considered to be the high end.

Second is the emerging area of the portable system, sometimes referred to as 'laptops'. This application places a premium on small size, very low power (especially for the battery versions), and substantial shock resistance. Growth in this part of the industry is explosive; just in the last six months, the entire subarea of 'notebook' systems has taken off with the announcement of the NEC ultralite system. Though these systems do not contain DASD as yet, they soon will, applying further pressure to the very low end entry points for DASD.

This area is very significant from a technology point of view in that the product requirements are driving the development of DASD related technologies for very low power, small size and weight. Thus, low power semiconductor chips, power management techniques, etc. will have application in improving the product set sitting above the extreme low end.

Several measures of the competitiveness of low end products have been chosen for analysis and tracking to better characterize the nature of the entire low end arena. Cost/MB, performance, reliability, volumetric density, areal density and power consumption are key to the arena of low end DASD.

The relative importance of each to the other varies across the span of low end products; an obvious example relates to entry cost vs cost/MB. At the very low end of the product spectrum, entry cost reigns; at the high end, cost/MB is the more important measure.

4.1 COST/MB

Cost/MB has been historically, and continues to be perhaps the most often looked at measurement parameter for low end DASD. Analysis of historical data shows a compound decline rate for low end devices in the range of 20% per year in general, with smaller form factor drives having the lowest $/MB.

Smaller form factor drives (3.5 - 5.25") have offered the lowest $/MB since 1987. This is due in part to the much higher volume of production lowering the base cost, and the extreme pressure on pricing and lower profit margins in the smaller drives.

4.2 AREAL DENSITY

The historical growth curve for areal density has been well quantified. For 3.5" form factors the trend shows areal density doubling approximately every 16-18 months.

Independent publications of areal density trends show similar growth over time, but add other interesting perspectives. The 2/10/89 publication of Storage News Report for example asserts that the areal density of small drives (3.5, 5.25) is increasing at a faster rate than larger drives (8, 14). This trend is consistent and is one of the factors in the more rapid decline rate in cost/MB for the small sizes relative to the larger sizes.

Low end storage products do not demonstrate clear areal density leadership in all cases; this should not be surprising in that many of these products currently use vendor heads and disks, 'street' technology. This results in little leverage for the key components of the recording subsystem.

This situation is expected to reverse somewhat with the planned introduction of the MR head into low end products. However, within the past six months or so, several reports from Japanese companies have fueled speculation that MIG heads are extendable to areal densities of 100 Mb/in2 and beyond. If such capabilities are shown to exist, the advantage of MR over MIG for the low end becomes less clear, especially in terms of the timing of the introduction of MR into the very low end of the product line.

A key issue just becoming more visible in low end competitive products is the emergence of constant density (or data banding) recording. IMPRIMIS, among others, is beginning to use this technique to achieve higher effective areal densities, some advertising up to 30%. One would expect data banding to become more pervasive, especially at the low end, where with the lower inherent data rates at the inner diameter, the cost of implementation is not prohibitive. This area is one where IBM's current efforts are behind competition.

4.2.1 VOLUMETRIC DENSITY

If "Volumetric Density" is used as a figure of merit, the growth curve is steep, approximately doubling every 14 months. LIGHTNING is the first product developed with maximum volumetric density as one of the key initial design objectives. This objective has been achieved, with a clear leadership position established.

The key technology elements driving this parameter are, of course, all of the elements of areal density, still the most significant element of volumetric density. But other technology developments are key as well. One example is in the area of electronics chip packaging. As various methods of direct chip attach such as TAB, DCA wire bond (to flex or other second level package carriers), and others become more mature, the volume occupied by the electronics will be further reduced. This development will permit easier replication of configurations like LIGHTNING, where the required electronics is truly 'wrapped' around the mechanical components.

These packaging techniques will also permit sub 3.5" drives to continue the trend toward smaller overall device sizes.

Advancements in spindle/spindle motors, aggressive actuator to disk stack merge techniques, reduction of disk thickness through the use of glass or glass ceramics and reduction in the slider/suspension dimensions are sample key technology developments that will fuel the further growth in volumetric density. Many of these are being examined and developed within IBM, but there is evidence of similar emphasis and activity in the competitive community as well.

4.3 PERFORMANCE

Compared with some of the other metrics, performance has only recently become an important issue in the low end drive arena. When DASD first appeared in the PC marketplace for example, access times in the vicinity of 100 ms were not uncommon. The basis for user comparison at the time was the relative speed of DASD vs the previous storage devices used in PC's, flexible disks and tape cartridges.

This situation has changed very rapidly however, with the result being that now the low end performance criteria differs very little from the high end, and in the next several years, may in fact surpass the larger drives.

A figure of merit was conceived in 1986 which consists of the required drive factors such as access time, latency and data transfer time for a 16 KB DASD operation. The decline rate for 3.5" drives for this operation time is about 20% per year. For the next several years, this trend is likely to continue.

It should be noted that this decline depicts the raw performance of the individual drives and does not address the recent proliferation of RAM caches at the low end to reduce the number of accesses actually made to the physical DASD.

This structure is becoming more typical to further improve performance in the more powerful of the low end machines.

Overall, the IBM low end storage products at present are competitive, with devices like LIGHTNING and REDWING showing clear leadership.

Key elements of technology that enable this performance gain are relatively low cost high energy magnet materials like Neodymium Iron Boron. This and like developments have permitted the construction of low cost rotary VCM actuators for even the very low end of the device spectrum. These devices have typical average access times ranging from 16 to 30 ms.

4.4 SERVO

Servo positioning systems vary widely in low end devices, and at the bottom end of the spectrum contribute in a substantial way to relatively conservative single track seek times (5-7 ms) as well as relatively slow settles. One typical example is the CONNER PERIPHERALS positioning system. Later CONNER drives improve this significantly, and one should expect that the servo area will continue to improve in competitor products as time passes. It should also be noted that the CONNER system is a simple digital servo which uses a low performance (and likewise very inexpensive) microcontroller. In net, the implementation cost of the actuator control for drives of this type is very small, i.e. somewhat under $10 for drives like CONNER.

The higher performance competitive drives continue to use dedicated servo with fairly simple control methods. Performance of these drives, e.g. MAXTOR, is generally better than the very low end designs, with typical average access times in the 16-18 ms range today, projecting down to 11-12 ms in the next year or so.

In general, IBM product offerings demonstrate clear leadership in positioning systems, especially in the servo area. With the continued focus on improvement of actuator controls, both in the pattern/demodulator area and control algorithms, this leadership position is anticipated to continue.

4.5 RELIABILITY

In a way, reliability in the low end drives was slower in becoming an important measure than cost and other parameters. Despite this delayed recognition, drive reliability has been in a state of continual improvement and now is a very important parameter in the measure of the competitiveness of any low end product offering. This is somewhat more difficult to quantify in that relatively little is known about the real reliability of competitive drives. In fact, even information about IBM DASD offerings in low end applications is limited. The environment of purchased machines such as the PC/PS marketplace limits the amount of reliability feedback, thus making the actual long term reliability difficult to verify.

As a result, the comparison parameter used in competitive analysis is the reliability advertised or claimed by low end competitors. Though difficult to compare, the known data on the IBM offerings typically show that the actual MTBF's run 2X or better than 'advertised' values. Our best analysis shows no such similarity in the competitive offerings in general. Products like the current LIGHTNING and REDWING devices are advertised at values above the average, with the actual much better.

A direct comparison with a competitive product has been made. In this analysis, LEE was compared with one of the current DEC offerings. This comparison shows clear leadership exists for the IBM product. Comparisons also exist for MAXTOR and other drives; in each case, clear leadership for the IBM products is the trend.

The future trend in this area is for continued improvements in reliability. One area that some of our low end competitors have yet to leverage effectively is the use of large scale integration. Even the Japanese (oddly enough given their electronics technology) continue to ship largely non-integrated electronics packages with large component counts. Selected drive competitors, for example CONNER PERIPHERALS, counter this general trend effectively with aggressive electronics packages that net better projected reliability of the drive electronics. More leveraging of LSI will result in continued improvements in reliability.

4.6 CONCLUSIONS

Several key trends remain clear at the low end. Device sizes will continue to shrink; 2.5" devices are emerging and will grow substantially in the next 3 years. 3.5" devices will be the dominant volume leader in this time frame, but 5.25" drives will remain strong and will be the margin (and likely profit) leaders.

All of the key metrics described will continue to improve aggressively, closing in on (or possibly surpassing in some cases) the high end in cost/MB, volumetric density, and in some cases performance.

The use of small drives in arrays or clusters is expected to continue to grow and to apply additional pressure to the high end arena.

5.0 APPENDIX (HIGH END JCM/PCM COMPANIES)

Hitachi

Hitachi is Japan's leading manufacturer of electrical and electronic equipment and is a major supplier of computer systems. The total net sales of $33.4B in 1987 included an estimated drive revenue of $640M of which approximately $215M is PCM. They currently market a wide range of fixed disk drives, which as captive drives are used with their Hitachi systems. Some are sold as OEM drives. They have had significant OEM sales of smaller disk drives and in addition have established IBM PCM marketing relationships with Comparex, Olivetti, and NAS of which it is part owner with EDS. Hitachi has a manufacturing facility in Norman, Oklahoma from which it has been shipping rigid disks drives since the spring of 1987.

Their "E" type 3380 has established an outstanding record in Reliability Plus. Their "K", FCS 3Q88, was considered best-of-breed because of its superior R+ performance, fastest average access time of 12.5 ms, high packaging density of 15GB/box, and lower power and cooling requirements.

Technology/development credits include:

- o First JCM to ship 'E' & 'K' equivalents
- o Advanced from low technology to 'K' equivalent at 35Mb/sq.in.
- o Highest areal density in a JCM OEM product, 64.4Mb/sq.in.
- o Highest R+ for both 'E' & 'K' equivalents
- o First with 15GB box
- o Introduce technology in OEM products and transfer to high-end products- T/F heads, linear actuator, surface mount technology (SMT), AE module
- o Different mechanical integration design point on their 'K'
  - low lube, low pitch angle, low flying height, start/stop on data, do not unload heads nor lock carriage or spindle before shipment
- o Material science - solid ceramic ways, Zr sliders
- o First with BI-CMOS and SMT in a high-end product
- o First to use (1,7) code in a high-end product
- o Highest DASD (OEM) data rate - 4.5 MB/s
- o Introduced 600MB 5.25" drive in 1987 with 4786 RPM
- o Announced 6MB channels with solid state disks and tape
- o Serial fiber optic DASD link - 1KM at 3 MB/s

Fujitsu

Fujitsu is known as the leading manufacturer of computers for the Japanese domestic market, from which it derived almost 70% of its total net sales revenue of $12.3B in 1987. They had an estimated drive revenue of $1.5B in 1987 with a PCM business of $215M. This is the result of strong OEM and PCM markets.

Fujitsu developed its own captive drives and aggressively marketed them in OEM versions using industry standard OEM interfaces. In this market they have been very effective in the high performance 8", 48 through 1000 megabyte drives, and with the 10.5" Eagle series of high performance drives which operate up to 3 MB/s. These Eagle drives have been a major factor in the IBM PCM market through their marketing relationship with Amdahl.

Technology/development credits include:

- o First PCM with a smaller disk - 10.5" Eagle HDA
- o Second highest areal density in a JCM high-end product - 32 Mb/sq.in.
- o High quality and high efficiency ferrite heads
- o Sputtered oxide disks with SIO2 overcoat
- o Low head-to-disk spacing - 6.5 uinch
- o State-of-the-art HDA packaging
- o Participant in GEMMY file development for NTT
- o Announced 9MB channels with solid state disks and cache

NEC Corporation

NEC attained total revenues of $16.9B in 1987 primarily from its communications and computer business. 44% is estimated to be from computers and disk sales were estimated to be $1.3B. Historically NEC has not been a PCM vendor. Current drive production ranges from large to small fixed disk drives for both their captive and OEM markets. Due to strong sales of smaller drives in the OEM market, as well as NEC's strong position in the personal computer market, a number of these products have enjoyed large scale production. NEC along with NTT and Fujitsu have jointly developed the 8.8 GB GEMMY file which was FCS 2Q87 using 40Mb/sq.in.

Technology/development credits include:

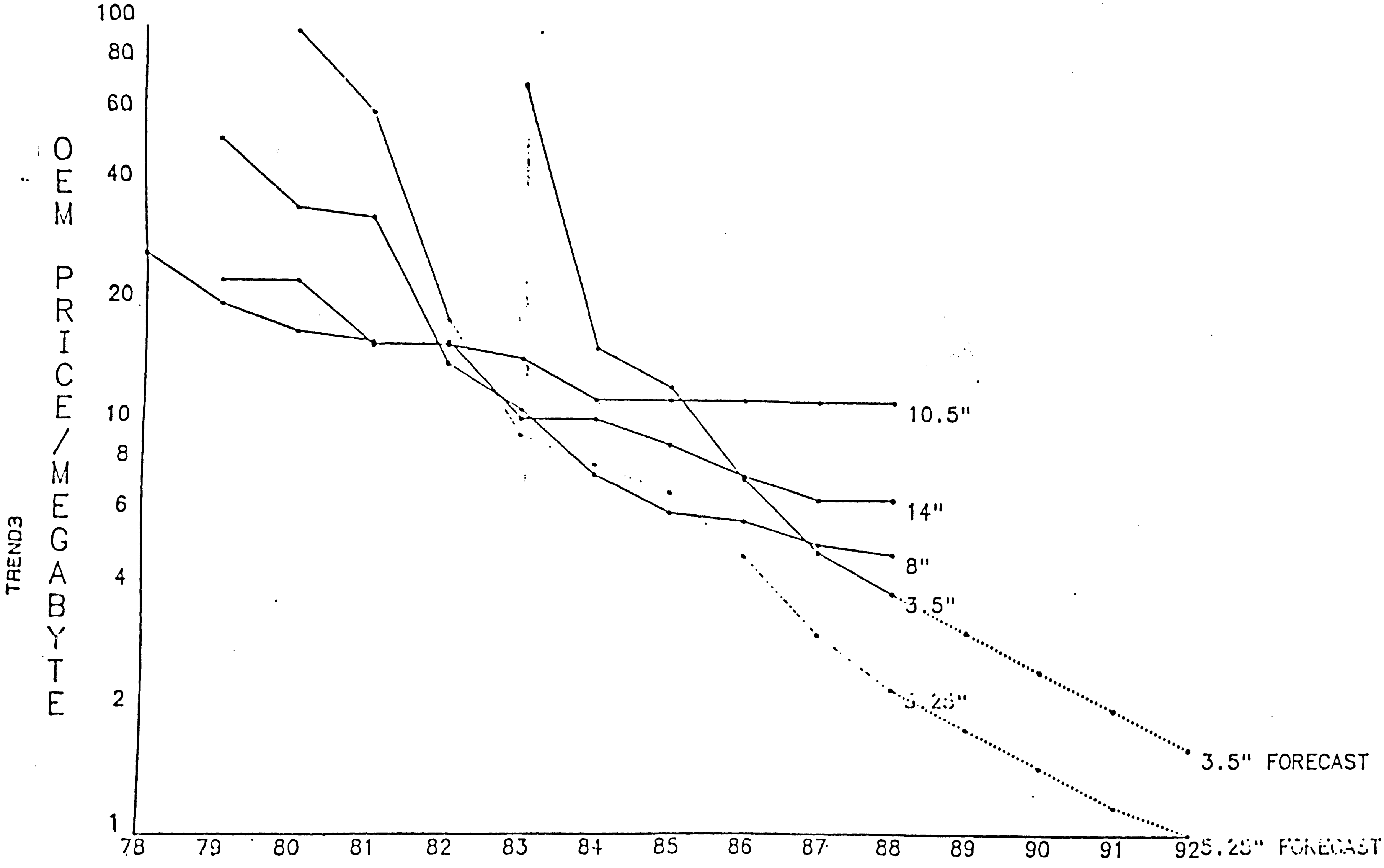
- o First T/F head in a JCM high-end product
- o Introduced PATTY file technology to an OEM product
  - Plated media with SIO2 overcoat
  - Taper/crown heads
  - Head-to-disk spacing of 9.5 uinch
  - Low cost HDA
- o NTT GEMMY file (NEC/Fujitsu)
  - High JCM areal density of 40Mb/sq.in.
  - Low head-to-disk spacing of 7 uinch
  - High data rate of 4.4 MB/s
  - First JCM DASD with film head and film media
  - Non SJ IBM magnetic design point
    - Thick pole piece T/F head of 3 um
    - High coercivity media of 700-820 Oe
  - Ceramic actuator components

Storage Technology Corporation

This company had total net sales of $750M in 1987 of which disk sales are estimated to be $179M. They had good success in the late 70's as a leader in PCM drives. Then their shipments dropped rapidly as the IBM 3380 products reached the marketplace. As a result of their management overextending their business ventures they were then thrown into Chapter 11. This coupled with late 3380 products has led to a declining PCM share: 1981=60% 1987= 28%. They delivered their first 'K' in 4Q88. They continue to have good U.S. large account marketing/service coverage. Information seems to indicate they are strategically focusing their efforts on tapes, libraries, and SSD's. Also, with development resources constrained, they appear to be negotiating outside for future HDA technology.

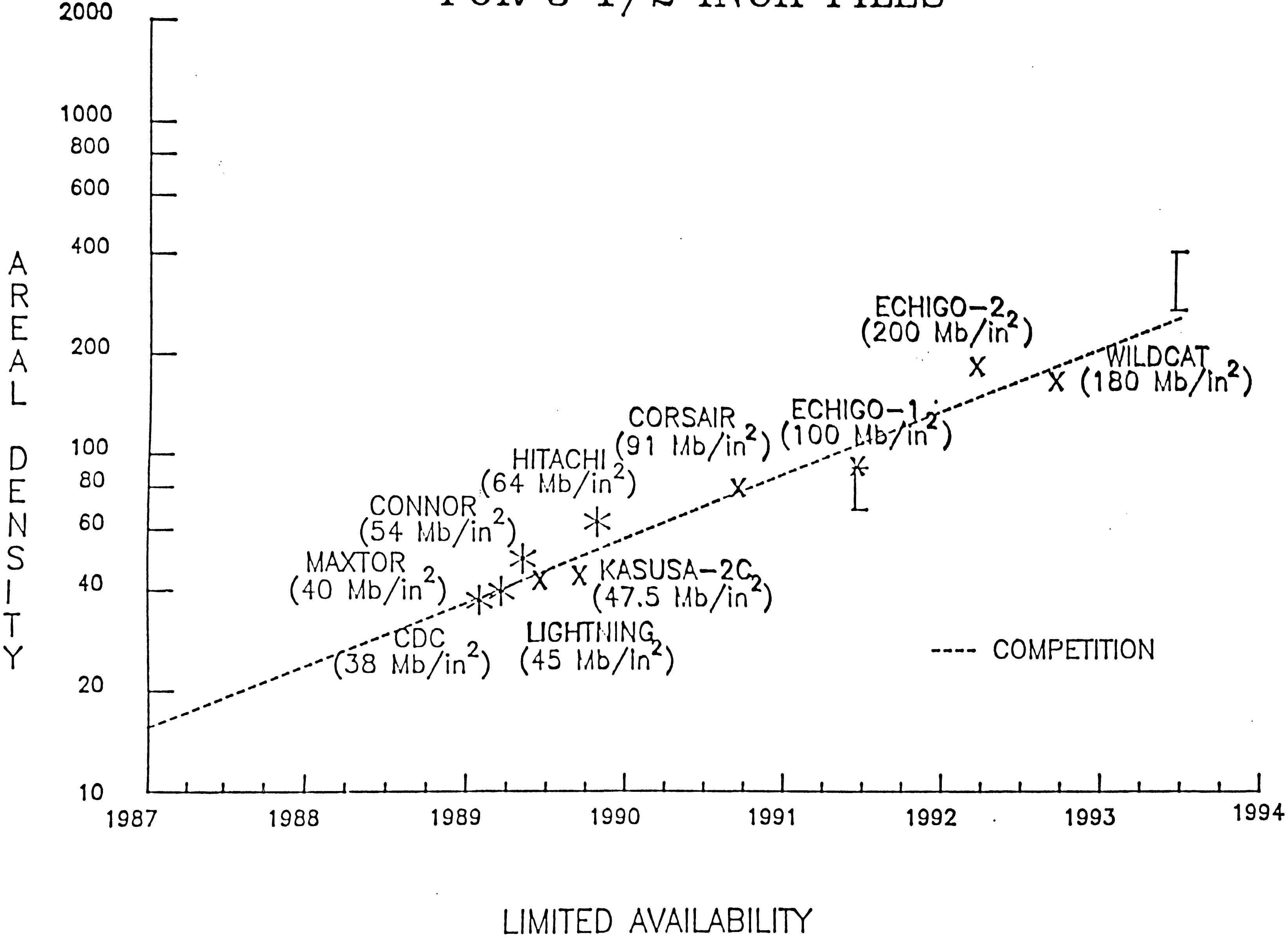
6.0 ATTACHMENTS

DASD $/MB OEM PRICE TRENDS
INDUSTRY LEADING PRICES / HIGH CAPACITY
BY FORM FACTOR



IBM INTERNAL USE

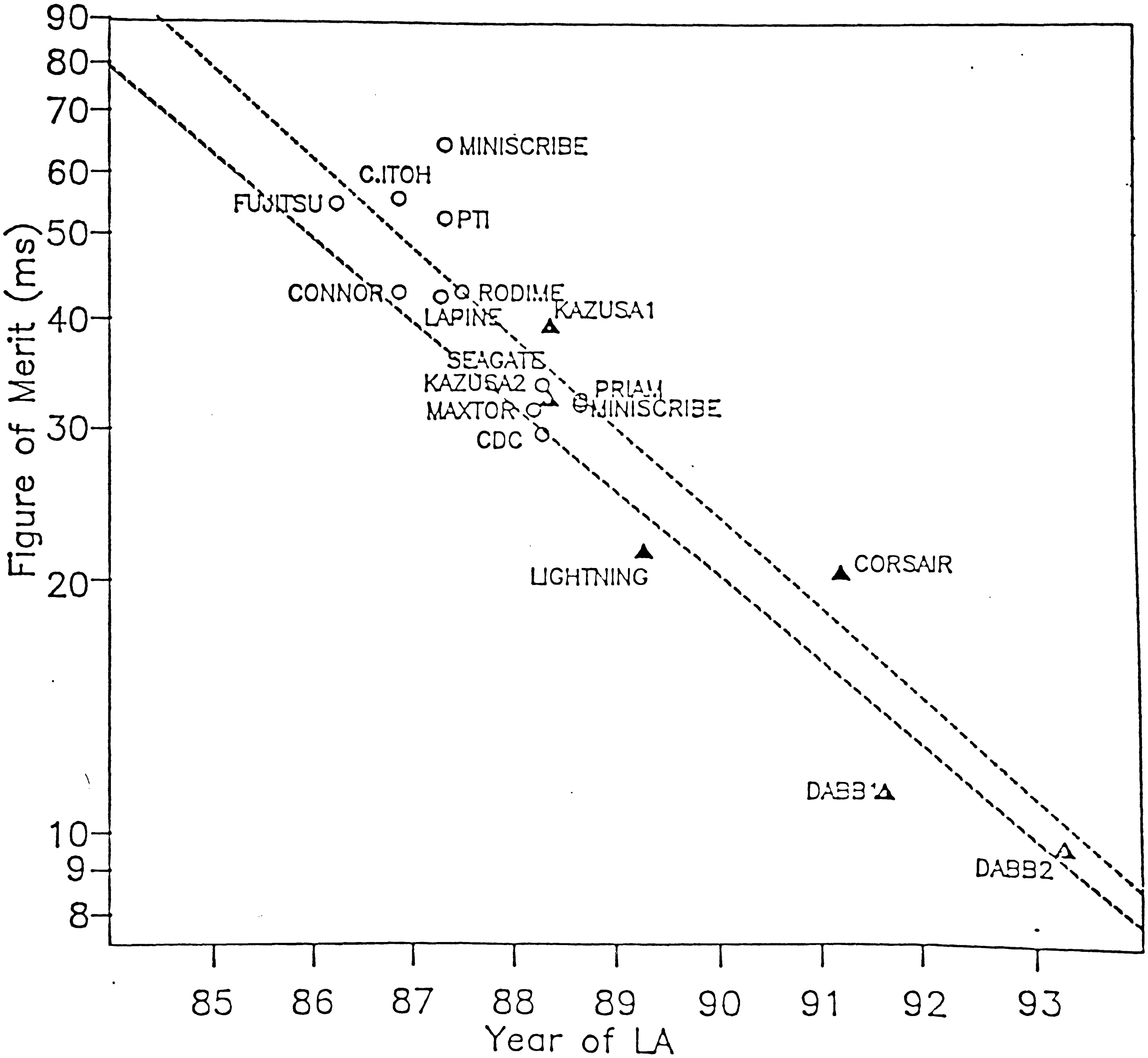
AREAL DENSITY VS LIMITED AVAILABILITY FOR 3 1/2 INCH FILES



twg05

IBM CONFIDENTIAL

Performance Figure of Merit
(3.5" and smaller drives)



Projection curves based only on OEM mfgrs
(Those shown plus 21 more not shown with LA's prior to 3/86)

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COMPETITIVE TECHNOLOGY REPORT
RIGID DISK FILES

December 4,1989

Hal C. Stephens
G93/025 San Jose
SJEVM5(STEPHENS)

IBM Confidential

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RIGID DASD ENVIRONMENT

- LOW END becoming:
  - o High Performance
  - o High Capacity
  - o Still cost under $1000
- HIGH END
  - o HDA shrinking to Low End Size
  - o Competent Competitive Companies
    - — Hitachi
    - — NEC (D2387) 9″ Form Factor at 3.1 GB and 4.5 Mb/sec (GA - 1Q90)
- LOW END - HIGH END HDA COLLISION
  - o High Range of Low End
  - o Imprimis Technology 5.25″ Elite

Table 1. Comparison between Imprimis Technology ELITE and IBM SUTTER

	ELITE	IPI/SUTTER
CAPACITY (GB)	1.2 (1.5 zone)	1.5
AVE SEEK TIME (msec)	12	12
LATENCY (msec)	5.6	5.6
DATA RATE (MB/sec)	3 (4 SCSI)	4.4
MTBF (Khours)	100	400+

HIGH END ENVIRONMENT

- Smaller Diameter Disk Stacks
  - o Fujitsu first with 10.5″ Eagle
    - — 3390 at 10.8″
    - — Sutter at 5.25″
  - o Power drops rapidly with reduced disk diameter
  - o Higher Frequency Mechanical Resonances
  - o Rotary Actuators in Smaller HDA's
- COST/MB
  - o Conservative Designs
  - o Components
  - o Reliability

HIGH END

- AREAL DENSITY
  - PCM's traditionally respond using Lower Areal Density
  - Hitachi at 64.4 Mb/sq.in.
  - MR heads
- PERFORMANCE
  - Access Time May be Surpassed by Low End
    - Rochester's prototype DABB sector servo at 7ms AAT and 3ms latency
  - Channel Speeds Pushed by Fujitsu (9 MB/s) and Hitachi (6 MB/s)
  - Data Rate Competition with IPI-2 Interface, e.g. Imprimis 8″ Sabre 5 at 6 MB/sec

HIGH END

- RELIABILITY
  - R+
  - Hitachi
- DISK ARRAYS
  - Potentially Faster
  - Less Expensive
  - Less Floor Space
  - May Increase MTBF
- FUJITSU FORECAST

Table 2. FUJITSU 4-6 YEAR FORECAST (1988)

DRIVE PARAMETER	CURRENT CAPABILITY	NEXT STEP
Linear density (bPI)	30K	80K
Track density (TPI)	2K	3K
Areal density (Mb/sq.in)	60	240
Access time (msec)	15	10
Data rate (MB/sec)	4.5	9.0
Rotating speed (RPM)	3600	5400
Cost of file ($/MB)	8	2.4
Cost of media (cents/MB)	40	12

HIGH END

- CONCLUSIONS
  - o HDA size will continue to shrink
  - o Key Metrics will continue to improve
  - o Use of Disk Arrays to increase
- RECOMMENDATIONS
  - o Rotary Actuators
    - — GPD has minimum experience & no activity
    - — Recommend joint activity with CSL
    - — Recommend ARC investigate composite & ceramic materials..
  - o MR head - TMR impact
    - — Recommend joint activity with ARC

LOW END ENVIRONMENT

- INTENSE COMPETENT COMPETITION
  - 26 US, 19 Asian, 7 European competitors
  - Rapid advances in technology
  - Dramatic reduction in $/MB
- Standard Form Factors Dominate
  - Leads to Low Industry Profit Margins
  - Five of top 7 industry leaders lost money in 1988
- Most US Companies Manufacture in Singapore
- Areal Density Closing on High End DASD
- Volumetric Density Exceeds High End DASD
- Significant 3.5″ & Sub-3.5″ Activity; > 50 MB Single Disk Capacity in 1989
- Low End Reliability & Performance Growing
- Clustered 5.25″ (soon 3.5″) Subsystems Offering High Capacity & Built-in Redundancy

LOW END ENVIRONMENT continued

- Competition has Very Short Develop Cycles
- Huge OEM Opportunity
- VERY BROAD SCOPE
  - 2.5″ to 5.25″ disk sizes
  - Very Low Power (Laptops), Size & Weight
  - High Performance

LOW END

- COST/MB
  - o 20%/year Decline
  - o 3.5″ Form Factor
    - — Lowest $/MB since 1987
- AREAL DENSITY
  - o 2x every 16-18 months
  - o Volumetric density 2x every 14 months
  - o Packaging Techniques
  - o Data Banding

LOW END continued

- PERFORMANCE
  - o Now an Important Issue
  - o May Surpass High End
  - o 3.5″ Form Factor
    - — 20%/year Decline in Figure of Merit
  - o IBM Servo Systems better than Competition
- RELIABILITY
  - o Now VERY Important
  - o Difficult to Quantify
  - o LSI will Improve
- CONCLUSIONS
  - o Device Size will continue to shrink
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MAJOR DASD VENDORS
FINANCIAL RESULTS
CALENDAR YEAR 1988 vs 1987

COMPANY		M $ 1988	M $ 1987	% CHANGE
Conner	Revenue	256.7	113.2	126.8%
	Net Income	19.7	11.4	72.8
	%	7.7%	10.1%	
Maxtor	Revenue	339.0	240.8	40.8%
	Net Income	10.0	12.5	-20.0%
	%	2.9%	5.2%	
Micropolis	Revenue	353.0	288.2	22.5%
	Net Income	-19.3	27.2	*
	%	*	9.4%	
Miniscribe @	Revenue	603.3	362.5	66.4%
	Net Income	25.8	31.2	-17.3%
	%	4.3%	8.6%	
Priam	Revenue	142.2	137.0	3.8%
	Net Income	-2.0	-4.8	*
	%	*	-3.5%	
Quantum	Revenue	172.5	178.3	-3.3%
	Net Income	-2.4	8.2	*
	%	*	4.6%	
Seagate	Revenue	1351.0	1076.8	25.5%
	Net Income	-5.5	115.3	*
	%	-0.4%	10.7%	
TOTALS	Revenue	3217.7	2396.8	34.2%
	Net Income	26.3	201.0	-86.9%
	%	0.8%	8.4%	

@ - Under review, being restated to reflect inventory write-down estimated at $20-$40M

MAJOR DASD VENDORS
FINANCIAL RESULTS
M$

COMPANY		1989	1988	Y/Y % +/-	1987	Y/Y % +/-
Conner **	Revenue	479.2	256.7	86.7%	113.2	126.8%
	E/R	5.6%	3.4%	64.7%	3.1%	9.7%
	Net Income	26.9	19.7	36.5%	11.4	72.8%
	%	5.6%	7.7%		10.1%	
Maxtor (Fiscal yr 3/26/89)	Revenue	351.0	271.1	29.5%	182.0	49.0%
	E/R	6.7%	8.8%	-23.9%	6.9%	27.5%
	Net Income	5.2	14.1	-63.1%	20.8	-32.2%
	%	1.5%	5.2%		11.4%	
Micropolis **	Revenue	226.4	353.0	-35.9%	288.2	22.5%
	E/R	8.5%	8.0%	6.3%	7.5%	6.7%
	Net Income	-45.6	-19.4	-135.1%	27.2	-171.3%
	%	-20.1%	-5.5%		9.4%	
Priam (Fiscal yr 6/30/89)	Revenue	122.7	142.2	-13.7%	129.6	9.7%
	E/R	6.5%	6.1%	6.6%	8.2%	-25.6%
	Net Income	-25.4	0.5	-5180.0%	-41.3	101.2%
	%	-20.7%	0.4%		-31.9%	
Quantum (Fiscal yr 3/31/89)	Revenue	208.0	188.5	10.3%	120.8	56.0%
	E/R	8.1%	6.4%	25.8%	9.5%	-32.6%
	Net Income	12.9	-3.2	503.1%	8.8	-136.4%
	%	6.2%	-1.7%		7.3%	
Seagate (Fiscal yr 6/30/89)	Revenue	1371.6	1266.0	8.3%	958.1	32.1%
	E/R	3.7%	4.0%	-5.9%	3.5%	12.8%
	Net Income	0.3	77.3	-99.6%	139.7	-44.7%
	%	0.0%	6.1%		14.6%	
Totals	Revenue	2758.9	2477.5	11.4%	1791.9	38.3%
	E/R	5.3%	5.3%	-0.7%	5.2%	2.1%
	Net Income	-25.7	89.0	-128.9%	166.6	-46.6%
	%	-0.9%	3.6%		9.3%	

** Conner and Micropolis are on a calendar year-end close. The data for 1989 reflects their 3Q89 Income Statements.

LOW END ENVIRONMENT continued

- Competition has Very Short Develop Cycles
- Huge OEM Opportunity
- VERY BROAD SCOPE
  - 2.5″ to 5.25″ disk sizes
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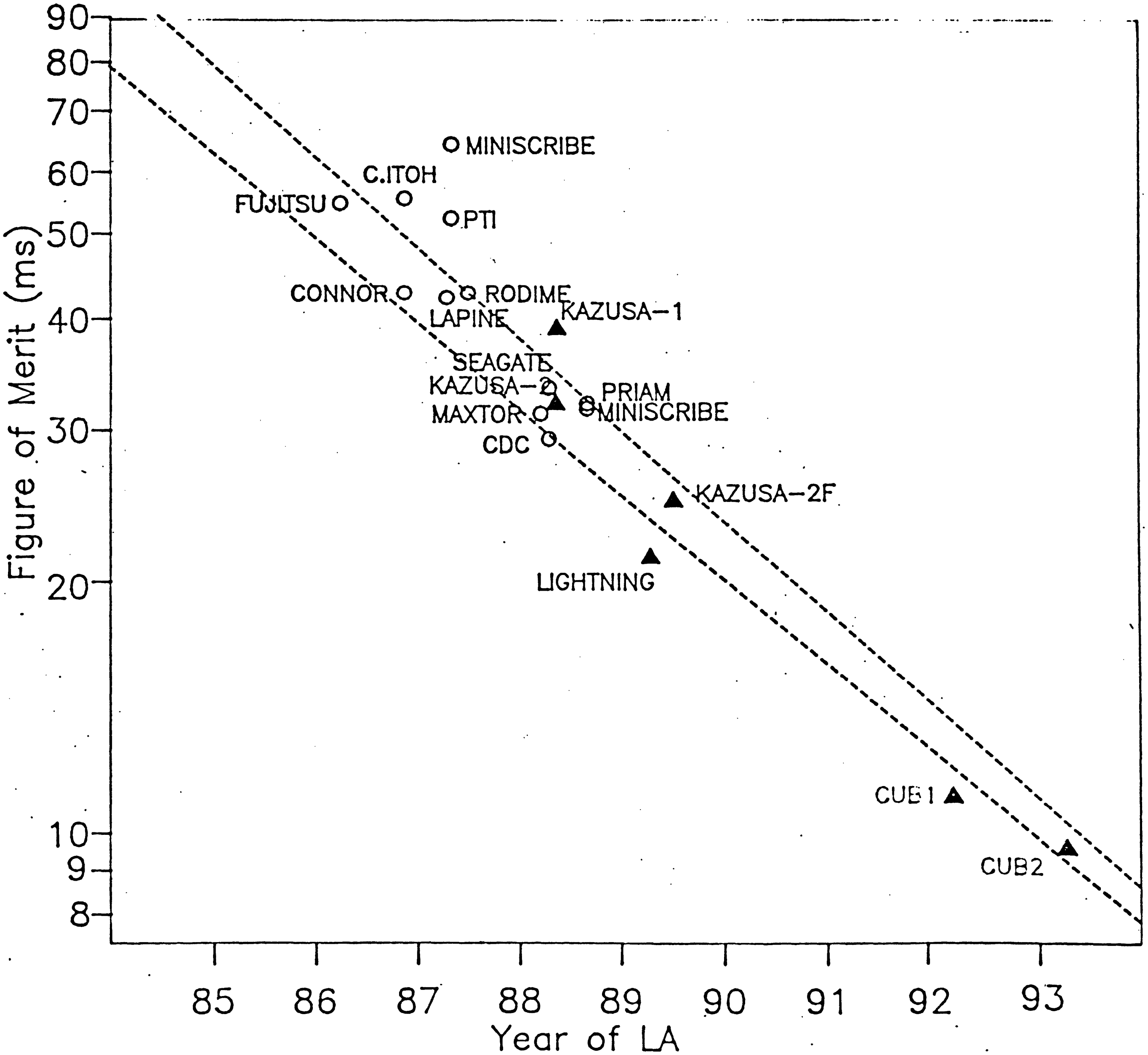
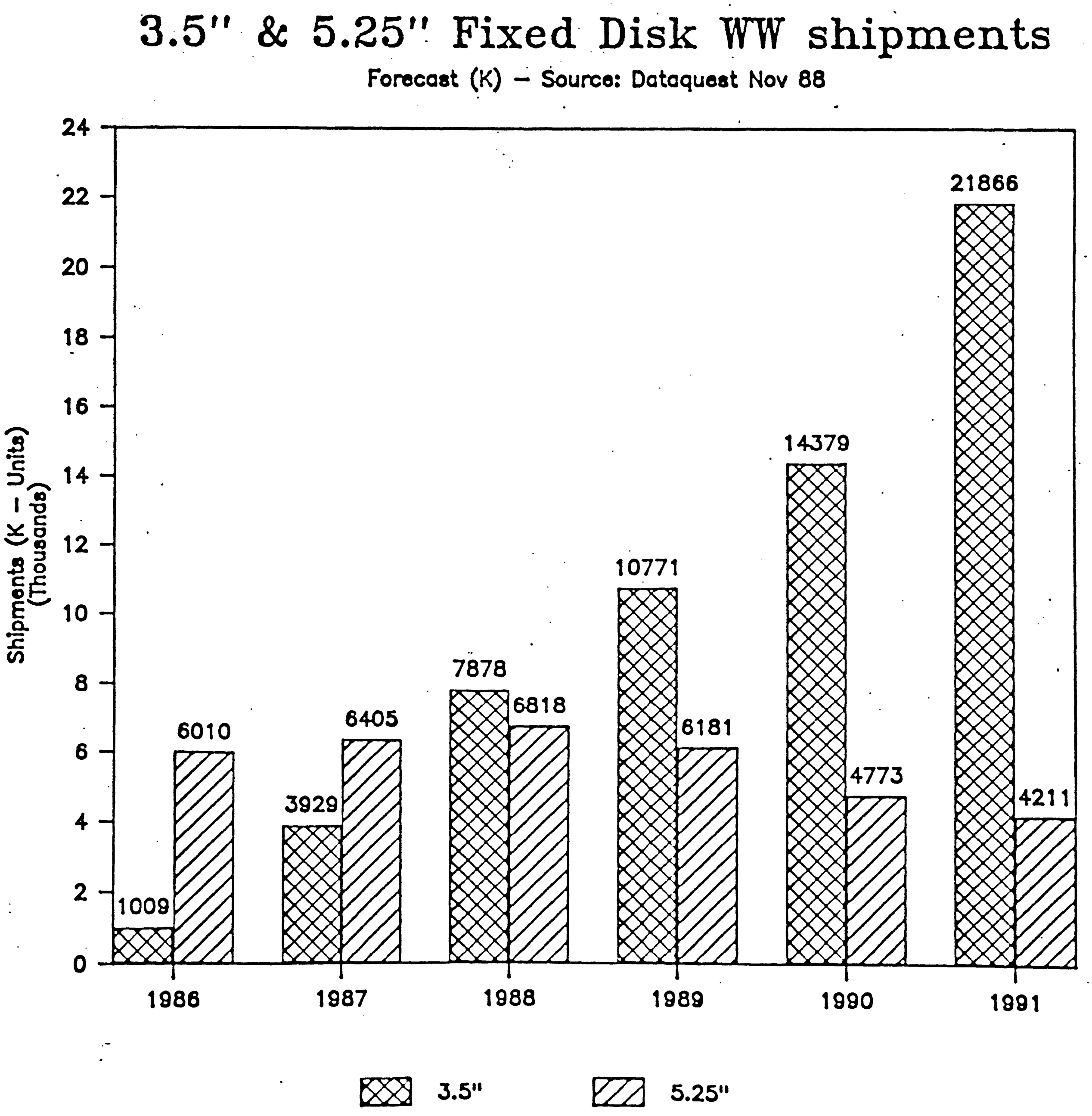
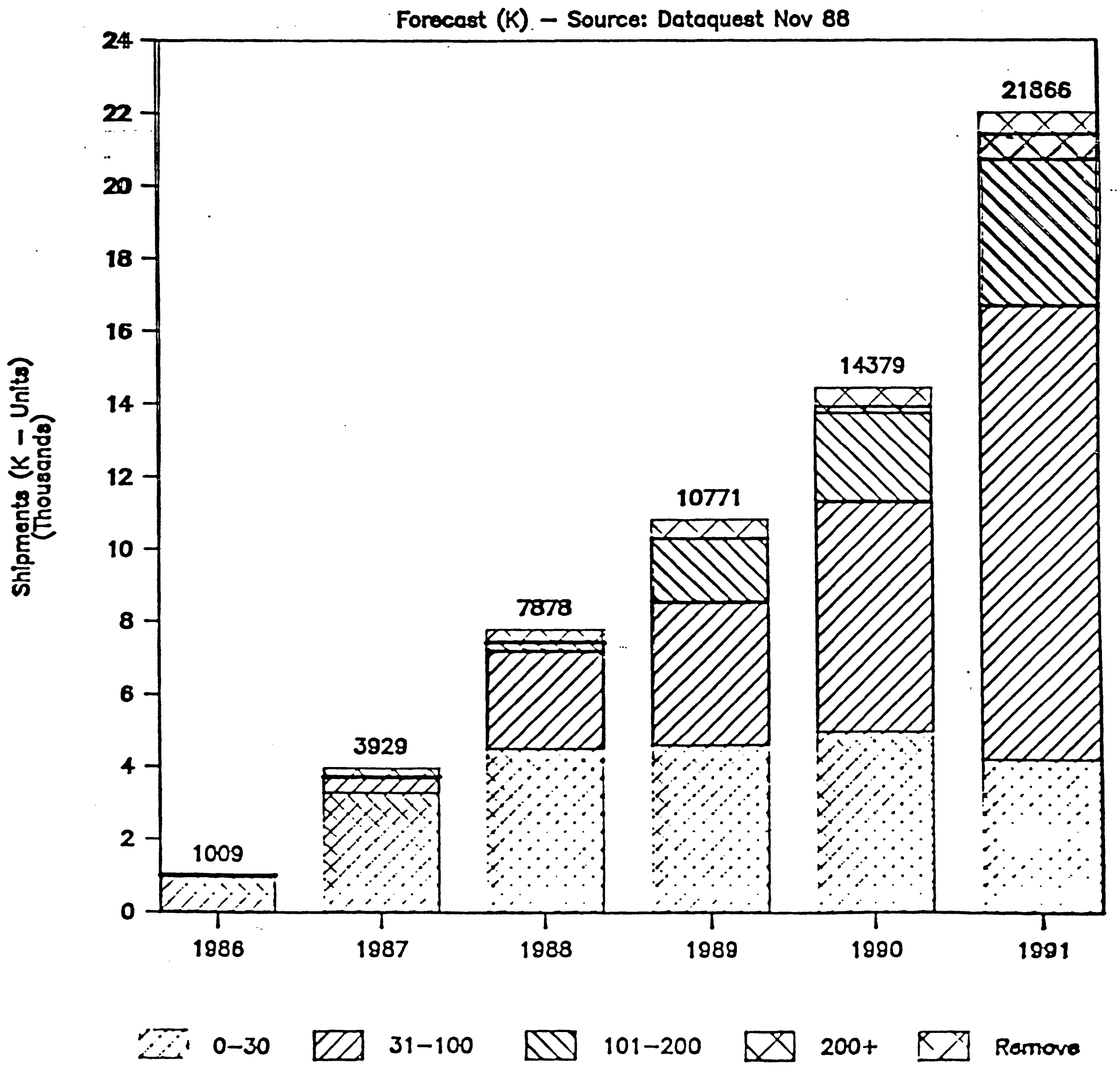


----- Total pop ----- Best of Breed

Projection curves based only on OEM mfgrs
(Those shown plus 21 more not shown with LA's prior to 3/86)


3.5" & 5.25" Fixed Disk WW shipments
Forecast (K) – Source: Dataquest Nov 88
Shipments (K – Units)
(Thousands)
24
22
20
18
16
14
12
10
8
6
4
2
0
1009
6010
3929
6405
7878
6818
10771
6181
14379
4773
21866
4211
1986
1987
1988
1989
1990
1991
3.5"
5.25"

3.5" Total Worldwide Shipments



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MEMO TO: C. Denis Mee

December 19, 1989 89353S130062

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IBM Corporation
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SJEVM13(CROLL)

SUBJECT: Rigid Disk Competitive Technology

Particulate disks still dominate high-end DASD reflecting the dominance of 3380 generation type products produced by IBM, Fujitsu, Hitachi, Memorex and Storage Technology. However, review of the technical literature and patent activity since 1986 shows little evidence of continuing particulate coating development. Although there has been development activity in advanced particulate flexible media using metal and barium ferrite particles, there is no indication of attempts to transfer these advanced particulate technologies to rigid disks.

Analysis of particulate disks used in Hitachi-K machines have shown them to be an extension of encore-type particulate disks, with the notable exception that very little disk lubricant is used, and the lubricant is a mixture of both Z-type and Krytox fluorocarbon constituents.

Film disks were first introduced in high-end performance files via the NTT Patti file with disk produced by NEC and Fujitsu. These disks were the result of extensive development programs by NEC on electroless plated CoNiP films and by Fujitsu on sputtered iron oxide films. Both NEC and Fujitsu have continued to manufacture these film disks for their own products, e.g. Fujitsu's Eagle 2 and 3 and NEC's D2352 and 2362. Both disks use an overcoat of spun-on and sintered SiO2. The Fujitsu disk uses anodized aluminum substrates rather than the polished electroless nickel phosphorus over aluminum substrate widely used for film disks. Analysis by the Tokyo Systems Evaluation Laboratory of recent Hitachi patent activity shows a large number of disclosures relating to plated cobalt alloys, sputtered cobalt alloys and sputtered iron oxide for film disks, indicative of research in film materials science over a broad range of compositions. There have been no film disks introduced by Hitachi in large files to date, but the Hitachi 3 inch DK312C and 5 inch DK515C files contain film disks. Information as to their origin and composition is not yet available.

The transition from particulate to film disks has been rapid for small low-end files, with film disks having effectively captured the marketplace. With the exception of Seagate, which has a large internal manufacturing capacity for film disks and HP, most of the disks are supplied to drive manufacturers by vendors. The Japanese have acquired ownership or equity positions in leading U.S. located film disk vendors (Akashic, Domain, Hitachi Metals, and Komag). Although the first volume production of film disks for the low-end used a cobalt phosphorus magnetic layer produced by electroless plating (Ampex and later Domain), the clear trend is to sputtered cobalt alloy films, with widespread and aggressive sputtered cobalt alloy film disk development activity at major Japanese computer manufacturers and U.S. located disk suppliers. A variety of cobalt alloys with different secondary and tertiary constituents have been worked on by many laboratories with emphasis on achieving high coercivity, low noise, and corrosion resistance. The most common alloys are cobalt alloys with Ta, Pt, or Ni to increase coercivity, and Cr for corrosion resistance. A recent research trend is toward reactive gas doping during sputtering to control coercivity and signal to noise. There has been increased activity on glass and glass ceramic substrates as a possible replacement for NiP clad aluminum. This activity has undoubtedly been stimulated by use of glass substrates for optical disks, and the desire of glass manufacturers to broaden this market. Along with this, there has been increasing interest in developing chemical means to texture disk substrates to replace current abrasive texturing techniques. Sputtered carbon overcoats are used by most disk manufacturers rather than spun-on SiO_2 used by NEC and Fujitsu. Sputtered ZrO_2 is used by Komag as an overcoat, and there are reports in the literature of exploratory work on a range of other overcoat materials.

Single disk sputtering equipment adapted by Varian from large wafer silicon processing tools has emerged to challenge large in-line systems for film disk production. The potential advantage is better control of magnetic uniformity, and production flexibility at the expense of lower throughput per tool compared with the multiple disk per pallet in-line systems made by Leybold-Hereus and Ulvac.

Conclusions

There is a transition from particulate to films for rigid disks and widespread film disk capability. Japan is strengthening its film disk position through aggressive research and development and by acquisition. Hitachi appears to be especially ubiquitous. Exploratory and advanced technology effort is being carried out in magnetic and overcoat films and on substrates. The use of single disk vacuum systems is emerging as an alternative to large in-line sputtering systems.

Recommendations

1. Rigorously evaluate single disk sputter tools.

2. Explore glass/ceramic substrates jointly with vendors.

3. In-Depth review of Hitachi film and particulate disk technology capability and trends.

INFORMATION SOURCES

SAN JOSE	J. K. HOWARD I. BARLOW C. Y. LIU W. BERNARD
ROCHESTER	B. BLUMENTRITT, ET AL C. BAJOREK
RESEARCH	I. SANDERS

TECHNICAL PUBLICATIONS (1982 - 1989)

TECHNICAL MEETINGS

PATENTS

VENDOR CONTACTS

IBM SPONSORED SUR CONTRACTS

RIGID DISK MEDIA SUMMARY

o PARTICULATE DISK STILL DOMINANT IN HIGH END (3380) IBM, FUJITSU (EAGLE 1 & 2) HITACHI, MEMOREX, STK

- LITTLE EVIDENCE OF PARTICULATE DEVELOPMENT SINCE 1986 FROM PATENTS AND LITERATURE

- TRANSFER OF FLEXIBLE PARTICULATE TECHNOLOGY (METAL, BAFERRITE) TO RIGID MEDIA NOT APPARENT

RIGID DISK MEDIA SUMMARY (CONTINUED)

- FILM DISKS INTRODUCED AT HIGH-END
  - NEC PLATED CoNiP
  - FUJITSU SPUTTERED Fe_2O_3
- FILM DISKS CAPTURING LOW-END MARKET
  - COBALT ALLOYS (SPUTTERED, PLATED)
  - WIDESPREAD SPUTTERED COBALT ALLOY FILM DISK DEVELOPMENT PROGRAMS
- JAPANESE HAVE TAKEN EQUITY POSITIONS AND OWNERSHIP OF FORMER U.S. -OWNED FILM DISK VENDORS

RIGID DISK MEDIA SUMMARY (CONTINUED)

- o RECENT EXPLORATORY TRENDS
  - GLASS/CERAMIC SUBSTRATES
  - CHEMICAL TEXTURING OF SUBSTRATES
  - ALTERNATE OVERCOAT MATERIALS (ZrO_2 KOMAG)
  - VARIETY OF FLUOROCARBON LUBRICANTS
  - REACTIVE GAS DOPING TO CONTROL Hc AND S/N
- o VACUUM EQUIPMENT
  - SINGLE DISK SYSTEMS CHALLENGING IN-LINE SYSTEMS
  - ADAPTING FROM LARGE WAFER SILICON PROCESSING

PARTICULATE MEDIA

SOURCES

- o COMPETITIVE ANALYSIS DATA BASE
  - HITACHI, 9.5", 34.5 MBITS/IN 2
  - FUJITSU, 8", 30.1 MBITS/IN 2
  - FUJITSU, 10.5", 22.1 MBITS/IN 2 (EAGLE II)

- o WORLDWIDE PATENT SEARCH
  - VERY LITTLE ACTIVITY SINCE '86 ON PARTICULATE TECHNOLOGY
  - LUBRICATION WORK DOMINATED BY FLUOROCARBONS, MIXTURES AND DERIVATIVES
  - INTERLAYER BETWEEN SUBSTRATE AND MAGNETIC MEDIUM TO ENHANCE MAG LAYER ADHESION AND DURABILITY, SCRATCH RESISTANCE (HIGH RIGIDITY POLYMER, PLASMA POLYMERIZED C OR C+H, N, O)

HITACHI-K DISK ANALYSIS
SUMMARY

LUBRICANT

Lube type: Z-type and Krytox (854 type) 2.5/1
Lube amount: approx 2 mg per disk total
Lube free vs "bound": 1.3 to 1.4 mg per disk free
approx. 0.5 "bound" .. all 854-type
ESCA/ESPD: Confirm presence of "bound" lube across entire disk
Relubed Lube amount: 4 mg.

MAGNETICS

Static Magnetics: Hc = 392 oe, OR = 2.31, Crystal=413/1.78
Mag Test:Low resolution, gives High MB, EB. They use 1,7 code.

DURABILITY

AWT: 13 to 15 K Dynasty: 38-39 K
OWT: ID 102 kc(F), MD 122 kc(F). Crystal 142 kc(T)

SURFACE

TOH: 92nm, Crystal = 77nm, E' = 119 nm
Asperity Count: 2 to 3X Crystal
Roughness: 5.5 to 5.8 nm RMS, Crystal = 7.3 to 10 nm

STRUCTURE

Binder Composition: Bisphenol-A epoxy, similar to IBM binder
Cure: Greater degree of cure than Crystal
Alumina size, shape, amount: size=0.44um, Crystal=0.46um
shape: similar tc AKP type.
quantity: approx. equal to Crystal
Iron oxide size, amount(PVC): 0.5um, PVC = 32. Crystal = 0.2/32.5
Coating Thickness: 14.2 to 16.5u", Crystal: 9.2u"
Alodyne Thickness: 0.8 - 1.6u", Crystal: 5u", E': 1 - 2 u"
Coating Quality: Generally uniform except very poor at extreme ID.

7/21/89

DISK TYPES IN HIGH END DASD

DASD COMPANY	DIAM	TYPE
FUJITSU/AMDAHL		
Eagle 1 (3350)	10.5	part
Eagle 2 (3380)	10.5	part
Eagle 3 (3380E)	10.5	sput Fe2O3
Eagle 4 (3380K)	10.5	sput Fe2O3
HITACHI/NAS		
H6585 (3380)	14	part
H6586 (3380E)	14	part
H6586H (3380K)	9.5	part
MEMOREX		
3680 (3380)	14	part
3682 (3380E)	14	part
NEC		
D2352 (OEM)	9	plated
D2362 (OEM)	9	plated
STK		
8380 (3380)	14	part
8380E (3380)	14	part

DISK STRUCTURES
IN HIGH-END DASD

1. NEC PLATED (D2300 SERIES HALF-WIDE DRAWERS, GA = 1Q84)

SUBSTRATE:	7000 AL
UL:	NI-P
ML:	CO-NI-P
OL1:	NI-P
OL2:	S_1O_2
LUBE:	FLUOROCARBON

2. FUJITSU SPUTTERED OXIDE DISK (GA = 3Q86).

SUBSTRATE:	AL-MG ALLOY
UL:	ANODIZE
ML:	SPUTTERED FE_2O_3
OL:	S_IO_2
LUBE:	HYDROCARBON, DOP, FLUOROCARBON(?)

SOURCE: J. CAROTHERS AND B. BERNARD

KBL/A0074489(1)/3

HITACHI PATENT ANALYSIS - FILM DISKS
(TSEL - 6/89)

- o PLATED COBALT ALLOYS
- o SPUTTERED COBALT ALLOYS
- o SPUTTERED γ-OXIDE
- o ION BEAM SPUTTERING
- o ALUMINUM SUBSTRATES
- o GLASS SUBSTRATES
- o CARBON OVERCOATS
- o ALTERNATE OVERCOATS
- o BROAD SPECTRUM OF COBALT ALLOY FILM COMPOSITIONS

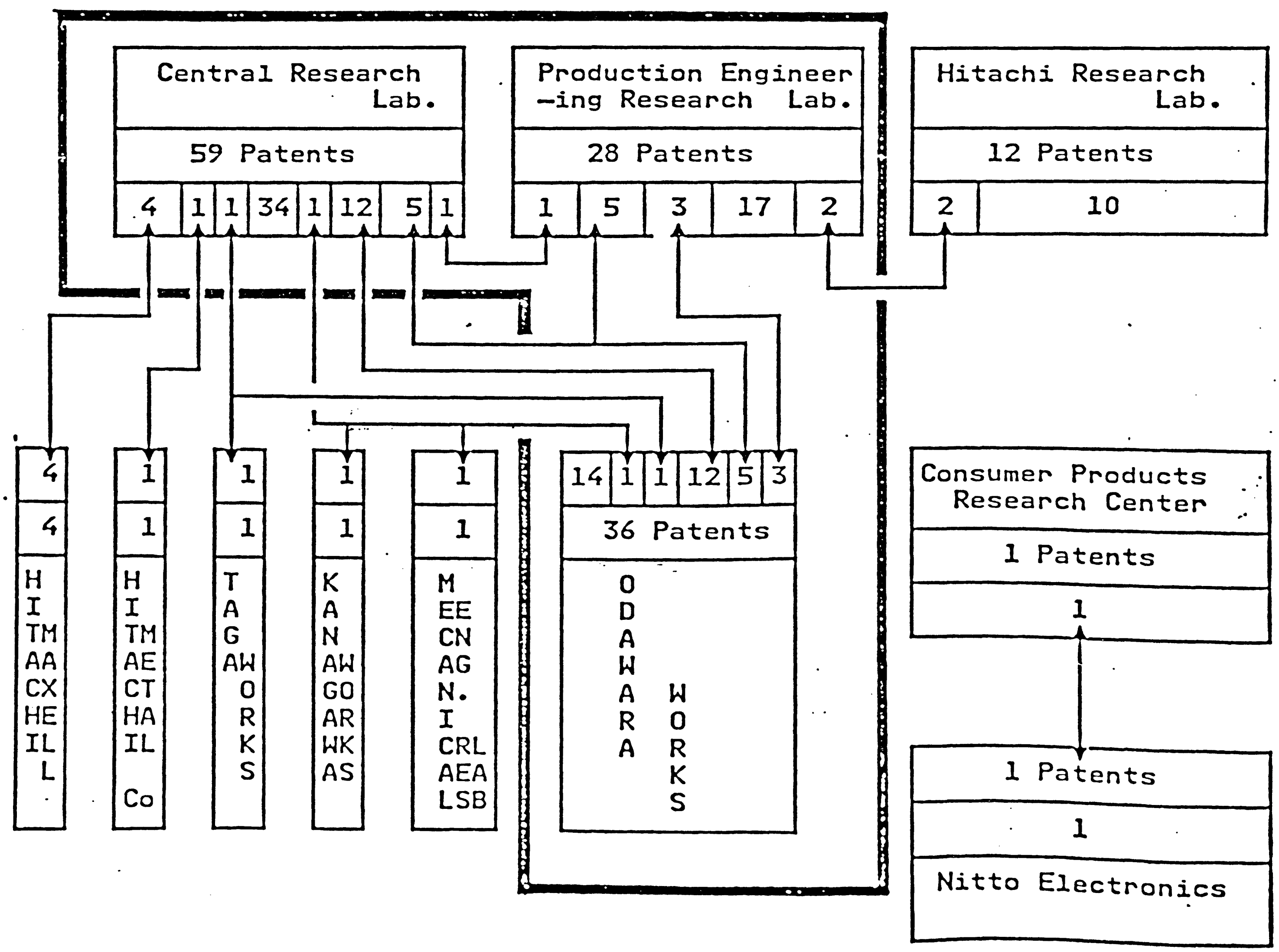
Sputtered Disk: Division Relation H/Patent Analysis

106 Patents concerning sputtered disk as hard disk medium are included in IPC C23C14/*, H01F41/18*, and G11B5/(62*,66*,70*,72*,82*,84*,85*), from Jan 1987 to Oct 1988.

The Hard Disk manufacturing Factory Odawara works has close relation with Central Research Lab.

Most of the patents are related to the Central Research Lab. and Production Engineering Research lab. and Odawara works

Therefore we may focus on the Central Research Lab Production Engineering Research lab. and the Odawara Works.



Announce date	DIA 35891 ....4 5285 5	Model type	MB	kBPI	kTPI	Technology
1989-04-11	3	DK312C	251	38.8	1.660	Sputter disk
1989-04-11	8	DK816-20	2000	35.47	1.256	Linear actuator Coating, Thin film
1988-10-25	5	DK515C-78	780	40.21	1.296	Sputter disk Monolithic head
1988-09-13		H6586-J,G				
1988-03-16	9	H6586-K	1890			15GB/8 = 1890MB Linear actuator Thin film head
1987-10-22	5	DK711S-60	600	26.00	1.033	
1987-06-11	5	DK514-38	382	26.00	1.033	
1986-10-28	5	DK521-5	51.4			
	5	DK522-10	103.4	18.5	0.960	
1986-06-07	8	DK815-10	1067	19.56	1.220	thin film (1st) coating disk
1985-03-	1	H6585	1260	15.24	1.100	1260MB×4 ferrite head rotary
1985-02-22	3	DK301	19.1			tough coating light head
1985-02-22	5	DK505	25.6			linear step motor
1984-07-06		H-6555-1	525			(525MB)×4
1984-07-06		DK-815-5	525			
	5	DK-512/512S	172.3			
	5	DK-512C	146.7			
	5	DK-524/524C	200.5			
	5	DK-503-2	13.3			
	5	DK-511	85.7			rotary
	8	DK-812/812S	170.1			

VENDOR	SUBSTRATE	TEXTURE	RA	UL	ML	OC	LUBE
1. KOMAG	1. NiP-Almg 35 mil 2. GLASS (25 mil)	Al_2O_3 (SINGLE) CHEMICAL	1. 55-60 A° 2. 30-35 A° 1. 10 A°	NiP (Sput)	CoNiPt (CoCrPt)	1. COC 2. ZrO_2-Y_2O_3	Z-DOL DIP BONDED
2. AKASHIC	NiP-Almg 35 mil	FIXED ABRASIVE		Cr	CoCrTa	COC	AM2001 DIP BOND
3. SEAGATE	NiP-Almg	TAPE		Cr	$Co_{84}Cr_{16}$ $CoCr_{13}Ta_2$	COC	OPTIONAL
4. DOMAIN	1. NiP-Almg 2. GLASS-CERAMIC 3. GLASS	Al_2O_3		Cr	CoCrTa	COC	AM2001-DIP
5. HMT	NiP-Almg	DIAMOND (SINGLE)		Cr-X Cr	CoCrTa-X CoCrTa	H: COC COC	AM2001-DIP BONDED
6. NASHU-LIN	NiP-Almg	TAPE		Cr	CoNiCr	COC	NONE DETECTED
7. HOYA ELECTRONICS	GLASS		7 A°	Cr	CoCrTa	COC	FOMBLIN DIP
8. DENKA	NiP-Almg	RADIAL	60 A°	Cr	CoCrTa	COC	PFPE
9. FUJI ELECTRIC	NiP-Almg			Cr	CoNiCr	COC	

IBM-SJ-553

lp-A0075989-1

SOURCE B. MARTIN

U.S. THIN FILM DISK MANUFACTURERS (OVERVIEW)

VENDOR		HIGHLIGHTS
1. AKASHIC	o	JAPANESE OWNERSHIP
	o	HIGH-END MARKET (MAXTOR)
	o	0.25 M/Mo (OPERATES FULL CAPACITY)
	o	EXCELLENT MAGNETICS (VARIAN)
	o	CLAIMS HIGH Hc-LOW MRT MEDIA
2. DOMAIN	o	U.S. OWNERSHIP (SOLD TO AKASHIC 11/89)
	o	CHAPTER 11 (05/89), DEBT PAID MINI-SCRIBE (08/89)
	o	PLATED 1.4 M/Mo, LOW-END MARKET
	o	NEW SPUTTER LINE (HIGH THROUGHPUT)
	o	QUALITY, COST, VOLUME
	o	GLASS OR GLASS-CERAMIC ACTIVITY
3. HMT	o	JAPANESE OWNERSHIP (HITACHI METALS)
	o	0.1-0.4 M/Mo, MEDIUM AND HIGH-END
	o	GETTING BACK ON TRACK!
	o	AUTOMATED FACTORY ROBOTICS
	o	NEW MATERIALS OBJECTIVE
4. KOMAG	o	U.S. OWNED (50% JAPANESE, ULVAC, KOBE, ASAHI)
	o	HIGH-END MARKET, 0.5 M/Mo
	o	TECHNOLOGY LEADER (HIGH-END)
	o	ADVANCED GLASS SUBSTRATE
	o	EXCELLENT DURABILITY - CORROSION AN ISSUE (CoNiPt)
	o	NEW MEDIA FOR HIGH Hc-LOW MRT (CoPtCr)
	o	MULTIPLE PROCESSES IN MANUFACTURING

U.S. THIN FILM DISK MANUFACTURERS (OVERVIEW)

(CONTINUED)

5. SEAGATE
   - o U.S. OWNERSHIP
   - o 2 M/Mo, MID HIGH-END
   - o EXCELLENT PROCESS CONTROL SYSTEM
   - o DISTRIBUTED SPUTTER (VARIAN)
   - o EXCESS CAPACITY
   - o LUBE-NO LUBE?
   - o LIMITED Hc PROCESS (1100 Oe)
   - o MR HEAD (IMPRISS)

SOURCE: B. MARTIN

GLASS OR GLASS-CERAMIC SUBSTRATE TECHNOLOGY

1. GLASS SUBSTRATE MANUFACTURER

   - HOYA (JAPAN)
   - ASAHI (JAPAN): KOMAG
   - CORNING (U.S.): DOMAIN
   - NIPPON SHEET GLASS (JAPAN)
   - PILKINGTON (U.S.): DOMAIN

2. TECHNOLOGY LEVERAGE

   - ELIMINATE NI PLATING, POLISHING
   - THIN, RIGID, SMOOTH (IMPROVED CAPACITY AND PERFORMANCE)
   - IMPROVE YIELD AT LOW FLYING HEIGHT (≤3 MICRO INCH) (3 MICRO INCH, 35 MIL: ASAHI/KOMAG)
   - UNIFORM TEXTURE, RA = 7-10A^{0} (CHEMICAL TEXTURE)
   - INCREASED DATA ZONE AREA

3. ISSUES

   - KOMAG/ASAHI SUBSTRATES AVAILABLE 1991
   - KOMAG HAS KEY PATENT ON CHEMICAL TEXTURE
   - GLASS NOT PUSHED BY DRIVE MANUFACTURERS
   - GLASS DISK COST ≥30% MORE THAN AL-MG (NIP)
   - COMPLEX PROCESSING ISSUES (LOW YIELD, MICROCRACKS)
   - SAFETY ISSUES FOR THIN GLASS SUBSTRATES (CLAMPING - MICROCRACKS - 10,000 RPM)

SOURCES: T. PETERSON, J. SHEN, K. JOHNSON

SPUTTER DEPOSITION EQUIPMENT

1. IN-LINE (CENTRALIZED SPUTTER)

A. FEATURES

- HIGH THROUGHPUT POTENTIAL (DISK/PALLET, CYCLE TIME)
- HIGH COST OF TOOLING (LOW COST PER CAPACITY)
- TOOLING COMPLEXITY
- LIMITED SPUTTER OPTIONS (BIAS, ALTERNATIVE SOURCES)
- DOWNTIME IMPACTS LINE
- MAGNETIC PROPERTY VARIABILITY (Hc, MODULATION)

B. VENDOR USAGE

- KOMAG (8-9, ULVAC)
- DOMAIN (1, IN-HOUSE DESIGN/BUILD)
- HMT (4 LEYBOLD)
- NASUHA-LIN (CPA)
- HOYA (LEYBOLD)

SPUTTER DEPOSITION EQUIPMENT

(CONTINUED)

2. STATIC-CIRCULAR MAGNETRON (DISTRIBUTED SPUTTER)

A. FEATURES

- LOWER COST PER TOOL (COST PER CAPACITY)
- LOWER THROUGHPUT - MULTIPLE TOOLS
- DOWNTIME HAS REDUCED IMPACT ON LINE FLOW
- IMPROVED MAGNETIC PROPERTY VARIABILITY

B. MANUFACTURERS USAGE

- AKASHIC (5-7, VARIAN M-GUN)
- SEAGATE (30, IN-HOUSE MODIFIED VARIAN)
- H-P (CAPTIVE) (4-5, VARIAN)
- DOMAIN (1, VARIAN)

SOURCE: B. MARTIN

THIN FILM DISK
(INDUSTRY TREND: CURRENT)

1. SUBSTRATE

   A. AL-MG

   B. NIP (PLATED)

      - 130MM/75MIL
      - 95 MM/50MIL

2. MAGNETIC LAYER STRUCTURE

   A. CR UNDERLAYER (300-2500 A^{O})

   B. Co CR_X TA_Y (X = 12-15%, Y = 1-4%)

      - Hc = 850 - 1200 OE

3. OVERCOAT

   A. COC

      - NON-REACTIVE
      - DC MAGNETRON

4. LUBRICANT

   A. AM2001

      - DIP
      - BONDED

VENDOR DISK TECHNOLOGY TRENDS

1. GLASS OR GLASS-CERAMIC SUBSTRATES
   - RA = 7-10A^{0}
   - 25MIL THICKNESS
   - CHEMICAL TEXTURE PROCESS (KOMAG)
2. HIGH Hc MAGNETIC LAYERS
   - CoNiPt, CoCrTa (CLAIM), CoPtCr (1800-2500 Oe)
   - HIGH Hc, Low MRT (CoPtCr)
   - CrX UNDERLAY DEVELOPMENT (HMT)
   - REACTIVE GAS DOPING (N_2, O_2, CH_4, CO) TO CONTROL Hc/SNR
3. IMPROVED OVERCOATS
   - ZrO_2-Y_2O_3 (KOMAG)
   - REACTIVE COC (HMT)
4. IMPROVED LUBRICANTS
   - BONDED AM2001 (AKASHIC, HMT)
   - BONDED Z-DOL (KOMAG)

IBM-VENDOR TECHNOLOGY COMPARISON

1. VENDOR TECHNOLOGY ADVANTAGE

   A. GLASS SUBSTRATE TECHNOLOGY (TEXTURE)

   B. ADVANCED MANUFACTURING

   - COST, QUALITY AWARENESS (DOMAIN)
   - AUTOMATION-ROBOTICS (AKASHIC/KUBOTA)
   - INTEGRATED DATA SYSTEMS (SEAGATE: TOKEN RING, 386 DATA SERVER; Hc TEST SEND AHEAD, ETC.)

   C. REACTIVE OVERCOAT TECHNOLOGY

   - RF MAGNETRON (ZrO_2-Y_2O_3)
   - REACTIVE PROCESSES (ZrO_2 - Y_2O_3; Ar-O_2)

   D. SPUTTER TOOL FLEXIBILITY

   - CIRCULAR MAGNETRON (Hc, MODULATION)
   - SUBSTRATE BIAS (Hc CONTROL)
   - ALTERNATIVE SOURCES (CVD, ECR, ION-BEAM)

2. IBM TECHNOLOGY ADVANTAGES

   A. MATERIALS SCIENCE - CHEMISTRY DEPTH

   - LUBRICATION
   - MAGNETICS (SNR, LORENTZ)
   - CORROSION

   B. ANALYTICAL SUPPORT FROM MATERIALS LAB

IBM-VENDOR TECHNOLOGY COMPARISON

(CONTINUED)

C. HIGH Hc-LOW MRT CoPtCr PROCESS EXPERIENCE

- EXCELLENT CORROSION
- LOW NOISE

D. ADVANCED OVERCOAT (REACTIVE SPUTTER COC)

- DIAMOND-LIKE CARBON (C; Ar-H_2, Ar-CH_4)
- DOC (C; Ar-H_2O)
- TEXTURED COC (WC + C; Ar-CH_4)

E. IMPROVED UNDERLAY MATERIALS

- CrV (Hc, SNR CONTROL)

IBM CONFIDENTIAL

THIN FILM DISK RELIABILITY
(PERSPECTIVE)

	MANUFACTURER		RELIABILITY	RATING
1.	AKASHIC	o	CoCrTa CORROSION	A
		o	COC CORROSION	C
		o	COC + AM2001 DURABILITY	B
2.	DOMAIN	o	CoCrTa CORROSION	A
		o	COC CORROSION	C
		o	COC + AM2001 DURABILITY	C/B
3.	HMT	o	CoCrTa CORROSION	A
		o	COC CORROSION	C
		o	REACTIVE COC CORROSION	A/B
		o	COC + AM2001 DURABILITY	B
		o	REACTIVE COC + AM2001	A/B
4.	KOMAG	o	CoNiPt CORROSION	C
			CoPtCr AVAILABLE)	(A)
		o	ZrO_2 CORROSION (FINE TEXTURE)	A
		o	ZrO_2 CORROSION (ROUGH TEXTURE)	C
		o	COC CORROSION	C
		o	ZrO_2 + Z-DOL DURABILITY	A
5.	SEAGATE	o	CoCrTa CORROSION	A
		o	COC CORROSION	C
		o	COC + ? (FILE)	A/B

SOURCE: B. MARTIN, T. PETERSON, K. JOHNSON, S. ROOT, K. HOWARD

U.S.A. INDUSTRY: THIN FILM DISK

1. IBM

- LONGITUDINAL Cr/CoCr, CrV/CoPtCr*, Cr/CoNiCr
- H : C* (SPUTTERED DIAMOND-LIKE CARBON OC)
- SPUTTERED CoCr, CoCrTa PERPENDICULAR MEDIA
- SNR MEASUREMENTS
- SPUTTERED Fe_2O_3
- MICROMAGNETICS
- CORROSION

2. KOMAG

- SPUTTERED ZrO_2* OVERCOAT
- CoNiPt* (SNR/Hc), CoRe
- GLASS SUBSTRATES*
- MICROMAGNETICS

3. SEAGATE

- SPUTTERED CARBON OC
- LONGITUDINAL Cr/CoCrTa* (CORROSION/Hc)
- CORROSION OF CoCr, CoNi, CoP

4. HEWLETT-PACKARD

- CORROSION OF CoCr, CoNi ALLOYS
- SPUTTER Cr/CoP LONGITUDINAL MEDIA
- SPUTTER CoCr PERPENDICULAR MEDIA
- SNR THIN FILM MEDIA*

* KEY TECHNOLOGIES

U.S.A. INDUSTRY: THIN FILM DISK

(CONTINUED)

5. MAGNETIC PERIPHERALS, INC. (CDC)
   - CIRCUMFERENTIAL TEXTURE AND·MODULATION
   - SPUTTERED CoCr PERPENDICULAR MEDIA
   - CoNi MEDIA ON KAPTON (Hc/CORROSION)

6. KODAK
   - CoNi-O ON FLEXIBLE MEDIA

7. VARIAN
   - M-GUN SPUTTER SOURCE, Cr/CoNiCr/C

8. MEMOREX
   - RF SPUTTER CARBON OC
   - CoNi LONGITUDINAL MEDIA/CORROSION

9. LIN DATA
   - Cr/CoCr LONGITUDINAL MEDIA

JAPAN INDUSTRY: THIN FILM DISK

1. HITACHI

- CSS TESTING/WEAR
- ALUMINITE/CoNiCr/C LONGITUDINAL MEDIA
- Cr/CoNi-M (Pt, Mo, Ta, Zr), CORROSION/SNR
- SNR MEASUREMENT Co-ALLOY
- CoCrTa PERPENDICULAR MEDIA
- IN-LINE SPUTTERING, MODULATION
- MICROMAGNETICS

2. NIT

- FRICTION, ADHESION, CSS
- SPUTTER Os- Fe_2O_3* (WEAR, SNR)
- Al-Mg/Al_2O_3/ Fe_2O_3/100 A^0 S_1O_2
- SPUTTER Fe_2O_3 PROCESS

3. NEC

- SPUTTER CoPt (HIGH COERCIVITY)
- SPUTTER CoNiPt* (Hc, CORROSION)
- Cr/CoNi ON POLYIMIDE
- PERPENDICULAR CoCr
- CSS/WEAR OF COC

* KEY TECHNOLOGIES

JAPAN INDUSTRY:
THIN FILM DISK

(CONTINUED)

4. ULVAC (INSTITUTE OF SUPER METALS)

   - CR-X (AL, SI, TI, V, CO, NI ---)/CONICR/C
   - DEVELOP CR/CONICR* LONGITUDINAL MEDIA
   - DEVELOP SPUTTER CARBON/CVD CARBON OC
   - SPUTTER TARGETS FOR MAGNETIC MATERIALS
   - ORGANIC LUBRICANTS FOR FILM DISK

5. MATSUSHITA

   - WEAR/DURABILITY (TAPE)
   - CR/CONI IN-LINE SPUTTER, TEXTURE EFFECT
   - SPUTTER COCR (PERPENDICULAR MEDIA, FLEXIBLE MEDIA)
   - DEVELOP CVD-CARBON* (DLC) FOR TAPE APPLICATION
   - WEAR PROTECTION FOR COCR ON POLYMER SUBSTRATES

6. TOSHIBA

   - TEXTURE EFFECT ON COPT MEDIA

7. FUJI ELECTRIC

   - CONI-O MEDIA ON POLYMIDE SUBSTRATES
   - AMORPHOUS CARBON ON COCR (CORROSION/WEAR)

* KEY TECHNOLOGIES

JAPAN INDUSTRY: THIN FILM DISK

(CONTINUED)

8. NIPPON GLASS
   - SUBSTRATES FOR RIGID DISKS
9. ASAHI-GLASS (KOMAG)
   - SUBSTRATES
10. SONY
    - BI/CONI MEDIA
11. KOBE STEEL
    - NICUP PLATED AL-MG SUBSTRATES

U.S.A. UNIVERSITY RESEARCH: THIN FILM DISK

1. UNIVERSITY OF MINNESOTA, MINNEAPOLIS
   - SLIDING WEAR
   - SPUTTERED Fe_2O_3
   - PERPENDICULAR CoCr
   - Cr/CoNi, Cr/CoCrTa
   - CORROSION OF Co ALLOYS

2. CARNEGIE MELLON UNIVERSITY
   - Cr/CoNiCr, Cr/CoNi LONGITUDINAL
   - SPUTTER CoCr PERPENDICULAR
   - MICROSTRUCTURE

3. STANFORD UNIVERSITY
   - SPUTTERED CoCr (RESIDUAL GAS DOPING)
   - CoPt, CoRe, CoV

4. UNIVERSITY OF CALIFORNIA, BERKELEY
   - CoNi (MICROSTRUCTURE)

5. UNIVERSITY OF CALIFORNIA, SAN DIEGO
   - CoCr PERPENDICULAR
   - Fe_2O_3

JAPAN UNIVERSITY RESEARCH: THIN FILM DISK

1. TOKYO INSTITUTE OF TECHNOLOGY

   - LONGITUDINAL CR/CONI, COPT, CONI-X
   - SPUTTERED BA-FERRITE (LONGITUDINAL-PERPENDICULAR)
   - PERPENDICULAR MEDIA (COCR)
   - FTS, ION-BEAM, FE_2O_3
   - MO MEDIA
   - FEN
   - WEAR COATING, CSS

2. TOHOKU UNIVERSITY, SENDAI

   - PERPENDICULAR COCR

3. TECHNOLOGICAL UNIVERSITY OF NAGAOKA

   - LONGITUDINAL $CONI-N_2$
   - CSS WEAR-TRIBOLOGY

4. TOKYO UNIVERSITY

   - CSS, SLIDING RESISTANCE

5. SHINSHU UNIVERSITY IN NAGANO

   - SPUTTERED BA FERRITE (LONGITUDINAL)

NEW THIN FILM DISK MATERIALS
(SINCE 1984, PARTIAL LIST)

MAGNETIC LAYER

1.	FeNx	SHINSHU UNIVERSITY (JAPAN)
2.	CoCr-Tm (TRANSITION METAL)	IMPRIMIS (U.S.)
3.	CoNiCr	ULVAC (JAPAN)
4.	CoNx	HITACHI (JAPAN)
5.	CoSi	NAGAOTA UNIVERSITY (JAPAN)
6.	CoCrTa	SEAGATE, IBM (U.S.)
7.	CoCrW	SEAGATE, IBM (U.S.)
8.	CoNiZr	HITACHI (JAPAN)
9.	CoNi-(Pt, Mo)	HITACHI (JAPAN)
10.	CoPtCr	IBM, NEC
11.	CoPt (Ge, W, Mo, V)	IBM, NEC
12.	CoNiTa	TOKYO INSTITUTE OF TECHNOLOGY (JAPAN)
13.	SPUTT. CoP	H-P (U.S.)
14.	CoPtTi	UNIVERSITY OF GRENOBLE (FRANCE)

NEW THIN FILM DISK MATERIALS
(SINCE 1984)

OVERCOAT

1.	SPUTTERED HYDROGENATED CARBON (H : C) ($Ar-H_2$, $Ar-H_2O$, $Ar-CH_4$)	IBM
2.	CVD C/SPUTT. C	ULVAC (JAPAN)
3.	PLASMA CVD C	MATSUSHITA (JAPAN)
4.	$ZrO_2-Y_2O_3$, $ZrO_2-Al_2O_3$	KOMAG
5.	ZrO_2, SiC	HITACHI
6.	H : C + WC	IBM
7.	B_4C	HMT
8.	REACTIVE COC	HMT

NEW THIN FILM DISK MATERIALS

UNDERLAY FILMS

1.	Cr-X (V, Fe, Co, W)	IBM
2.	Cr-Y (Si, Gd, ---)	HITACHI
3.	Sn	IBM

THIN FILM DISK:
IBM-SPONSORED SUR CONTRACTS

1. IBM ROCHESTER: "HIGH COERCIVITY AND HIGH SIGNAL/NOISE THIN FILM LONGITUDINAL MEDIA," J. JUDY AND J. SIVERSTEN, UNIVERSITY OF MINNESOTA, TWO YEARS ($126K/YEAR), SECOND OF TWO YEARS

2. IBM ROCHESTER: "CORROSION OF COBALT ALLOY MEDIA," W. SMYRL, UNIVERSITY OF MINNESOTA, 1985-1987 (COMPLETED)

3. IBM SAN JOSE: "NOISE SOURCES IN LONGITUDINAL THIN FILM MEDIA," M. KRYDER, CMU, STARTS 1989

4. IBM SAN JOSE: "TRIBOLOGY OF THIN FILM RECORDING MATERIALS," L. BAUER, CMU

5. ARC: "POROSITY OF CARBON FILMS," J. KRIM, NORTHEASTERN

6. ARC: "SIMULATION OF VISCOUS FLOW," MA, U.C. BERKELEY

7. ARC: "CARBON OVERCOAT ADSORBATES," DRUGER, NORTHWESTERN

8. ARC: "BONDED PERFLUOROETHERS ON OXIDES AND CARBON," SOMORJAI, U.C. BERKELEY

9. ARC: "TRIBOLOGY OF THIN INTERFACIAL FILMS," PINCUS, U.C. SANTA BARBARA

THIN FILM DISK: IBM-SPONSORED SUR CONTRACTS

(CONTINUED)

10. ARC: "FRICTION, WEAR, AND INTERFACIAL CHEMISTY," CHENG, NORTHWESTERN

11. IBM SAN JOSE: "MAGNETIC DOMAIN IMAGING STUDIES," FERRIER, UNIVERSITY OF GLASGOW

CONCLUSIONS

- o WIDE SPREAD FILM DISK CAPABILITY
  - VARIETY OF MATERIALS/PROPERTIES
- o TRANSITION FROM PARTICULATE TO FILM DISKS
- o JAPANESE STRENGTHENING FILM DISK POSITION
  - AGGRESSIVE R&D BY JCM'S
  - PURCHASE OF U.S. DISK VENDORS

GRANULARITY OF TOOLING AN ISSUE

  - PRODUCT MIX
  - DISK UNIFORMITY
- o ALTERNATE SUBSTRATES/TEXTURING BEING PURSUED

RECOMMENDATIONS

- RIGOROUS EVALUATION OF SINGLE DISK SPUTTER TOOL

- EXPLORE GLASS/CERAMIC SUBSTRATES JOINTLY WITH VENDORS

- IN DEPTH REVIEW OF HITACHI FILMS & PARTICULATE DISK TECHNOLOGY (CAPABILITY AND TRENDS)

Competitive Technology Report- DASD Heads

Kanu Ashar, Jan 12, 1989

Strategic issues on Heads

The following issues and concerns constitute the major part of the discussion on Magnetic recording Heads for rigid disks.

1. Can MIG heads be significantly enhanced with retention of low cost advantage and yet provide densities comparable to those achievable with film heads or MR heads for next several years?
2. Can design and process extensions of thin film heads reduce need of MR heads in coming 3 to 5 years? Can competition use the strategy and be cost/performance competitive in low and high end DASD products?
3. Inductive heads both MIGs and thin films have advantage of higher signals at high R.P.M. (high datarate). Does this fact again reduce need for higher cost MR's for competitors?
4. Can the new laminated alloy head technology currently used for a few consumer tape products and employed in HDTV-VCRs be adapted for rigid disk drive?

Above items are looked at from the standpoint of possible exposures to our current strategic road map. I thankfully acknowledge contributions from following individuals' written inputs and private conversations in the process of writing this report.

Thin film Heads	R. Jones, Y. Moradzadeh
MIG heads	E. Cunningham, R. Schiedecker, J. Costello
MR, rigid disks	P. Bonyhard, L. Rosier
Perpendicular recording Heads	T. Beaulieu

The material on laminated heads grew out of conversations with Dr. Shibaya of NHK and Mr. Kaminaka and Nakamura of Matsushita. For economic and business outlook on recording heads for rigid disks SCCG (Santaclara Consulting Group) report of May 1989 was referred for this study. Numerous IEEE transaction papers and IECEI (Japanese meetings) papers have also been referred.

Business and Economic environment for DASD Heads

Global market of heads for rigid disk drives in 1988 was 104 Million units of approximately 900 M$ value. 83% of the units were ferrite heads, thin films constituted 15% while less than 2% were MIG (Metal in gap ferrite) heads. However every disk drive manufacturer in the world has activity and plans of introducing drives with MIG heads. It is estimated that in 1993, of 170 Million unit market, proportion of Ferrite, thin film and MIGs will be 40%, 20%, 40% respectively. During 1988-89 introduction of MIGs pushed thin film head usage to drives with over 700 MB capacity. Imprimis, IBM, AMC, Read Rite and others share 34, 27, 12, 11, 16 percent of the thin film market respectively. Others include Japanese and European companies including captive users like Hitachi, NEC, NTT, Fujitsu, Siemens and head suppliers, TDK, KME etc.. Average price of the thin film head dropped from $15.70 in 1988 to $12.70 in 1989. It is expected that with the introduction of micro-sliders (70% size next year and 50% size in two years) and improved yields (from 40% to 75%) prices of film heads should become competitive with MIG heads in two to three years. Both MIGs and thin film heads are expected to go under $10 per head by 1993.

The table 1 shows expected evolution of Ferrite, MIG, thin film and MR heads. With some degree of success with fine grain ferrite heads, monolithic and composite ferrites would be able to reach between 5 to 8 um trackwidths. However their market share would reduce to 40% from current 85% and before the end of the decade they are likely to be replaced by MIGs. Saturation magnetization of ferrites (5 KG-6 KG) would be insufficient to write on future high coercivity thin film disks. MnZn ferrite has one advantage of higher permeabilty at high frequency and that is why Fujitsu and NEC continue to use ferrites even for high capacity high (3MB/sec) data rate files. However MIGs are improving and will be widely used in similar capacity disk drives. Currently used MIGs using thick sendust layer (10-11 KG saturation field) can provide adequate writability for film disks of up to 1200-1400 Oe. coercivities.

However higher field saturation materials are explored and are likely to be introduced in 3 to 4 years. The laminated alloy heads currently explored for VCR for high definition TV and other consumer products may be applied to rigid disk market in 5-7 years.

The table 2 shows relative merits of thin film, ferrite, MIG and MR head technologies. The reason for negative in thin film column for linear density is due to the current strategy of using small PGP (summation of pole and gap widths) to magnetically slim the pulse out put and hence obtain higher linear density on low coercivity (particulate) media. Thicker poles and high Bs materials as discussed later could change that negative to positive. MR superiority in track density is due to higher reading sensitivity and controlled write wide read narrow recording procedure. The term "Baggage" refers to additional electronics required to handle thermal asperity and other peculiarities of MR heads.

The table 3 shows a list of high density disk drives and head technologies used. All three technologies are used for up to 60 Mb/sq.in. density and low data rates (< 2 MB/sec). The choice of component by a manufacturer depends on his prior experience, availability of heads and cost considerations. For high end or higher data rates (> 3 MB/sec) thin film heads are preferred.

In 1988 Hitachi introduced thin film heads for its 3380K equivalent and dual density (62.8 Mb/sq.in.) drives and Areal Technology employed film heads to achieve 98 Mb/sq.in. density in its 3.5", 100 MB files.Matsushita 'announced' 123 Mb/sq.in. density file using thin film head. Yamaha claimed to have developed a thin film head on microslider (50% area and 33% volume of conventional size) with two layered 42 turns for over 100 Mb/sq.in density. At 1988 year end Comdex show, new drives were announced and hinted with densities approaching 100 Mb/Sq.In.. All of these drives use thin film heads.

Thin film head enhancements

A number of enhancements in improving performance and cost of thin film heads are being worked on throughout the industry. Both the manufacturers of thin film and ferrite heads are working on reduced mass microsliders first to 70% of the normal (3370 size) dimensions and then to 50% in each of the three dimensions. Advantages of microsliders are (1) Reduced mass sliders allow shorter and stable flying heights with reductions in stiction and friction tendencies. 2)Smaller physical size allows reduction in disk to disk spacings from .15" to less than .12"increasing volume density of future drives. 3)Reduced core size of ferrite heads reduce inductance and hence improve higher data rate capability. 4)More sliders per wafer allow higher production efficiency when yields are stabilized. This is particularly important for film heads with many process steps per wafer and high costs of intermediate testing.

IBM's wet process i.e. electroplating of NiFe and Cu has been adopted by manufacturers like AMC, Imprimis, Read-Rite along with Japanese manufacturers like TDK, KME and NTT. However, Magnex Siemens and Hitachi use dry processes i.e. Sputtering for deposition of head poles. Dry processes are more suitable for use of high Bs materials and laminated poles. It is interesting that NTT used thick (PGP=6.5um) plated poles for its Gemmy drive which claimed higher density (40 Mb/sq.in.) earlier than IBM's 3380K (in 1985) while Hitachi which was one of the vendors in developing Gemmy uses sputtered thin (PGP=3.45um)poles for its 3380K equivalent density drive. This Hitachi head appears to have near ideal domain pattern control (low "Al-John" numbers) in pole regions and low error rates.Hitachi has published on permalloy thick laminated pole heads with 7 um track widths. The May 89 paper also shows results of thick pole heads. Laminated thick pole heads with high Bs material can extend thin film head technology for next five years and a strong contender to MR heads.This would require sophisticated adaptive equalization for changes from inner to outer diameter response. As used by NTT earlier Japanese and some U.S. drive manufacturers are leaning to use of thick (2-3um) pole thin film heads.

High Bs (saturation flux density) materials have been actively pursued in magnetic recording for last 20 years. Bs of MnFe ferrite commonly used in most low end drives and few high end drives is 5-6 KGauss. Alloy called sendust (FeAlSi) of Bs value of 10-12 KGauss has been studied heavily and used in applications needing higher field densities. With procedure for depositing sendust on ferrite material perfected, a hybrid head called MIG (Metal in gap) emerged for consumer tape industry. Thin film head of permalloy also has Bs of 9-10 KG and it can be economically electroplated so that there was no advantage in making sendust film head. However poles of thin films made with higher (between 10 and 22KG) are desirable to write on ever increasing coercivities of thin film disks. Development of higher Bs materials for heads has been a prime activity in every magnetic material laboratory in Japan. High Bs materials are necessary for almost every kind of new head developments. Future version of MIGs will use them, write head of piggyback MR structure could use it and new alloy laminated heads (currently used in consumer tape industry) also use them. Hence research on high Bs Materials is very important for Magnetic recording technology. In U.S. except IBM there is very little activity in the industry. This is one of the topics which warrant more attention by U.S. industry and research community for retaining strong position in future magnetic recording products.

For film heads, higher Bs material allows use of higher coercivity disks and hence higher linear densities. Hitachi has been very active in the field reporting head Bs values 14KG (compared to 9KG for 82/18 NiFe) with Co-Ni-Fe-Pd and Fe-C with potential of up to 22KG. The May 89 paper of Hitachi claims successful operation of laminated pole Co-Ni-Fe-Pd heads with 6 db improvement in overwrite capability than sputtered Ni-Fe pole heads. This capability can be transformed into higher linear densities. T. Kobayashi and others at Hitachi have also studied layered films of Fe and magnetically soft materials such as NiFe or one of the Cobalt based amorphous alloys. Plated films such as CoFe are also candidate materials. The advantage in this case is that the presently preferred plating technology can be retained. It is fairly certain that one or more of these materials will be introduced in a product in near future, possibly to compete early MR head use. Laminated high Bs material pole heads can extend the thin film head use at high end for next five or more years and densities of over 200 mb/sq.in. appear feasible with such heads.

Much of the progress in film heads has been by increasing number of turns. Starting with 8 turns, second generation used 17 or 18 turns and current third generation uses 30-31 turns. The record holder was Cybernex design with 50 turns in two 25-turn layers. More turns result in higher inductance and lowers resonance frequency at the output which in turn produces high peak shift for high data rate applications. So number of turns is only one of the parameter to optimize specific design point and not a substitute for improvements in other variables of the design.Most low end (low data rate <3MB/sec) users are likely to use this parameter to increase densities and obtain higher effective rates by buffering or paralleling procedures.

Metal in Gap heads and their extensions

MIG head is a ferrite head with a layer of 'sendust'(FeAlSi) alloy on either one or two sides of the gap (which is usualy glass). The structure came into use in consumer tape industry in early 80's. With this feature tape recording reached a new high of over 100 Mb/sq.in. density in 1987 (Sony). Alps company of Japan which has been making MIG heads for VHS-VCR, 8 mm video and

RDATs applied it to rigid disk industry. IBM has been the major customer (Rochester and Fujisawa) of these heads and has announced drives with these heads. Currently up to 40 KBPI linear density and up to 1700 TPI products are marketed with this technology. Fig. 1 shows possible enhancements of the technology. Fig.1a, shows most commonly used single sided sendust head, Fig.1b shows double apex head which improves efficiency, Fig.1c indicates double sided sendust MIG head, Fig. 1d indicates use of higher Bs material in place of sendust. Sendust has a Bs value of 9 KG to 11 KG depending on fabrication process. Rochester has done computations using the probable extensions of the technology i.e. all of above and pole material with Bs of 12KG. Using above heads flying at 3 u″ over a media with coercivity of 1720 Oe., density of 115 Mb/Sq.In. (60KBPI, 1910 TPI) and data rate of 6 MB/sec has been projected. If MIGs retain the cost advantage over thin film heads along with enhanced features indicated above, they will become the main line head technology for low and intermediate drives. There are two major problems with MIG head technology (1) At the interface between sendust and ferrite there is usually a secondary gap which results in additional small peak in output waveform. Because of such a problem VHS and RDAT industries employed complicated sendust deposition process. Often the problem seems solved but it does recur and two sided sendust will possibly make it worse. (2) Basically MIG is a ferrite technology so large grain structure of ferrite limit track widths of 10 um or larger. New fine grain ferrites and single crystal ferrites are explored but no low cost products are expected in near future.(3) Due to wound coil and large ferrite bulk surrounding coil, inductance of the ferrite head is an order of magnitude higher than a film head. This results in resonance frequency of output voltage in ferrite/MIG heads about 10 to 15 Mhz compared to 75 to 100 Mhz for a thin film head. However as pointed out in Rochester report of Redwing extension, use of composite MIG head, lowering number of turns and increasing current through the coil, inductance of the head can be reduced by a factor of three i.e. from about 3.5 uH to 1.1 uH. This would increase resonance frequency and data rate as high as 6MB/sec would be possible.

Rochester exercise of MIG head extendibility and expected performance improvements is important since it shows some of the directions competitors are likely to take.

Obviously MIG has cost and immediate performance advantages for low and intermediate size (under GB) disk files and will be heavily pursued. Their use in high performance, high density files is strongly doubtful in next 3-5 years until significant advances in technology at competitive costs could be realized. On the other hand availability of competitively priced thin film heads with improved high Bs poles could swing the drive industry towards thin film heads.

Competitive MR head Activities

In U.S., Imprimis and Kodak has the most knowledgeable individuals to develop and produce MR heads for rigid disks. Imprimis is in the process of setting up a pilot line to produce heads for customers. Considering the success of Imprimis in producing thin film heads and implementing them in their own as well as customers' disk drives it is possible that drives with MR heads be announced in one to two year time.

In Japan, Hitachi has extensive Patent portfolio on MR heads. The patent activity started in 1982, it peaked in 86-87.The quality of disclosure range from poor to excellent and indicate following emphasis (1) For rigid disks several patents are applied to cover modifications of shielded, soft biased and winged track structure. (2) Alternative bias schemes like electrical vs. magnetic (3) Variety of materials to improve performance (4) Improvement of performance by geometrical variations of MR element and optimization of heads for inner and outer range of tracks etc.. NEC has consistent efforts on rigid disk drive related MR head activity. Shielded, soft biased version being the most popular. Maruyama of NEC also has a MR structure with deposition defined track width concept which can allow very small track widths and flux guide provide back mounted differential head. Such a head would be much less efficient than MR element close to the surface but deposition defined track width is an interesting concept for future developments. Sony has presented a paper on vertical MR head structure. It has an advantage of very narrow trackwidth without sacrificing MR stability but connection to lower terminal near air bearing surface and height control by mechanical lapping process are severe problems.

Laminated alloy heads

For the future digital VCRs and VCR's for HDTV, Japanese industry has a goal of 1 sq.um bit cell (625 Mb/sq.in. density). Such a density requires 3um track width x.33 um bit width. Bit density of close to 75 KBPI is close to what is already used in RDATs. The research towards narrow tracks for consumer tape industry has over 12 year history. Use of plating or sputtering process to define track widths has been pursued for this purpose. Fig. 2 shows various heads made with such a process. Fig. 2a shows Sony head used in a 1987 product EV-S700, a 8 mm VCR with dual capability for 24 hours of audio sound per tape. Fig. 2c shows alloy laminated heads currently operating in a prototype VCR for HDTV at NHK. Fig. 2b shows a laminated head for Hi-Fi S-VHS movie camera marketed to day. The NHK head operates up to 120 Mhz frequency indicating that laminated high Bs materials are developed for writing on 1700 Oe. metal particle tapes and with gap and inductance small enough to give over 100 Mhz performance. Chances of such a technology to migrate in rigid disk arena are quite high within next five years.

Horizontal Head and Perpendicular recording Head

Horizontal head (Ref: 1987 Intermag proceedings) is being pursued jointly by Leti and Thomson-CSF. Currently 27 individuals are working on the project. The head combines silicon planar technology with plating and/or sputtering processes to fabricate heads on silicon slider. It offers lower cost due to 14 mask levels vs. 25 for conventional thin film head and lower inductance by a factor of two so has potential for very high data rates. Moreover electronic support circuits may be integrated with the head in future. The main advantage of this and other horizontal head structre is reduced "back end" fabrication cost.

Difficulties of the head structure are (1) Large surface area of the head is exposed to air bearing surface and planarity and control of head surface could be difficult (2)Critical gap making process and tolerances on gap dimension. (3) Lack of experience with silicon slider and film disks.

Relatively new company "Springer Technology" has also developed horizontal head which claims drive density of 90 Mb/sq.in. with 2000TPI, 45 KBPI, 60 turn head flying between 3 to 6 u" over disk.

Extensive activities took place in Japan during last five years on perpendicular recording. Theoretically much higher densities have been expected with this recording. However practically no such advantage is clearly observed. The work done on materials for heads to make them efficient has been very relevant to longitudinal recording. Considerable experience has been obtained by Japanese researchers in fabricating heads and media and still efforts are underway to make it a commercial reality in tape recording systems of the future. Cestor in U.S. has done a very significant work in developing perpendicular recording head and media. Its head is compatible with thin film head making processes and efficiency of the head on dual layer media is the best in the field.

Summary

Summarizing the above study-

- Disk drives of up to 100 Mb/Sq.In. density with low data rate (<2MB)are likely to be in the market in next 3 to 5 years. All three head technologies MIGs, thin film and MR are would be used for such files. In general MIGs require lower flying heights than thin film heads for achieving similar density.

- For data rates of over 4.5 MB/sec film heads will be preferred

- Microsliders and improved yields will make film heads more cost competitive. Japanese manufacturers who have been lagging are likely to make strong efforts in manufacturing film heads in large quantities.

- Between 100-200 Mb/sq.in. densities extended film heads will compete with MR across the board.

- Over 200 Mb/sq.in. densities and higher performance MR will predominate with Imprimis, Hitachi and NEC as possible contenders in developing manufacturing and applying them in disk files.

- Some form of laminated alloy technology may be introduced in rigid disk head business within next five years

Recommendations

- We need to reexamine our policy of thin pole thin film heads and should commit to enhancing film head technology with high Bs thick pole, laminated heads. At least our R & D capability should be second to none in the film head development. Along with component development, channel issues of equalization and alternative error control procedure for using such heads should be diligently pursued. It is possible that the "commodity" disk drive would be most optimum with film head and high coercivity film media.

- In cooperation with vendors we should develop alloy laminated head for rigid disk with objective of over 100 Mb/sq.in density for intermediate and low end drives.We should also have a consistent monitoring and experimentation using such heads for high end drives

- To make IBM head community more aware of competitive pressures and technology alternatives, we need to formulate vigorous program of inter-company and intra-company communications. Japanese companies have developed strong network of communications at every level of magnetic recording development. Bay area is not much different than Tokyo in its concentration of disk drive industry and we should motivate and support local academic institutions to take aggressive role in enhancing communications among U.S. recording community for retaining technology and market edge enjoyed by U.S. industry to day.

DASD Heads

Head type	To day	Next	Future
Ferrite -	Use 85%	Small grain 40%	- -
MIG (Hy-brid) -	Use 1.5%	High Bs 40%	Laminated Alloys -
Thin film -	High end 13.5%	High Bs, MS 20%	Low cost, NS -
MR	R&D	Use	Merged and High Bs write
Total #	104M	170M	

Table 1

K. Ashar, 12/8/89

DASD Head Comparison

Parameter	Thin-film	Ferrite	MIG	MR
Linear Density	-	-	+	+
Track Density	+	-	-	+ +
Data Rate	+	-	-	+ +
Cost	-	+ +	+	-
Amount of Experience	+	+ +	+	-
"Baggage"	na	na	na	--

Table 2

K. Ashar 12/8/89

Heads for greater than 34 Mb per sq.in. density files

Manufacturer	KBPI	TPI	Mb/ sq.in.	Head
Gemmy	31.5	1270	40	film
Hitachi DK816	38.8	1660	64	film
Hitachi DK515	40.21	1296	52	film
Conner	31.8	1700	54	film
Imprimis	33.7	1867	62.8	film
Hitachi	40	1250	50	MIG
Hitachi	35.1	1660	58	MIG
NEC	26.8	1290	34.6	ferrite
Miniscribe	31.24	1495	46.7	Ferrite
JVC 2.5″	40	1456	58	Ferrite
Maxtor	31.6	1376	43.25	film
Areal	38	2500	98	film
Siemens	30.8	1476	45.5	film
Matsushita	63	1800	113.4	film
NEC D5892	45.9	1603	73	Film
Hitachi Prel	49.8	1900	95	Film
Yamaha 42T M.S.	--	----	60-100	film

K. Ashar, 11/13/89

Table 3

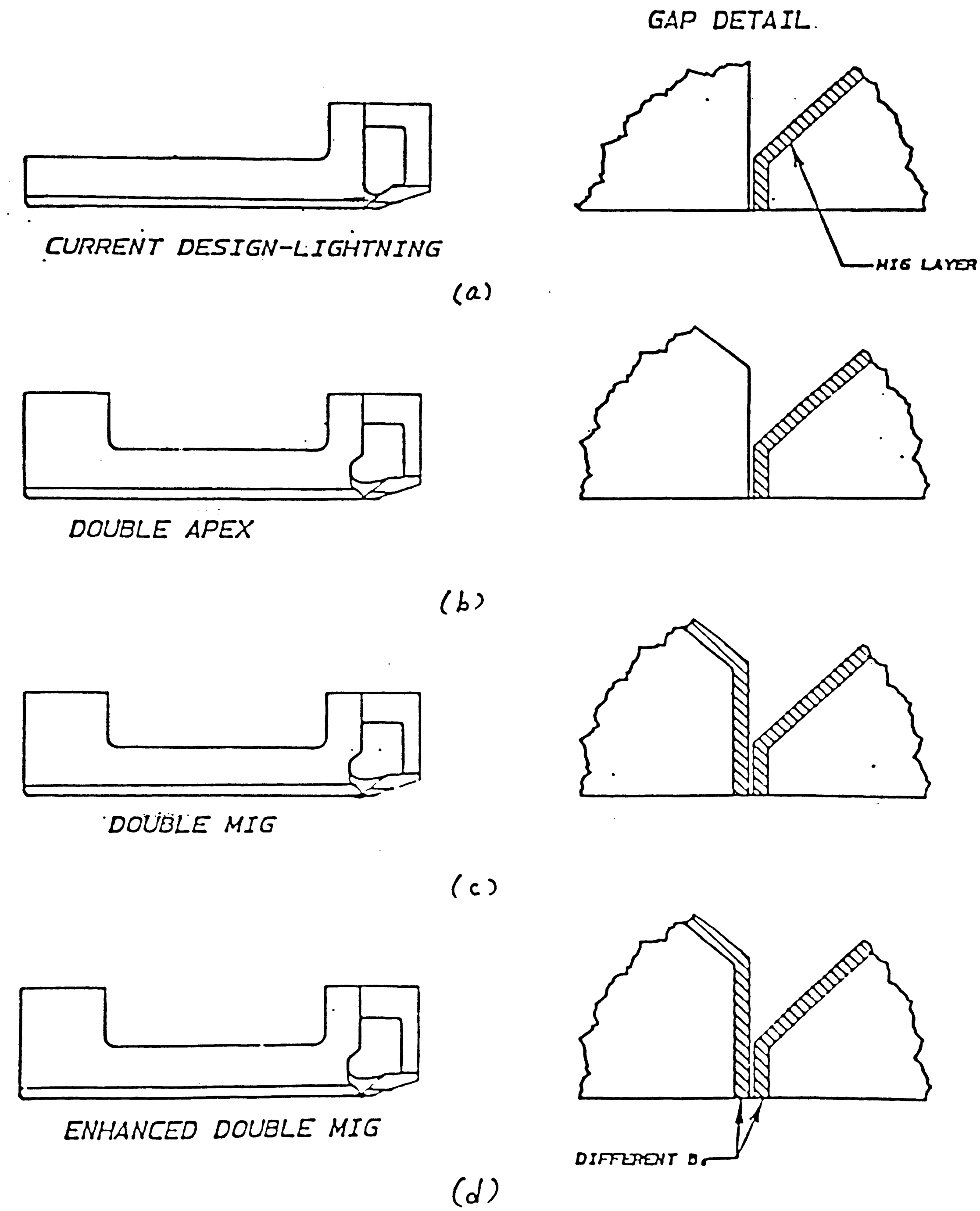
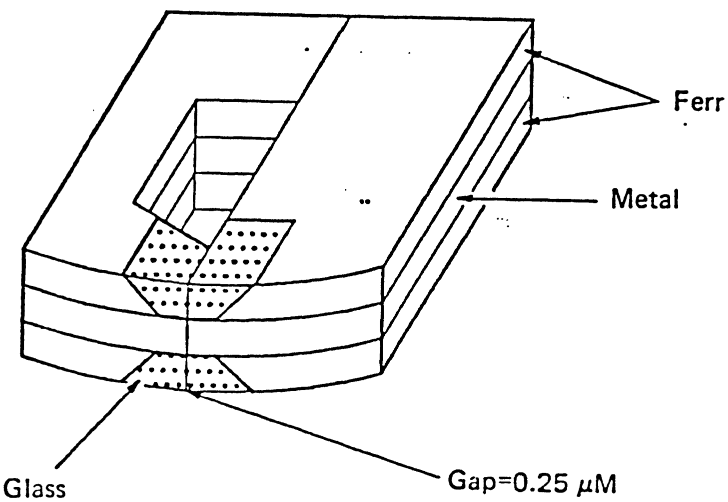


Figure 1 MIG Technology Flow

JDC 5 SEP 89

Applications of Alloy Laminated Heads

- Sony microfine head for 8 mm VCR/ 24 hr audio, 87
- First time 100 Mb/sq.in.



- Matsushita S-VHS Movie heaa
- 1989-12 layers of 3um thick each for digital VCR

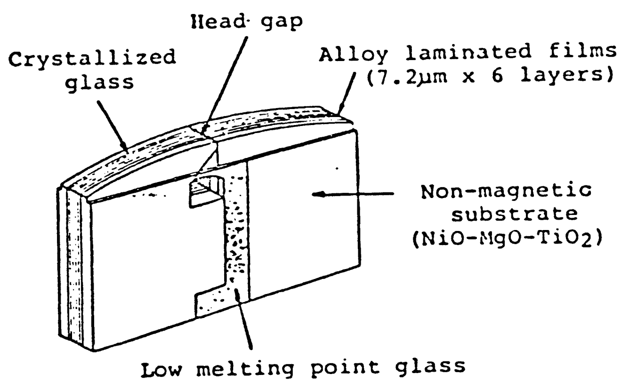


Fig.2. An outside view of the alloy laminated films head.

- NHK HDTV-VTR head
- 1989-5um layers
- 120 Mhz operation

Figure 2

K. ASHAR 12/8/1989

Competitive technologies- Rigid disk Heads

- Ferrite, MIG and Film head comparisons and future
- Thin film and MIG technology extensions
- MR head competitive activity
- New head technology from HDTV-VCR and digital tape systems
- Summary

K. ASHAR 12/8/1989

Rigid Disk Heads- Inputs

- Thin film heads

  R. Jones, Y. Moradzadeh

- MR

  P. Bonyhard, L. Rosier

- MIG

  E. Cunningham, R. Scheidecker (Rochester)

- Alloy Laminated heads

  Conversations with Shibaya (NHK) and Kaminaka (Matushita)

DASD Heads

Head type	To day	Next	Future
Ferrite -	Use 85%	Small grain 40%	- -
MIG (Hy-brid) -	Use 1.5%	High Bs 40%	Laminated Alloys -
Thin film -	High end 13.5%	High Bs, MS 20%	Low cost, NS -
MR	R&D	Use	Merged and High Bs write
Total #	104M	170M	

K. Ashar, 12/8/89

DASD Head Comparison

Parameter	Thin-film	Ferrite	MIG	MR
Linear Density	-	-	+	+
Track Density	+	-	-	++
Data Rate	+	-	-	++
Cost	-	++	+	-
Amount of Experience	+	++	+	-
"Baggage"	na	na	na	--

K. Ashar 12/8/89

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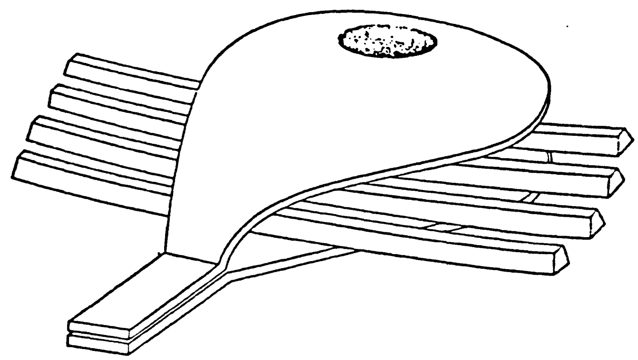
Hitachi Prel	49.8	1900	95	Film
Yamaha 42T M.S.	--	----	60-100	film

K. Ashar, 11/13/89

FILM Head Extensions



- High Bs Poles
- Thick Poles
    - Requires adaptive equalization and probably laminated poles
- Laminated poles
    - Narrow track stability-domain controls
    - High frequency response
- Increasing number of turns

Hitachi activities on film Heads

- Sputtering process with polyimide insulation
- Ni-Fe sputterred laminated heads (Bs=8.7 KG)
- CoNiFePd/Al2O3 laminated 3.2 um poles Bs=14 KG, 6 db better overwrite than permalloy
- Fe based materials e.g. Fe-C with Bs=20 KG.

May 1989 paper

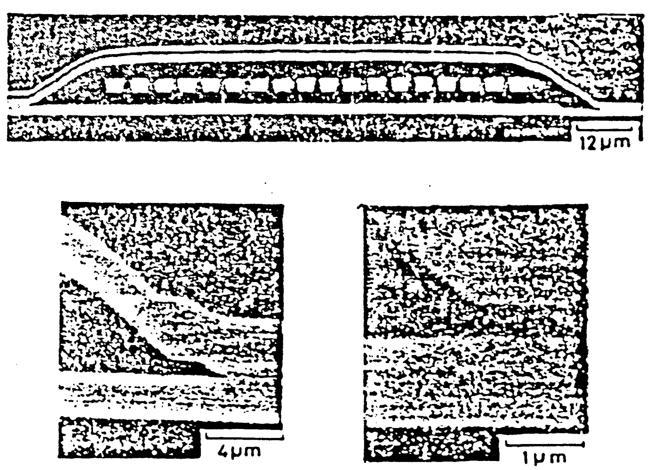


Fig. 10. Cross section of multi-layered Co-Ni-Fe-Pd/Al_2O_3 head.

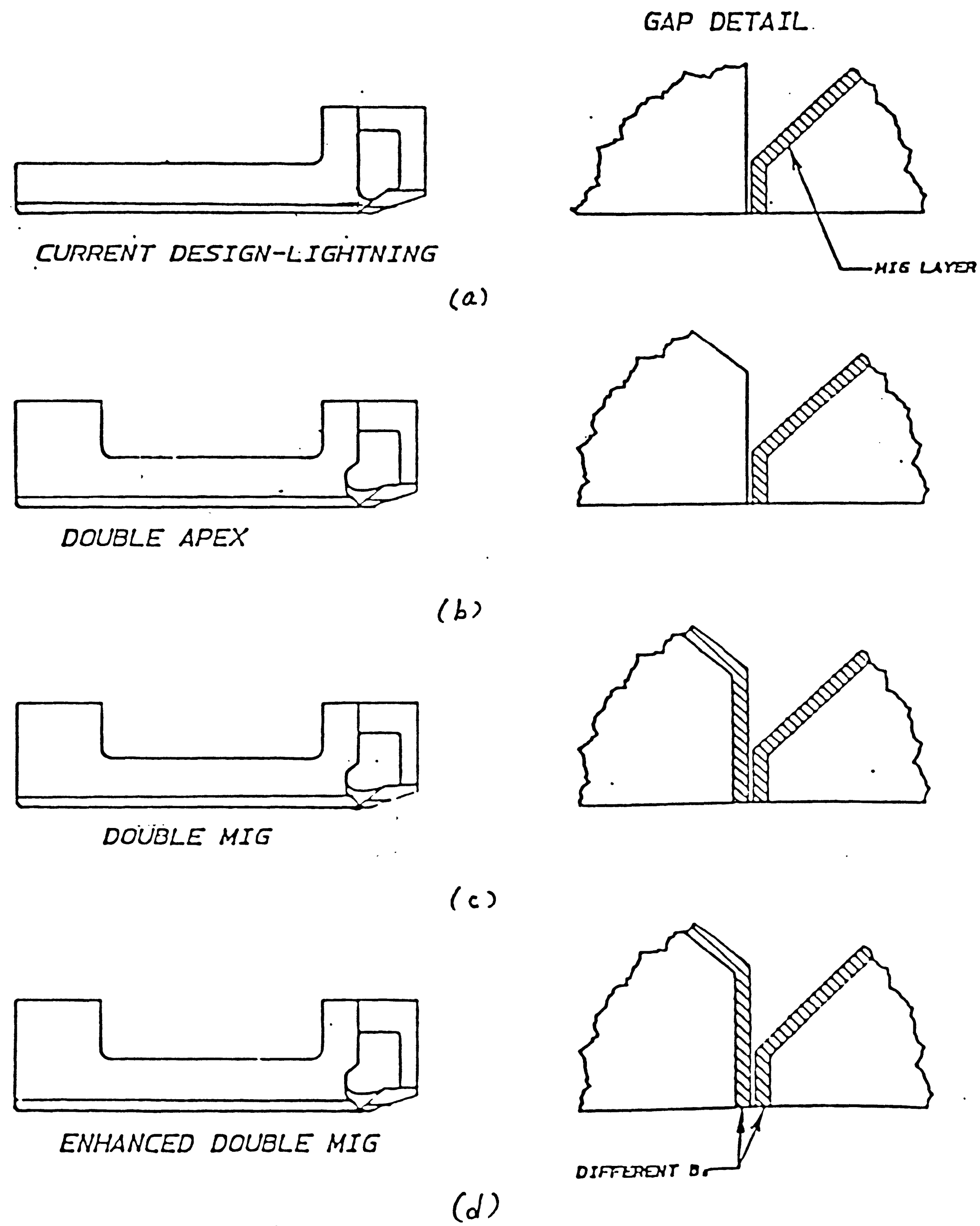


Figure 2. MIG Technology Flow

JDC 5 SEP 89

REDWING DOUBLE LINEAR DENSITY

	REDWING		DOUBLE LINEAR DENSITY	
LINEAR DENSITY	30.3	Kbpi	60.6	Kbpi
DATA RATE	3.0	MB/s	6.0	MB/s
GAP LENGTH	0.60	um	0.30	um
FLY HEIGHT (min mech)	8.0	uin	3.0	uin
FLY HEIGHT (center of mag)	10.6	uin	5.3	uin
DISK COERCIVITY	860.	Oe	1720.	Oe
Mrt (in E-3 emu/cm**2)	3.0		3.0	
B gap	6000.	G	12000.	G
MMF	0.55	A-t	0.45	A-t
Turns	11.		9.	
Inductance	3.5	uHy	1.1	uHy
Capacitance (approx)	25.	pf	25.	pf
Resonant frequency	17.0	MHz	30.3	MHz
Current	50.	ma	50.	ma
Peak flyback	4.7	v	3.0	v
Readback Voltage (2*9/11)	Vs	v	1.64 Vs	v
Noise V (2*(1+.63**2)/2)**.5)	Vn	v	1.18 Vn	v
Signal to Noise Voltage ratio	S/N		1.39 S/N	
Nominal track width	9.8	um	9.8	um
Minimum track width	8.3	um	8.3	um
Maximum track width	11.3	um	11.3	um
Maximum excess write width	3.9	um	2.0	um
Pitch	15.2	um	13.3	um
Track density	1668.	tpi	1910.	tpi
Areal density	50.5	Mbpi2	115.7	Mbpi2

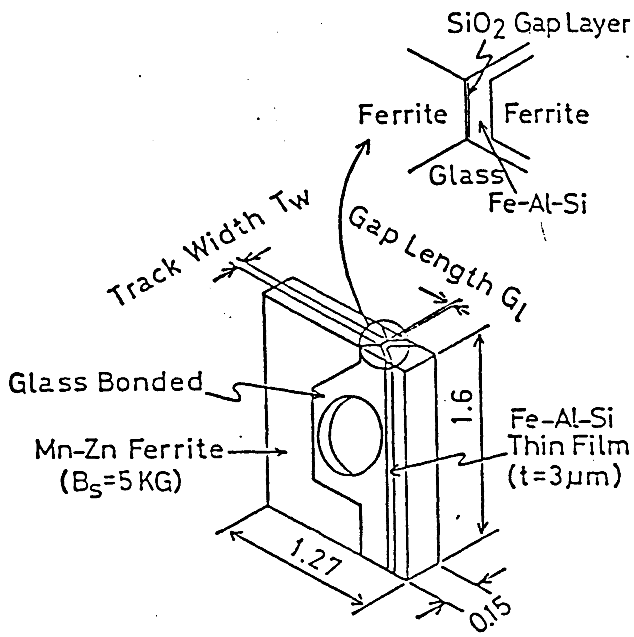


Fig. 1 Schematic structure of magnetic core

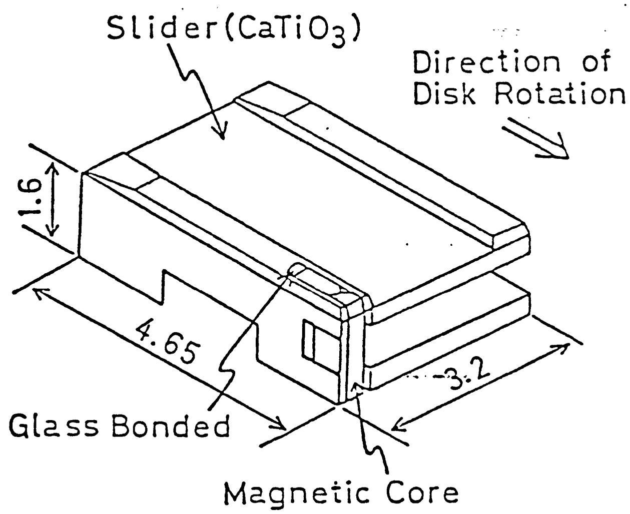


Fig. 2 Schematic structure of metal-in-gap mini composite head

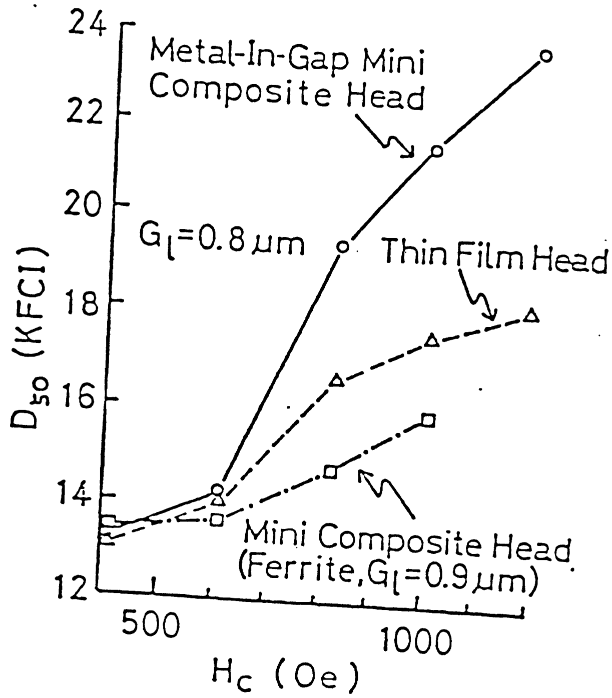
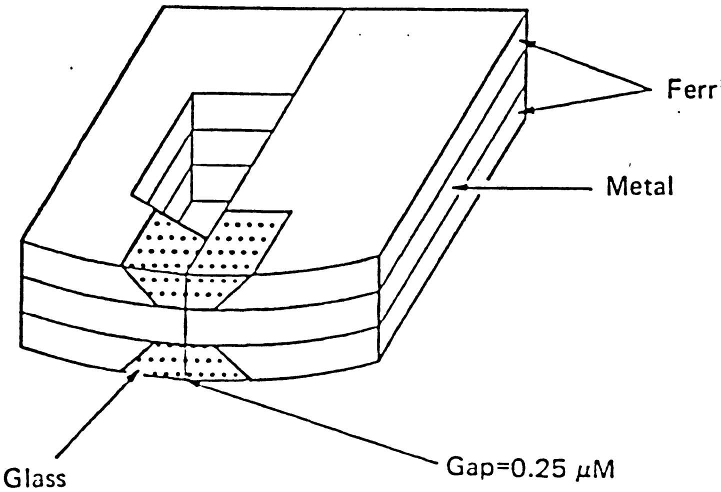


Fig. 8 Dependence of recording density D_{50} on coercive force of disk

Applications of Alloy Laminated Heads

- Sony microfine head for 8 mm VCR/ 24 hr audio, 87
- First time 100 Mb/sq.in.



- Matsushita S-VHS Movie heaa
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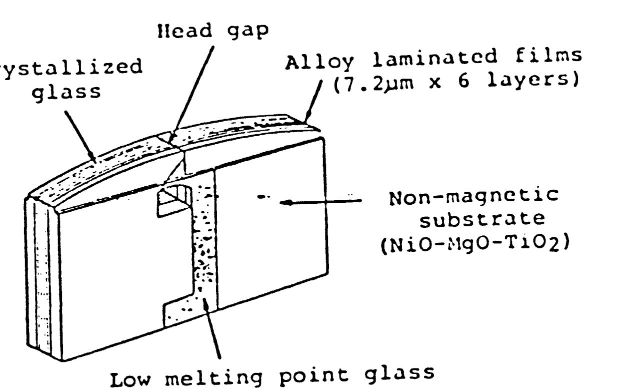


Fig.2. An outside view of the alloy laminated films head.

- NHK HDTV-VTR head
- 1989-5um layers
- 120 Mhz operation

K. ASHAR 12/8/1989

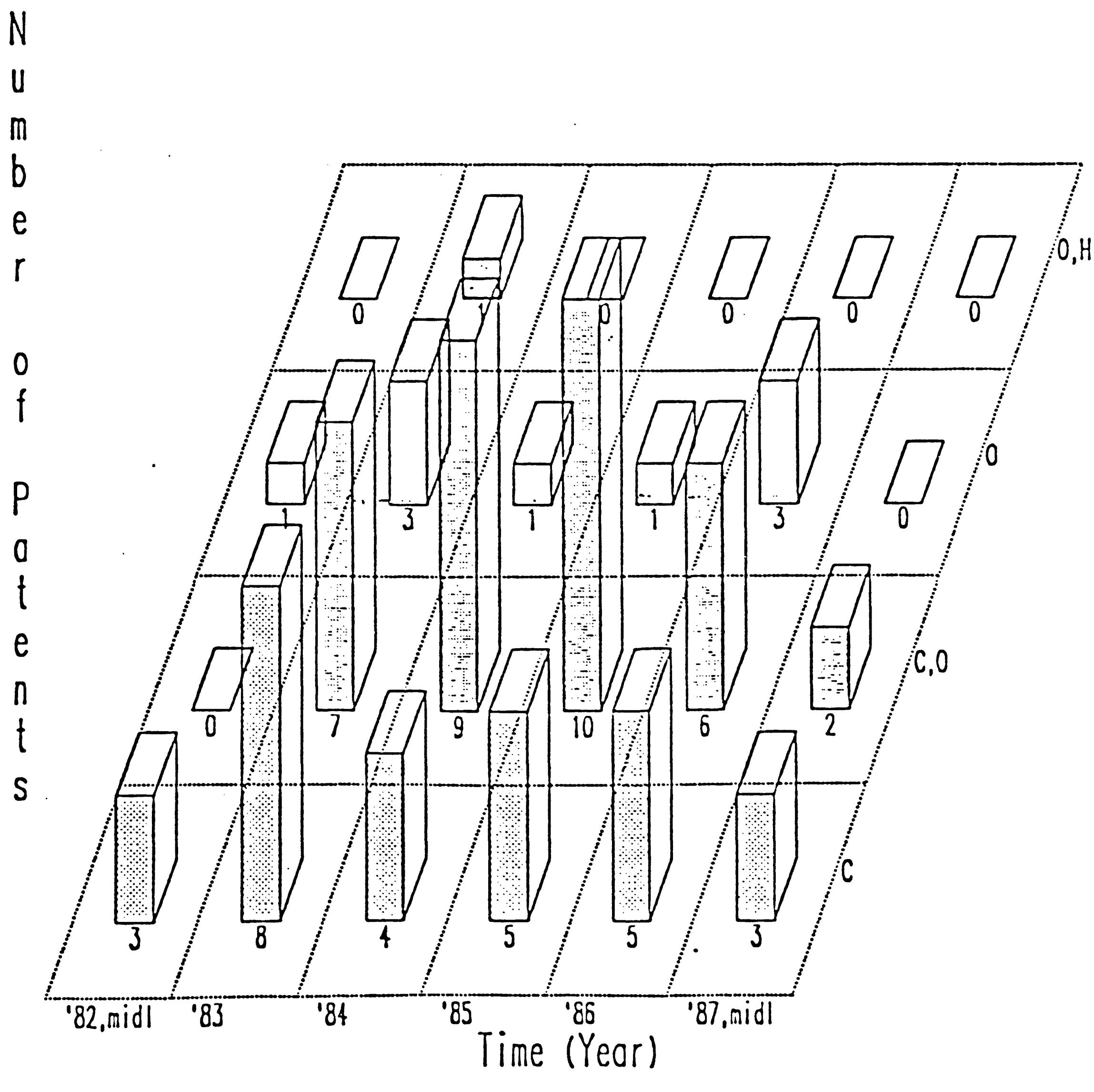
Summary

- 100 Mb/sq.in. (<3MB/sec), possible with MIG, film and MR
- Film heads preferred for >4.5 MB/sec data rate
- Microsliders and yield increase will make film heads cost competitive with MIGs in 2-3 years
- In the 100 to 200 Mb/sq.in. range, in addition to film heads, MR may be pursued by Imprimis, Hitachi and NEC
- Some form of laminated alloy technology may be introduced for high density rigid disk drives
- IBM is leader and ahead of competition by a couple of years in MR head development
- Recommendations
    - ♦ Study and implement thick pole thin film head strategy
    - ♦ Initiate monitoring and experimental testing of MIGs and alloy laminated heads for high end files

Transition of applied patents.

(from Sept 1982 to 1987 july, applied date)

(included in H01L43/*, G11B5/02, 12*, 30, 31, 39)



RECENT RECORDING HEAD RESEARCH WORKS IN MAGNETIC RECORDING RESEARCH LABORATORY

1. LAMINATED AMORPHOUS ALLOY VIDEO HEAD

   - Co-BASED AMORPHOUS ALLOY THIN FILM
   - SUPER-STRUCTURED NITRIDE THIN FILM

2. METAL-IN-GAP HEAD

   - ELIMINATION OF SECONDARY GAP

3. THIN FILM HEAD WITH FLAT YOKE STRUCTURE

   - EFFICIENCY AS HIGH AS VIDEO HEAD

4. PERPENDICULAR MAGNETIC RECORDING WITH RING HEAD AND SINGLE-LAYER CoCr

   - 1 BIT/μm^2 DIGITAL VIDEO RECORDING

5. TAPE-HEAD INTERFACE AND TRIBOLOGY:

   - METAL-HEAD TO THIN-FILM METAL-TAPE INTERFACE

SUMMARY OF COMPETITIVE STUDY of READ-WRITE CHANNEL and SIGNAL PROCESSING for DASD RECODING

R. A. Jensen et al

San Jose GPD LAB

December 8, 1989

TECHNICAL AREAS	TEAMS	
▪ DETECTION AND ENCODING	Roger Hoyt	Chairman
	Tom Howell	(ARC)
	Rob Lynch	(ARC)
	R. Peterson	(Rochester)
	Paul Seger	(Tucson)
	Roger Wood	(San Jose)
▪ ERROR CONTROL	Bob Rutledge	Chairman
	Mario Blaum	(ARC)
	Jim Carothers	(San Jose)
	John Eggenberger	(San Jose)
	Martin Hassner	(ARC)
	Arvind Patel	(San Jose)
	Jeffrey Johnson	(Rochester)
	Greg Kerwin	(Rochester)
	Donald Vosberg	(Rochester)
	Paul Seger	(Tucson)
	Stephen West	(Tucson)
	Jud Mcdowell	(Tucson)
	Elna Otter	(Tucson)
▪ ELECTRONICS, PACKAGING AND DESIGN TOOLS	Irv Feinberg	Chairman
	Chuck Nielsen	(San Jose)
	Bill Wright	(San Jose)
	Jim Rae	(Rochester)
	Paul Seger	(Tucson)
	Nhan Bui	(Tucson)
▪ RECORDING ALTERNATIVES	Roger Wood	Chairman
	Tom Beaulieu	(San Jose)
o ZONE OR BANDED	Jim Carothers	(San Jose)
	Roger Hoyt	(ARC)
o VERTICAL	Greg Kerwin	(Rochester)
	Mike Melas	(ARC)
	Jim Rae	(Rochester)

SUMMARY -- DASD RECORDING CHANNEL COMPETITIVE STUDY

DETECTION AND ENCODING

Over the past six years we have demonstrated, in IBM, considerable density advantages over 2,7 code peak detection with a progression of encoding, processing and detection techniques. As far as we can tell we are leading the industry in the development and planned product implementation of advance partial response and maximum likelihood detection channels. These include: the VLSI implementations of PRML* for three Rochester products at 2, 3, and 4.5 Mbyte/sec (Redwing, Corsair and Cub) and 9 Mbytes/sec for Placer; 1,7 ML* for Soquel 3; and work on several advanced detection techniques beyond PRML at data rates up to 18 Mbyte/sec.

The industry is using 1,7 and 2,7 code peak detection in all four areas of recording. Some products use various forms of pulse Soquel and Sutter. The high-end DASD and tape environments offer the opportunity for signal processing innovation. Hitachi and perhaps STC (Storage Technology Corp.) have introduced a technique in their 2,7 and 1,7 peak channels where the decision on a bit with intermediate amplitude is made based on the polarity of the next bit. Hitachi claims a 2 dB SNR gain in the off-track mode with this approach. They state that they use this approach instead of "maximum likelihood or interactive feedback detection" because it does not require high speed calculations as do the other approaches. We, on the other hand, are choosing more complicated approaches and designing chips to handle the high speed calculations with the potential of greater SNR gains.

There is publication and discussion of more advanced signal processing work but no evidence of product use in the near future; however, the potential is clearly there. Of some twenty three patents in the area, IBM holds 11 with the other 12 spread among ten other companies.

Low-end DASD tends to be constrained by cost via the use of chip sets available from vendors. Magneto-Optical recording is highly constrained by ANSI and ISO standards.

We have no recommendations for the pursuit of outside technology in this area at this time.

ERROR CORRECTION

The dominant ECC strategy in all of digital magnetic recording is the use of of interleaved Reed-Solomon* codes. The trend in every area has been to put more error protection into magnetic storage products by using more powerful versions of these techniques. Since this is driven by the fact that ECC can compensate for the increased

---

* See Glossary for all words with

raw error rate resulting from increased density or data rate, we expect the trend to continue into the future. Improvements continue to take place in two areas: the creation of customized code arrangements (e.g. AXP*, Two-Level ECC) to match the error characteristics of the channel, and the implementation of fast and efficient decoding algorithms (e.g. ON-The-Fly decoding of Reed-Solomon codes). IBM is a leader in both areas and well positioned to maintain that leadership. Several recommendations to help exploit our leadership are given below.

ELECTRONICS AND PACKAGING

The future direction for high and low end DASD, tape and optical recording is to reduce the number of chips though higher density VLSI and combined functions per chip. Packaging will be surface mount of direct chip attachment to conformal mulilayer flex cables.

There are a number of companies that offer channel chips at ever increasing sophistication even including inputs for banding adjustments. (See report for a detailed chart). The data rates of these channels make them more readily applicable to low and mid range DASD products.

Present IBM channel designs are a mixture of in-house bipolar analog, bifet and CMOS VLSI chips. We lag in the area of high speed technology that relates to high end DASD channel. Our high volume production is for main frame logic and application to channels results in compromises on both sides. We have not had a complementary PNP transistor the lack of which leads to inefficient and costly designs. Our channels have been built by East Fishkill; however, Burlington has some better technology but not track record with us. We must yet develop a technology to meet Tehama requirements while it appears that AT&T already has such a technology.

IBM low end DASD will be using a specially developed IBM, VLSI, PRML channel in all of their future products. They currently have a 3 MB/sec channel with plans for 4.5, 6 and 9 MB/sec through 1995 with target costs of $15 to $25.

There is some use of surface mount technology (SMT) by Hitachi. The Japanese are the distinct leaders in SMT and automated production for SMT but to date have applied it primarily to consumer products. The potential for application to DASD products is there. We are not yet using SMT for channel cards but the packaging approaches for Sutter and Tehama are moving us in that direction.

Our recommendation is to pursue alternative chip vendors where there is a potential performance/time/cost advantage. AT&T is being looked at for Tehama.

Another area where we need to take advantage of out side capability is in the area of channel design tools. What we have is non-integrated and have a very low level of support. Our design requires a degree of expertise base on lots of experience. The problem is worsening as channels become more complex and data rates increase. There are some excellent design programs available that are integrated to include both circuit performance and chip layout.

Our recommendation is that we should seek out and obtain the best tools available. There is activity to this end in process.

ZONE BIT OR BANDED RECORDING

Banded recording is being pursued vigorously out side of IBM. Competitors such as Maxtor and Seagate have products that demonstrate a 25% capacity advantage for a given maximum linear density. (See chart in report.) To date both the low end and tape areas in IBM have looked at and dismissed banded recording because it was not needed to achieve the immediate density targets. Banded recording is readily applicable to the low end architecture and interface. Commercial channel chips are available. One of the complications at the high end is the use of could key data; however, it can be designed around. A second and perhaps more serious constraint is 1.5:1 data rate range required. Right now we are pushing the data rate as hard as we can for the high end. We would either have to achieve a 50% yet high data rate for the OD or be satisfied with 2/3 of the current targeted data rates for the ID.

In perspective banded recording allows our competitors to achieve a good part of the capacity gains that we achieve through more expensive technology developments such as the MR head. For us it would be additional capacity.

Our recommendations are that banded recording should be implemented where cost justified in the low and mid range products and more thoroughly studied for the high end. This would include the setting of design point beyond what the head disk and channel technologies can achieve without banding. In GPD we need a more thorough study of the application with count key data and with parallel channels.

PRESENTATION

on

COMPETITIVE STUDY

of

READ-WRITE CHANNEL

and

SIGNAL PROCESSING

for

DASD RECODING

R. A. Jensen et al

San Jose GPD LAB

December 8, 1989

1. PRODUCT AND TECHNICAL AREAS STUDIED

1.1 PRODUCT AREAS STUDIED

- HI-END DASD
- LOW-END DASD
- TAPE
- MAGNETO-OPTICAL

1.2 TECHNICAL AREAS

TECHNICAL AREAS	TEAMS	
DETECTION AND ENCODING	Roger Hoyt	Chairman
	Tom Howell	(ARC)
	Rob Lynch	(ARC)
	R. Peterson	(Rochester)
	Paul Seger	(Tucson)
	Roger Wood	(San Jose)
ERROR CONTROL	Bob Rutledge	Chairman
	Mario Blaum	(ARC)
	Jim Carothers	(San Jose)
	John Eggenberger	(San Jose)
	Martin Hassner	(ARC)
	Arvind Patel	(San Jose)
	Jeffrey Johnson	(Rochester)
	Greg Kerwin	(Rochester)
	Donald Vosberg	(Rochester)
	Paul Seger	(Tucson)
	Stephen West	(Tucson)
	Jud Mcdowell	(Tucson)
	Elna Otter	(Tucson)
ELECTRONICS, PACKAGING AND DESIGN TOOLS	Irv Feinberg	Chairman
	Chuck Nielsen	(San Jose)
	Bill Wright	(San Jose)
	Jim Rae	(Rochester)
	Paul Seger	(Tucson)
	Nhan Bui	(Tucson)
RECORDING ALTERNATIVES	Roger Wood	Chairman
o ZONE OR BANDED	Tom Beaulieu	(San Jose)
o VERTICAL	Jim Carothers	(San Jose)
	Roger Hoyt	(ARC)
	Greg Kerwin	(Rochester)
	Mike Melas	(ARC)
	Jim Rae	(Rochester)

READ-WRITE CHANNEL COMPETITIVE STUDY FOR DASD

- DETECTION AND ENCODING
  - IBM CHANNEL TECHNOLOGIES
  - COMPETITIVE POSITION
- ELECTRONICS AND PACKAGING
  - CHIPS/TECHNOLOGY *
  - PACKAGING
  - CHANNEL DESIGN TOOLS *
- ERROR CORRECTION
- ZONE RECORDING *

DETECTION AND ENCODING

IBM CHANNEL TECHNOLOGIES --> DIGITAL SIGNAL PROCESSING

- HIGH LEVERAGE, 30 - 40% DENSITY GAINS

- RESEARCH AND DEVELOPMENT ARE PURSUING THE LEADING SIGNAL PROCESSING APPROACHES:

  - o PRML --> REDWING, CORSAIR, CUB, PLACER
  - o 1,7 ML --> SOQUEL 3,
  - o EPMRL
  - o TRELLIS CODE
  - o DECISION FEEDBACK
  - o 18 MB/S EXPERIMENTAL DISCRETE COMPONENT CHANNEL DEMONSTRATED 2Q89
  - o SELECTION OF BEST APPROACH FOR 18 MB/SEC PRODUCT CHANNEL IS IN PROCESS

COMPETITIVE POSITION

- TODAY, IBM AND COMPETITORS ARE USING 1,7 AND 2,7 CODE PEAK DETECTION.

MANUFACTURER	MODEL	CODE	DATA RATE
Amdahl	6380BK4	2,7	3 MB/s
Hitachi	H-6586	2,7	3 MB/s
Memorex	3890 2K4	2,7	3 MB/s
STC	8380 R33	2,7	3 MB/s
NEC	Gemmy	1,7	4.4 MB/s
Fujitsu	M239K	1,7	3 MB/s
Hitachi	DK816-20	1,7	4.5 MB/s
	DK515-78	2,7	2.46 MB/s
HP	97548E	2,7	2.5 MB/s
Priam	676/776	1,7	1.25 MB/s
Areal	BP100	2,7	1-1.3 MB/s (est.)
Conner	CP3200	2,7	1.5 MB/s
Matsushi	7/89 PROD	2,7	??
Maxtor	LXT-200	2,7	1.68 MB/s

- HITACHI AND PERHAPS STC USE A TECHNIQUE IN 2,7 & 1,7 CHANNELS WHERE DECISION ON BITS WITH INTERMEDIATE AMPLITUDES IS BASED ON POLARITY OF NEXT BIT.

  - CLAIM 2 dB SNR ADVANTAGE IN OFF-TRACK MODE.

  - CHOSEN FOR SIMPLER IMPLEMENTAION

    "because both these methods (ML and interactive feedback) require high-speed calculations and feedback, problems arise in practical implementation."

COMPETITIVE POSITION (CONTINUED)

- PUBLICATION AND PATENT ACTIVITY ON PR AND ML TYPE DETECTION AND OTHER SIGNAL PROCESSING APPROACHES BY OTHERS IS SCATTERED.

	PATENTS	PUBLICATIONS
IBM	11	3
HITACHI	1	2
NTT	1	4
FUJITSU	1	3
PHILIPS	1	3
KODAK	1	1
TOSHIBA	2	
JVC	2	
MATSUSHITA	1	
DEC	1	
AMPEX	1	
CMRR		4
DATA GENERAL		1
SONY		1
SPERRY		1
	12	20

- NO EVIDENCE OF PRODUCT IMPLEMENTATION OF PRML OR 1,7 ML IN NEAR FUTURE.

- POTENTIAL IS THERE.

COMPETITIVE POSITION (CONTINUED)

- WE FEEL IBM IS LEADING THE INDUSTRY
  - o FUTURE APPLICATION OF PARTIAL RESPONSE AND MAXIMUM LIKELIHOOD APPROACHES.
  - o DIGITAL SIGNAL PROCESSING IMPLEMENTATION

- WE ARE BUILDING DIGITAL, VLSI CHIPS TO IMPLEMENT MORE COMPLICATED APPROACHES THAT HAVE GREATER THAN 2 DB SNR GAINS.

- WE MUST SELECT OPERATING POINTS TO CAPITALIZE ON THE ADVANTAGE.

- SOME COMPETITORS ARE ACHIEVING HIGH DATA RATES BY PARALLELING
  - o LINEAR DENSITY OR RPM DECREASE.
  - o WE WILL USE THIS APPROACH FOR 27 MB/SEC PLACER.

RECOMMENDATIONS FOR JOINT ACTIVITIES

NONE AT THIS TIME

ELECTRONICS AND PACKAGING

- FUTURE DIRECTION
  - o REDUCTION IN THE NUMBER OF CHIPS
    - HIGHER DENSITY
    - COMBINED FUNCTION
  - o SURFACE MOUNTED PACKAGES
  - o DIRECTLY ATTACHED TO CONFORMAL MULTILAYER FLEX CABLES.

CHIPS/TECHNOLOGY

- PRESENT IBM CHANNEL DESIGNS ARE A MIX OF IN-HOUSE BIPOLAR ANALOG, BIFET AND CMOS VLSI CHIPS.

- LOW END HAS AN IBM, VLSI, PRML CHANNEL AT 3 MB/SEC WITH PLANS FOR 4.5, 6 AND 9 MB/SEC PRML CHANNELS THROUGH 1995...$15 - $25

- AT HIGH END IBM LAGS IN THE AREA OF HIGH SPEED TECHNOLOGY THAT RELATES DASD CHANNELS,
  - o IBM HIGH VOLUME PRODUCTION IS FOR MAIN FRAME LOGIC
  - o LACK OF COMPLEMENTARY PNP LEADS TO INEFFICIENT AND COSTLY DESIGNS.
  - o CHANNELS HAVE BEEN BUILT BY E. FISHKILL.
  - o BURLINGTON CURRENTLY HAS SOME BETTER TECHNOLOGY BUT NO TRACK RECORD WITH US.
  - o IBM MUST YET DEVELOP A TECHNOLOGY FOR TEHAMA REQUIREMENTS.

CHIPS/TECHNOLOGY

- A NUMBER OF VENDORS OFFER CHANNEL CHIPS AT EVER INCREASING SOPHISTICATION.

VENDOR	TECHNOLOGY/ PARTIAL CHANNEL	COMPLETE CHANNEL	CUSTOM DESIGN ?
AT&T	5 & 3.5 GHz NPN & PNP 18 MB/SEC?	WORKING ON CHIP SET FOR CHANNEL ?	PRIMARILY, IS SUPPLIER TO OTHER VENDORS
ANALOG DEVICES	6 MB/S 1,7 & 2,7 AGC, DETECTOR NO VFO	5 MB/S COMPLETE CHANNEL SINGLE CHIP (SOON) 3 MB/SEC COMPLETE CHANNELS SINGLE AND MODULAR	OFF SHELF CHIPS, SOME CUSTOM
SILICON SYST. (TKD)		≤ 3 MB/SEC SINGLE CHIP WITH RLL ENCODE/DECODE, PRECOMP, AGC, VFO, EQUALIZER. ALL ADJUSTABLE FOR DATA BANDING.	CUSTOM, SUPPLIES MAXTOR
NATIONAL SEMICONDUCTOR		≤ 3 MB/SEC LARGE MULTICHIP MENU FOR LOW END	
MOTOROLA		UP TO 6 MB/S HAS SUPPLIED 6 MB/S SINGLE CHIP, COMPLETE CHANNEL TO COMPETITOR	CUSTOM
VTC		UP TO 6 MB/S LARGE MIX, INCL ARM ELECT. MODULAR + ADJUSTMENTS FOR DATA BANDING	OFF-SHELF IS SUPPLIER TO CONTROL DATA

CHIP/TECHNOLOGY CONTINUED

- IBM LEADS INDUSTRY IN THE INTEGRATION OF MULTIPLE FUNCTIONS INTO CHIPS OF ARM ELECTRONICS -- NOT NECESSARILY AN ADVANTAGE.

    o DRIVEN BY SELF IMPOSED REQUIREMENTS AND HIGH COST OF SI AREA.

    o REQUIRES LONGER AND MORE COSTLY DEVELOPMENT.

    o LESS PARTS MORE RELIABLE ?

RECOMMENDATION

WE SHOULD PURSUE ALTERNATIVE CHIP VENDORS WHERE THERE IS A PERFORMANCE/TIME/COST ADVANTAGE.

o AT&T BEING LOOKED AT FOR TEHAMA

o FIRST STEP NOT EASY.

PACKAGING

- IBM NOT YET USING SURFACE MOUNT TECHNOLOGY FOR CHANNEL CARDS.

  - SOME COMPETITORS ARE USING SMT FOR ARM ELECTRONICS AND CHANNEL -- HITACHI

  - JAPANESE ARE THE DISTINCT LEADERS IN SMT AND AUTOMATED PRODUCTION FOR SMT -- CONSUMER PRODUCTS

  - RECENT PACKAGING APPROACHES FOR SUTTER AND TEHAMA HAVE PUT US ON SAME COURSE AS THE LEADING COMPETITORS.

CHANNEL DESIGN TOOLS

- IBM DESIGN TOOLS FOR ANALOG AND CHANNEL CHIPS
  - o NON-INTEGRATED
  - o LOW LEVEL OF SUPPORT
  - o DESIGN REQUIRES HIGH EXPERTISE, BATCH PROCESS, CUT & TRY
  - o PROBLEM WORSENING
    - HIGHER DATA RATES
    - HIGHER DEGREE OF INTEGRATION
    - MORE COMPLICATED CHANNELS
- THERE ARE EXCELLENT DESIGN TOOLS AVAILABLE THAT ARE USED BY COMPETITORS, E.G. BY CADENCE (REQUIRES SUN SYSTEM)
  - o DESIGNER INTERACTIVE
  - o INTEGRATED CIRCUIT AND CHIP DESIGN
- RECOMMENDATION
  - o WE SHOULD OBTAIN AND USE THE BEST DESIGN TOOLS AVAILABLE.
    - DESLER PURSUING PURCHASE

ERROR CORRECTION

DOMINANT ECC STRATEGY IN ALL FOUR AREAS IS USE OF INTERLEAVED REED-SOLOMON CODES.

- HIGH-END DASD
  - o OUR TREND IS TOWARD IMPLEMENTATION OF MORE POWERFUL VERSIONS AS DENSITIES INCREASE
    - 3380 J AND K   TWO LEVEL ECC.
    - SOQUEL, SUTTER AND PLACER MORE EFFICIENT SUBBLOCKS.
    - TEHAMA   MORE POWERFUL TWO LEVEL ECC.
  - o TO THE BEST OF OUR KNOWLEDGE, COMPETITION TENDS TO FOLLOW OUR LEAD.
    - FUJITSU 6425 AND HITACHI 6586 USE SAME ECC AS OUR 3380E INTRODUCED TWO YEARS EARLIER, HOWEVER
    - WE DO NOT KNOW WHAT KIND OF ECC THE HITACHI DK186K-20 AND THE NEC GEMMY ARE USING.

ERROR CORRECTION

- **LOW-END DASD** [illegible]
  - o LOW END MANUFACTURERS, INCLUDING IBM, USE VENDOR SUPPLIED CHIPS
  - o SAME WESTERN DIGITAL CHIP FOR LEE, LIGHTNING AND REDWING.
  - o CORSAIR AND WILDCAT MUST HANDLE LONG BURSTS. WE ARE NEGOTIATING WITH WESTERN DIGITAL FOR A CHIP WITH THREE WAY INTERLEAVING, DOUBLE BYTE CORRECTING CODE. MAY BE BUILT IN HOUSE, TIME PERMITTING.
- RECOMMENDATIONS

  WE HAVE NO RECOMMENDATIONS AT THIS TIME

RECORDING ALTERNATIVES

- ZONE BIT RECORDING (ZBR)
  - o AGGRESSIVELY PURSUED OUT SIDE OF IBM
  - o SEGATE AND MAXTOR BOTH SHOW 20 - 25% DENSITY INCREASE WITH 4 TO 5 ZONES

	MAXTOR PANTHER 1	MAXTOR PANTHER 2	SEAGATE ELITE	IBM REDWING	IBM SUTTER
FORM. CAPACITY GB	1.15	1.42	1.32	0.871	1.5
ZONED	NO	YES	YES	NO	NO
TPI	1500	1500	1867	1667	2404
ID KBPI	52.1	52.1	33.7	30.3	44.7
MAX AREAL DENSITY	78.1	78.1	62.8	51	107
# OF SURFACES	15	15	17	20	15
FORM MB/SURF	77	94.7	77.6	43.6	100
MB/SURF/AD	0.99	1.21	1.24	0.85	0.93
VOL DENS MB/CUIN	60.2	74.1	57.1	46.6	47.4
DATA RATE MB/S	4	4	3	3	4.4
LATENCY MS	8.3	8.3	5.6	6.0	5.6
RPM	3600	3600	5400	5000	5400
AVE SEEK MS	13	13	12	12	<10

FROM ED GROCHOWSKI, ARC

ZONE BIT RECORDING (ZBR) CONTINUED

- LOW END APPLICATION EASIEST
  - o FIXED BLOCK
  - o INTERFACE SUPPORTS VARIABLE DATA RATES
  - o ROTARY ACTUATORS --> CONSTANT ID TO OD FLYING HT.
  - o VENDOR CHIPS AVAILABLE

- CONSIDERED THE CUB/DAB 2.5" BUT REJECTED
  - o COST ... ≈ $25
  - o POWER DISSIPATION
  - o RISK IN DIGITAL DETECTOR ≥ 4.5 MB/S

- CONSIDERED FOR THE AJO 3.5" FLOPPY BUT REJECTED
  - o COST
  - o NOT NEEDED FOR TARGET

ZONE BIT RECORDING (ZBR) CONTINUED

- USE AT HIGH END COMPLICATED
  - o COUNT KEY DATA
  - o CURRENT PUSH IS FOR HIGH DATA RATE

- ZONE BIT RECORDING ACHIEVES GOOD PART OF DENSITY ADVANTAGE WE GAIN WITH MR HEAD AT LOWER COST.

- PERSPECTIVE
  - o ZBR OFFERS 20% + IN DENSITY IMPROVEMENT
  - o ADVANCE DETECTION TECHNIQUES BEYOND PRML OFFER PERHAPS 10%

RECOMMENDATION

- LOW END
  - o IMPLEMENT ZBR, WHERE COST JUSTIFIED, IN FUTURE LOW AND MID RANGE PRODUCTS.
  - o SET DENSITY OBJECTIVES TO TAKE ADVANTAGE OF ZBR.

- HIGH END

  MORE THOROUGHLY INVESTIGATE IN GPD OF THE APPLICATION WITH COUNT KEY DATA.

S. M. Vogel

December 20, 1990

MAGNETIC TAPE UNIT COMPETITIVE TECHNOLOGY ASSESSMENT, 1989

OUTLINE

* 1989 Tape Subsystems Market
* 1993 Tape Subsystems Market
* 1989 Competitive Devices and Formats
* Business Area 1 Competitive Environment
* Business Area 2 Competitive Environment
* Business Areas 3/4 Competitive Environment

1989 COMPUTER MAGNETIC TAPE SUBSYSTEM MARKET

In general the applications for tape in data processing systems for 1989 remain unchanged from prior years. These applications are common in the use of tape as the lowest cost form of data storage, as a form of storage where sequential processing of datasets is suitable, or as means of interchange or transport of data.

Examples of such applications are listed:
- DASD Save/Restore
- Long Term Archive
- Disaster Recovery
- Sequential Processing
- Dataset Interchange
- Software Distribution

The new element in tape application is the emergence of automated tape subsystems as a key element in data processing system operation The automated tape subsystems are focused on elimination of requirement for operators to load/unload tape drives and manage tape libraries.

1993 COMPUTER MAGNETIC TAPE SUBSYSTEM MARKET

The major element of change predicted for 1993 is a significant increase in number of applications requiring use of automated tape subsystems. This is an increase BEYOND the expected continued growth due to elimination of operator requirements. The motive for the additional increase will be NEW applications available to tape device/library subsystems capable of offering data access times that are much shorter than previous tape subsystems. This capability, coupled with very large capacities offered by automated systems, plus the high data rates and low storage media cost of tape is expected to result in numerous opportunities for tape application beyond those listed above for 1989.

Properties of future automated tape subsystems:
- Automated tape library offering multiple terabytes of capacity
- Rapid access to any dataset
  (less than 10 seconds on average)
- Complete automation of all function, no operator support required
  (Unattended remote location of tape system)
- Compact library system including mechanics, devices, controllers
  (approx 2 to 3 square meter floor space)
- Tape transport/controller integrated in 5.25" formfactor unit
  (interchange with non-library PC systems)

Examples of systems offering SOME of each of the items listed above are available today. By 1993 the expectation is that ALL of the items will be available in individual offerings.

1989 COMPETITIVE TAPE DEVICES and FORMATS

A wide variety of tape devices and associated media packages and formats are available today.

With very few exceptions, media packages contain both the supply and take-up reels;

exceptions: IBM 3480/3490 cartridge
IBM 3850 cartridge
10.5 inch reel

There is a wide variety of media width within the differing packages

minimum :	3.8 mm	RDAT/DDAT
	1/4 inch	Data Cassette
	1/4 inch	Q I C (Mini)
	1/4 inch	Q I C (Std)
	1/4 inch	Kodak/Verbatim *
	8 mm	Exabyte
	1/2 inch	VHS-VLDS
	1/2 inch	10.5 inch Reel
	1/2 inch	3480/3490
	19 mm	Ampex ACL *
	1 inch	Masstor 1000
maximum :	3 inch	Masstor 960

* Initial Announcement only, not generally available

In general, the media width, related media package, and device technology are derived from designs originally intended for applications other than computer data storage.

examples :

RDAT/DDAT	from Consumer Audio
Digital Cassette	from Consumer Audio
Exabyte	from Consumer Video
VHS-VLDS	from Consumer Video
Ampex ACL	from Broadcast Video
Masstor 1000	from Military Instrumentation

Producing data storage systems from technology originally developed for other applications provides significant leverage for assuring refinement of the technology and a larger production base for BMC advantages.

BUSINESS AREA 1 COMPETITIVE ENVIRONMENT

1989 Competitive environment for BA1 is almost exclusively based on 3480 cartridge compatible subsystems.

Principal competitors : FUJITSU/MEMOREX
HITACHI/NAS
STORAGETEK

1993 Competitive environment is expected to remain focused on 3480/3490 format compatible subsystems. Competition is not expected to introduce new formats because of IBM's established presence and market share and strong requirement for format interchangeability. BA1 competition is expected to continue to introduce IBM format compatible products which target function and price advantages.

Function Projections :

	1989	1993
Host Channel Data Rate	4.5 MB/s	18 MB/s
Device Data Rate	3 MB/s	4.5 MB/s
Cartridge Capacity	200 MB	720 MB
Library (Silo) Capacity	1.2 TB	4.3 TB

Most significant potential for the introduction of an IBM independent pendent format is expected to be based on professional broadcast video technology. This technology is currently maturing for digital video studio broadcast applications including library systems. The initial version of this broadcast video technology is referred to as D1 and the next generation is called D2. Both technologies are based on helical scan format, D1 uses Fe2O3 media, D2 uses metal particle. D2 library systems for computer data storage applications are currently under development by Ampex. These library systems are expected to offer 15 MB/s data rate, average access time of 15 to 20 seconds. D2 library capacity totals over 7 TB and requires less than 20 square feet of floorspace. ECC corrected data reliability of these systems for video applications is approximately 1E9 Bytes/error. Ampex recognizes this is insufficient for computer data storage needs and is currently targeting system enhancements to 1E12 Bytes/error. Because this technology is based on broadcast video D1/D2 systems, device cost, form-factor and interchange limitations are expected to restrict computer data storage uses to BA1. Cost reduced follow-on products including "portable versions of the D2 studio recorder will result in significantly lower drive costs in the next 3-5 years.

By mid 1990s, Consumer Home Digital TV recorders are expected to become available. These units will be capable of recording standard NTSC color television (525 line) in composite digital form..... the same capability currently performed in studio by D2 systems. The Home Digital units are expected to rely on Evaporated Metal 8 mm media for data recording capability and extensive compaction use to increase recording duration. One-half inch Metal Particle media formats may also compete for this market. Assuming success in the consumer TV market, this technology will offer D2-like recording performance combined with smaller form-factor and lower cost than D2 for computer digital data storage applications.

BUSINESS AREA 2 COMPETITIVE ENVIRONMENT

1989 Competitive environment for BA2 is based heavily on 10.5 inch reel systems however 3480 cartridge systems are rapidly displacing the older technology.

Principal competitors : STORAGETEK
FUJISTU
CIPHER
LMSI

Storagetek, Fujitsu and LMSI all offer rack-mount products that are completely format compatible with IBM 3480. Cipher rack-mount product uses the 3480 cartridge but records in a serpentine format that is NOT compatible with the IBM 3480.

1993 Competitive environment for BA2 is expected to completely focus on 3480/3490 format compatible subsystems. 10.5 inch reel systems will have minimal market presence. BA2 tape systems offer all the capability of "full-sized" 3480/3490 systems (including 10 cartridge ACLs) but in 8" form-factor rack mount size (single drive). BA2 competition is expected to continue to introduce IBM format compatible products which target function and price advantages.

Function Projections :

	1989	1993
Host Channel Data Rate	4.5 MB/s	6 MB/s
Cartridge Capacity	200 MB	720 MB

IBM Rochester has selected STORAGETEK and LMSI as candidates considered for IBM logo qualification for AS400 (9406 systems) save/restore application. In addition, IBM Complementary Products (Princeton, N.J.) is considering offering a similar product available from Fujitsu.

Kodak/Verbatim has announced a 1/4" media device in unique cassette offering 2 GB capacity, 3 MB/s data rate and 5.25" form-factor device. The technology in this product is metal particle media, a magnetoresistive read head (with unshielded MR element), , and a head servoing capability. Kodak is not expected to establish market-presence in BA2 by 1993.

BUSINESS AREA 3/4 COMPETITIVE ENVIRONMENT

1989 Competitive environment for BA3/4 is quite varied. Three different system/media formats are dominant in BA3 and high-end of BA4.

The three formats :	8 mm media --	Exabyte device
	1/4 inch media --	Q I C device
	3.8 mm media --	RDAT/DAT device

Principal competitors :	8 mm ----	Exabyte, Gigatape
	1/4 inch ----	Alloy, Archive, Caliper Cipher, Mountain, Tallgrass Tandberg, Wangtek, 3M
	3.8 mm ----	Fujitsu, Hitachi, HP, Sony WangDAT

1993 Competitive environment is expected to see continued improvement in datarate and capacity of all three format/device systems. Each system type offers features attractive to specific applications.

Example : RDAT --- 3.5" formfactor capable (5.25" in 1989)
Exabyte - 9 GB cassette capacity projected in 1993
QIC ----- Broad range of data rates/capacities

Based on estimated improvements in data rates, capacity and estimated unit costs, the following price/performance comparisons are offered.

Function Projections:		----- 1989 -----			----- 1993 -----		
		8 mm	1/4"	RDAT	8 mm	1/4"	RDAT
Data Rate	(KB/s)	246	240	180	1500	1500	1000
Cassette Capacity	(MB)	2300	320	1200	9000	2600	2500
$/KB/s		28.46	20.83	38.89	4.67	3.33	3.50
$/MB		3.04	15.6	5.83	0.78	1.92	1.40

IBM Rochester has qualified Tandberg QIC units (150 MB and 320 MB) for qualification for AS400 save/restore application. Rochester plans to continue qualification of QIC units for AS400 applications.

IBM Rochester has qualified Exabyte (2300 MB) for RIOS (Austin) save/restore application.

S. M. Vogel

December 20, 1990

MAGNETIC MEDIA COMPETITIVE TECHNOLOGY ASSESSMENT, 1989

OUTLINE :

* 1989 Magnetic Tape Media Marketplace
  - IBM Environment
  - Leading Media Producers
    - Domestic
    - Japanese
    - European

* Media Component Technology
  - Magnetic Element (Particles)
  - Magnetic Particle Comparison
  - Particle Binder Systems
  - Binder Comparisons
  - Media Substrates
  - Substrate Properties

* Technical Summary

IBM is no longer in the flexible media (tape or disk) manufacturing business. However, new IBM tape products continue to require enhanced media performance for them to be competitive at the system level. Media must be optimized for signal processing characteristics in conjunction with the recording channel and heads as well as optimized for durability characteristics in conjunction with tape path and head contour.

Today, IBM must focus on maintaining necessary development expertise for productive joint development relationships with vendors contracted to provide media for future IBM tape system products. The list below identifies key technical areas involved in the trade-offs necessary to optimize a tape device/system.

(1) Test/Evaluation/Integration Capability
- Signal Processing
- Head design options
- Tape path mechanical trade-offs

(2) Magnetic Particle Material Science
- Archive stability
- Magnetic ink dispersion

(3) Formulation Chemistry
- Binder mechanical properties/durability
- Magnetic ink dispersion

(4) Substrate
- Mechanical properties

Magnetic tape devices involve physical contact between the tape and head for recording processes and edges of tape and guiding elements of tape device for position control. The various performance and durability problems associated with physical contact are not present in the case for optical disks. It is interesting to note that many of the leading magnetic tape producers are now also producers of recording systems for digital data.

1989 MAGNETIC TAPE MEDIA MARKETPLACE

IBM Environment

---> Leading 1989 Magnetic Tape Producers <---

Domestic producers of magnetic tape are:

AMPEX	B
3M	B, C, D

Japanese producers of magnetic tape are:

SONY	B, C, D
HITACHI/MAXELL	B, C, D
FUJI	B, C, D
TDK	B, C, D

European producers of magnetic tape are:

BASF	B, C, D
PDM	C

B = Broadcast
C = Consumer Audio/Video
D = Data Storage-Computer

--- DOMESTIC PRODUCERS OF MAGNETIC TAPE ---

None of the major domestic media producers also provide systems for computer data storage.....yet. Ampex has announced a product for high performance computer data storage applications.

* AMPEX

Ampex is a producer of both media and complete recording systems. However, the primary focus for Ampex is currently the professional video recording systems market. Ampex's most recent products are devices for recording video information in digital format. This technology is known as D2 and is based on the use of metal particle media. Recently Ampex has announced intentions of producing a product for very high performance computer data storage applications. This product is a derivative of D2 known as DD2. There is considerable interest by the US government for use of DD2 in applications requiring very large data storage systems and very high data rates. IBM FSD has recently begun to work with SSPD (Tucson) to consider possible bid proposals employing DD2 systems.

Ampex currently focuses production on media for broadcast video application although the same media would likely be used in DD2 format for computer data storage application in the future. In the past Ampex has produced media for consumer audio/video application but no longer participates in this market.

* 3M

3M currently produces media for consumer audio/video application as well as broadcast video. 3M has announced products (for broadcast video) utilizing metal particle. Currently, this capability comes from 3M-Sumitumo in Japan, domestic 3M production is expected shortly.

In addition to 1/4" Data Cartridges (QIC), 3M also produces media for other major computer data storage applications. 3M is the sole producer of 1/2" (Chromium Dioxide) cartridges as IBM logo product for use on IBM 3480/90 subsystems. 3M also markets a slightly different version of this product for sale under the 3M logo.

3M has long provided a leadership role for definition of 1/4" Data Cartridges and is the predominant manufacturer of such cartridges, but 3M no longer manufactures devices utilizing the data cartridges. However, the technical nature of the 1/4" Data Cartridge is such that almost all key functions of the tape path (velocity/tension control, guiding, stacking...etc) are contained WITHIN the data cartridge. Therefore, 3M has acquired considerable experience in refining tape transport devices for optimum performance by adjusting the mechanical and the media design points. The current performance capabilities of the 1/4" Data Cartridge (QIC) offer less capacity than 8mm helical scan cassettes and significantly less data rate than 1/2" tape systems. QIC has, however, found good market acceptance as a streaming save/restore device in the very cost sensitive market of Business Area 3 (AS400 9404 Series). Rochester has qualified, for IBM logo, a vendor (Tandburg) produced QIC device that is included in every AS400 Low-End 9404 System (C05, B10, B20).

--- JAPANESE PRODUCERS OF MAGNETIC TAPE ---

Sony and Hitachi (Maxell) are producers of recording devices as well as media. Fuji and TDK produce only media.

* SONY

Sony produces devices for consumer audio/video applications as well as professional broadcast video applications. Sony and Ampex worked cooperatively to develop the D2 format. Sony and Ampex now compete in the marketplace for sale of D2 hardware and metal particle media. Sony also markets D1 recording devices (using Iron Oxide media). D1 systems are predecessors of D2 but are limited today to special studio video applications and a D1 derivative for military use. At this time, Sony has not announced a derivative of D2 for computer data storage application, although they have technical capability for developing such a device (and associated media).

Sony also produces both the metal particle media and the transport mechanism that form the basis for Exabyte products. IBM Rochester has qualified the Exabyte Model 8200 for IBM logo sale (IBM 7208) with Austin's RS-6000 systems. A specially screened version of Sony media was also IBM logo qualified for use with this device.

* MAXELL

Hitachi (Maxell) produces 3480 compatible recording systems and media. Maxell also produces metal particle media for broadcast video use. Hitachi has announced intention to market a D2 recording system for video use but has not yet shown the product in the marketplace. Assuming Hitachi brings D2 to market as planned, they will have both media and system capability to produce a "DD2-like" system for computer data application. Hitachi has not yet revealed intention to do this.

* FUJI/TDK

Fuji and TDK produce only media....no systems. Fuji currently enjoys a reputation as a producer of a quality broadcast video product (metal particle). On going evaluations by Canadian Broadcasting Corp to test best-of-breed metal particle media for use on D2 systems ranks Fuji as best for durability and recording signal quality.

--- EUROPEAN PRODUCERS OF MAGNETIC TAPE---

* BASF

BASF produces Co-doped Fe_2O_3 tape for various applications and is the largest (in cartridge quantity) producer of CrO_2 tape for 3480/90 applications. BASF does produce Fe_2O_3 tape for video applications but is not known to market metal particle tapes for video.

* Cobalt Doped Iron Oxide (Co-Gamma Fe2O3)
* Chromium Dioxide (CrO2)

Co-Gamma Fe2O3 and CrO2 both have similar magnetic properties. and hence are complementary/competitive in the same performance range. The industry emphasis is clearly with Co-Gamma Fe2O3. This particle was used for VHS video application as well as 1/4" data cartridge and 1/2" reel data storage systems. Improved versions of Co-Gamma Fe2O3 currently provide the basis for D1 professional video, S-VHS consumer video and new versions of 1/4" data cartridge. CrO2 media does have the disadvantage of 2 to 4 times higher wear rates on heads than Co-Gamma Fe2O3.

* Metal Particle

Considerable momentum has been established for the introduction of new products utilizing metal particle (MP) media. The higher coercivity (1500 oe) and very smooth surface offer superior recording properties. MP media is capable of 10-50% higher overall density compared to Co-Gamma Fe2O3. Major products utilizing MP media are:

- D2 broadcast video
- M-II broadcast video
- Betacam-SP electronic news gathering (ENG broadcast) video
- 8mm Camcorder (consumer) video
- Rotary Digital Audio (RDAT)
- 8mm (Exabyte) and RDAT computer data derivatives
- D2 computer data derivatives

In addition, a 2nd generation MP media (Hi-Band 8) has been introduced. This new generation offers an additional 1-3 db SNR improvement through use of smaller particles and better particle dispersion.

Early concerns about metal particle stability in temperature/humidity stress environments are being addressed by addition of aluminum or silicon alloy to the metal particles to provide passivation. Design trade-offs between saturation magnetization and T&H stability are possible. Engineering optimization is in progress.

* Barium Ferrite

Ba-ferrite is capable of excellent short wave-length recording response. Control of particle chemical composition and size permits a wide range of operating parameters. Ba-ferrite and Metal-particle both have similar high density response. Detrimental characteristics for Ba-ferrite (hence limiting recording performance) are:

(1) Poor overwrite noise characteristics....this necessitates a separate erase head as utilized in the Toshiba FD drive.

(2) Reduced signal at longer wavelengths....hence not compatible with 8mm video recording channel designed for MP media

(3) Playback signal waveshape is dependent upon orientation of the plate-like Ba-ferrite particles. Ba-ferrite can more easily support perpendicular magnetization components. However, recording channel error rates can also be expected to be more dependent upon media fabrication orientation controls.

Current products utilizing Ba-ferrite are limited to high-density floppy disks. A possible future use of Ba-ferrite is for slave tapes in reproducing pre-recorded RDAT tapes. This application effectively utilizes the vertical recording component of Barium-ferrite. Industry product trends favor Metal Particle (MP) media compared to Ba-ferrite.

* Magnetic Film

Evaporated/sputtered magnetic films on flexible substrate media is capable of yielding the highest overall density recording of any media type. However, widespread use of evaporated media will be dependent upon solving key tribological problems related to media durability and long-term archival reliability. Film media offers 3 to 6 db SNR enhancement over MP media. Early products have been introduced utilizing evaporated film media. Electronic cameras use film media in disk form. HiBand 8mm video uses either Hi8 Metal Particle media or evaporated film media. However, no widespread consumer use of film media is anticipated before the mid-90's. This widespread use is subject to satisfactory solutions to media durability, reliability and cost issues. Without significant cost reductions for film media, widespread consumer use may be precluded for a considerable time.

MEDIA COMPONENT TECHNOLOGY

- Magnetic Element (Particles)
- ---> Magnetic Particle Comparison <---
- Particle Binder Systems
- Binder Comparisons
- Media Substrates
- Substrate Properties

The table below lists some key comparisons between major magnetic particle types as described in the prior section.

Particle:	s (emu/gm)	Coercivity (oe)	Surface Area (m2/gm)	Particle Volume (um3 * 10-4)
CrO2	65 to 80	500 to 950	30 to 50	<9
Co-gamma Fe2O3	75	500 to 950	40 to 50	<6
Metal Particle	120 to 155	700 to 2000	20 to 60	<5
Barium Ferrite	50 to 70	500 to 1500	30 to 60	1

Flexible media durability and data reliability are critically dependent on the binder formulation and ink dispersion technology. Media formulation must be custom developed for each tape path and head design. Intelligent trade-off between headwear, environmental media stability, head debris build-up, media durability, HTI/HDI control and resulting recording performance requires continued development of media optimized for each new flexible media application. There is evidence of growing awareness of the importance of the formulation to media performance by major media manufacturers.

In general media designed for use on helical scan transports are optimized with a binder system that has fairly soft and "rubbery" properties. This binder is tolerant of the aggressive penetration of helical scan heads. However, the soft nature of the binder will also cause the heads to acquire a build-up of "gummy" material resulting in a head clog....particularly if the head rotates for prolonged periods on the same helical track. To extend the period of operation under these circumstances, most helical scan binder formulations include additional abrasive particles designed to wear away (at reasonable rate) the continuously accumulating layer of "gummy" material on the head surface. The abrasive particles also increase the head wear rate....thus a compromise must be reached seeking acceptable head life balanced against acceptable resistance to head-clogs.

By contrast, tapes optimized for use on fixed head systems are ideally designed to have a binder formulation that has a high glass/plastic transition temperature. This assures that the surface of the media is smooth and not "gummy" in nature. A soft, compliant surface is not required by fixed head HTI. The accumulation of soft material is greatly reduced and the addition of abrasive particles to the binder is not required. The lack of abrasive particles permits fixed head systems to expect much longer head life than helical scan systems. In addition, the hard "glassy" character of the binder system assures that debris generated by the media will be in small loose clumps or flakes. This is a form that is easily cleaned from the tape path and head. Moreover, the loose character to the debris tends to cause the impact of the debris to the recording channel to be transitory in nature. The transitory nature of debris caused errors is much more easily accommodated by the ECC.

MEDIA COMPONENT TECHNOLOGY

- Magnetic Element (Particles)
- Magnetic Particle Comparison
- Particle Binder Systems
- ---> Binder Comparisons <---
- Media Substrates
- Substrate Properties

The table below lists some key comparisons between major particle binder system types and expected trends.

		PRESENT	FUTURE
TAPE			
	Dominant	TPU, PVC, PVA, EPOXY	UV, E-Beam (Dispersant Resins)
	Emerging	(1) Dispersant Resins	(1) Ring-Opening Polymer binders
		(2) Custom Binders	-
		(3) High Modulus	(3) Plasma polymerized
		(4) Higher Tg	(4) Optimized thermal-mechanical properties
		(5) Environ stability	(5) Environ & Dimensional stability
FLOPPY DISKS			
	Dominant	TPU, PVC, PVA, EPOXY	UV, E-Beam
	Emerging	(1) E-Beam, networked	(1) Plasma polymerized
		(2) Increased cure	(2) Optimized binder-particle interaction

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- TPU = thermoplastic polyurethane
- PVC = polyvinyl chloride
- PVA = polyvinyl acetate/alcohol copolymers
- EPOXY = bisphenol A-epichlorohydrin polymers
- UV = ultraviolet light curable polyurethane-acrylics
- E-Beam = electron beam cured polyurethane, epoxy, silicone or acrylics

MEDIA COMPONENT TECHNOLOGY

- Magnetic Element (Particles)
- Magnetic Particle Comparison
- Particle Binder Systems
- Binder Comparisons
- ---> Media Substrates <---
- Substrate Properties

After three decades of use, poly-ethelene-teraphalate (or PET) remains by far the "substrate of choice" for magnetic recording media. Mylar is DuPont's trade name for poly-ethylene-teraphalate. Other polymer films have not offered an equivalent cost/performance balance. At present, PET substrate film (very smooth grade, tensilized, 57 gauge thickness) is in the range of $8 to $12 per pound. Thinner PET films are higher on a per pound cost basis.

Materials other than PET are available and new ones are being developed. Listed are various substrate materials:

-COMMON TERM-	---MATERIAL FULL NAME-------	COST --($/lb)--
PET (Mylar)	Poly ethylene terephalate	8 to 12
PEN	Poly ethylene 2, 6-napthalate	80 to 120
Aramid	Aeromatic nylon	50
Kapton	Polyimide	75

Listed are film thickness used by some familiar tape formats:

--APPLICATION--	-----FORMAT-------	SUBSTRATE THICKNESS --(Microns)-	-(Gauge)--
Consumer Video	Beta VHS, S-VHS	14.5	57
		9.4	37
	8mm Camcorder, Hi8	9.4	37
Audio	RDAT	9.4	37
Broadcast Video	D1, D2	9.4	37
Computer Data	IBM 3480/90	23.4	92

Biaxially oriented PET is anisotropic. This is a result of the forces applied during the manufacture process to stretch the film to the desired thickness. PET film is not dimensionally stable, but will show a slow shrinkage with time, as molecular retraction takes place. The rate of shrinkage is a function of temperature and and the degree of amorphous molecular chain orientation in the measurement direction. Increased temperature will increase rate of shrinkage. In addition, PET film will also expand or contract as a function of temperature and humidity. Expansion (or contraction) is reversible, shrinkage is not. The combination of these effects causes circular tracks written on flexible disk media to become elliptical and straight tracks written on helical scan devices to assume a different helix angle (possibly beyond capability of device to track accurately).

One state-of-the-art PET film not yet extensively used in digital applications is "tensilized" film which has been oriented much more in the original web direction. The advantage is increased stiffness for thin media substrates (offering manufacturing advantages). The disadvantages have been greater thickness variation across the whole coated web (prior to slitting). Ampex D2 (helical scan) uses tensilized substrates to minimize track angle changes due to shrinkage.

"Supertensilized" PET film is more extensively oriented, and balanced. This should reduce reversible (temp/humidity) expansion coefficients in all in-plane directions. If this film can be heat stabilized (i.e. crystallized and amorphous phase relaxed) if becomes very appealing for future media. At the present time, the Japanese film suppliers (Tiejin....et.al.) appear to be ahead of domestic suppliers in developing Super Tensilization processes. Some film is now nearing commercial availability.

Another possibility for improved substrate is PEN (poly-ethylene 2,6-mapthalate) film. This film was made by Teijin Ltd. about 15 years ago for electrical insulation, but was withdrawn for lack of market. Teijin is now reevaluating PEN as magnetic recording substrate. PEN should stress relax at a significantly slower rate than PET. Major disadvantage is cost; PEN is projected to be 10 to 100 times that of PET.

Increased data rate and higher areal density will continue to be the major challenge for tape data storage for the 90's. Increases in areal density by increasing linear recording density will require high performance metal particle tape and eventually metal evaporated tape. Improvements in metal particle tape will be through use of still smaller particles and better particle dispersion. Maintaining the necessary chemical stability of the new metal particles will be a requirement for computer data archive.

Metal Evaporated media offers superior recording properties. No widespread use of evaporated/sputtered film media for computer data recording is anticipated before mid-90's. Significant time is expected to be required to satisfactorily address durability, reliability and cost issues of evaporated media.

PEN, Kapton, or Aramid substrates are expected to find use in evaporated or sputtered media processes. Such process require high temperatures which these films can tolerate. Currently PET is used for evaporated media but the metalization process is limited to temperatures that the substrate can tolerate. Cost is clearly a major factor (and will continue) in substrate choice.

Increased areal density will also come by significant reduction in track width. This will require the use of track-follow servo systems for tape. New substrate materials can provide improved stability for geometric tracking of information recorded on particulate media. Smoother substrate surfaces can significantly improve data recording characteristics; offering reduced media modulation noise and fewer substrate-related media defects. Adhesion-promoting coatings (applied to substrate surface) offer greater flexibility in choice of binder polymer(s) to optimize binder/particle interaction without sacrificing coating adhesion.

S. M. Vogel

December 20, 1990

MAGNETIC TAPE HEADS COMPETITIVE TECHNOLOGY ASSESSMENT, 1989

OUTLINE

* 1989 Magnetic Tape Head Industry
  - Producers
  - Leadership

* Tape Head Design Choices
  - Inductive Write
  - Magnetoresistive Sensor
  - Helical Scan (Rotary) Head Systems
  - Magnetic Head Materials

* Challenges and Summary

1989 MAGNETIC TAPE HEAD INDUSTRY

* TAPE HEAD PRODUCERS *
Producers of 3480 compatible heads are:
STK, Hitachi, Fujitsu
Sony, AMC, Matsushita (Panasonic / KME)

The first three listed are also manufacturers of 3480 compatible subsystems. The latter three are not subsystem manufacturers and it is not presently known who their customers are for 3480 compatible heads.

Leading producers of other types of linear tape heads include:
Fujitsu, Matsushita, AMC (Nortronics), Gold Star, Alps, and Philips
In addition, NEC, Sharp, and Kodak have development efforts.

Helical scan (Rotary) head producers include:
Sony, Hitachi, Matsushita, Mitsubishi, Sharp, NEC, Philips and Ampex

* LEADERSHIP *
Innovation leader: Hitachi.
Hitachi has an impressive portfolio of patents and patent files. These cover not only improvements to 3480 head design/process, but also describe design extensions to support higher recording performance. Examples are an optimized soft film biased MR sensor and several schemes for quieting Barkhausen noise in MR sensors. Hitachi has also invested heavily in magnetic materials research.

Linear head product leader: STK.
After beginning 3480 compatible tape unit shipment using AMC-made heads, STK has quickly brought their own head line into full production. STK heads are performing very well in the field.

Helical scan head product leader: Sony
Sony dominates rotary head technology, in both very high performance tape units and in very compact, low-cost tape units. At the high end, Sony is first to demonstrate a very high performance video recorder for High Definition Digital Television (HDDTV). This machine utilizes a 134mm diameter rotor with 8 write heads, 8 read heads, 2 erase heads and electronics all rotating at 7200 RPM. Each head has an effective data rate of 148 megabits per second providing a total thruput of 1.2 Gbits/s. At the low end, Sony is the pioneer of RDAT for digital audio as well as computer data storage applications. RDAT features 2 W/R head pairs on a 30mm diameter rotor, each head recording a track 13 microns wide. The device is very compact, offers high areal density, and threatens to dominate the low end computer data storage market.

1989 MAGNETIC TAPE HEAD DESIGN CHOICES

* INDUCTIVE WRITE HEADS *

Options inductive write head design:

- -1- 3480 All-Ferrite Tape Head
- -2- DASD 3380 Style Thin Film Head
- -3- Buried Head

All-Ferrite Head --- This head features a very small physical gap length (1 to 2 microns) and is a proven performer with harsh wearing CrO2 media. Unfortunately the ferrite alone lacks the saturation magnetization needed to write high coercivity metal particle tape. To overcome this will require auxiliary metal pole tip layers. This adds additional material into the physical gap and therefore increases length. Multiple track (array) heads fabricated from ferrite require magnetic isolation between the tracks and to define track widths. This is currently being done by cutting slots (later glass filled) in the ferrite with the precision and accuracy required for proper track registration. Higher track densities require tolerances difficult to achieve with this process. A final drawback of this head type is that the magnetic gap length is determined mechanical bonding of the chip-closure. Variations in mechanical gap length cause considerable changes in head write/read performance at increased linear densities.

DASD 3380 Style Thin Film Head --- This is a popular style of thin film inductive head. However to write high coercivity metal particle media the permalloy pole layers will need to be at least 4 microns thick. This, plus the requirement for a thick insulator between the pole layers results in an overall physical gap between substrate and closure of 15 to 20 microns. The potential for erosion of material within the gap structure increases significantly as gap length increases beyond a few microns.

Buried Head --- The objective of this design is minimization of physical gap length while maintaining the ability to write high coercivity media. Ideally based on a ferrite substrate, the intent is to "bury" the coils, auxiliary pole tips, and insulators into a recession in the substrate. The objective is to locate the recession below the head-tape surface. A secondary pole tip layer connects the magnetic path to the head-tape surface. The thickness of the connecting films decrease as the head-tape surface is approached. This design has been the subject of several Japanese patents in the past 3 years.

1989 MAGNETIC TAPE HEAD DESIGN CHOICES (Continued)

* MAGNETORESISTIVE SENSORS *
Options for MR sensor design:
- -1- 3480 All-Ferrite Tape Head
- -2- DASD 3380 Style Thin Film Head
- -3- Buried Head

MR Sensor with Thin Film Shields --- Shielding the MR films results in superior bit resolution by the head; a feature generally assumed as necessary for very high linear density recording. The thin film shields must be deposited with precision since the thickness defines the physical gap length. The presence of the shield enlarges the gap length and subjects the head structure to erosion of the shield permalloy in th region of the head-tape interface.

Unshielded MR --- The penalty of poor high density bit resolution may be overcome by more aggressive electronic equalization. Kodak recently demonstrated a prototype tape device that could achieve impressive high density recording performance with an unshielded MR sensor. The positive gains may be worth the tradeoff since the MR structure was deposited on very smooth sapphire substrate with potential physical gap length of only a few tenths of a micron. This would completely eliminate concerns for wear and recession of gap. Also, the task of biasing and stabilizing (Barkhausen noise control) of the MR was much simplified. Without the thick permalloy shields to shunt the magnetic signal flux, Kodak was able to use a permanent magnet located remotely from both the head-tape interface and from the MR film itself. This results in a very straightforward device to manufacture.

Yoke MR --- Because of the constant abrasion of the MR films located at the head-tape interface, and because of the constant presence of chemically corrosive agents in the head-tape interface, it is desirable to consider moving the MR films to a remote location. This is possible to achieve by using thick, deposited, ferromagnetic flux guides. There is some reduction in MR signal output and there are subtleties associated with noise stabilization and non-linearities. However, this is a sound approach to the problem. Philips has had a development effort on thin film heads based on yoke MR design for the past 10 years. Philips currently offers heads of this type for sale.

1989 MAGNETIC TAPE HEAD DESIGN CHOICES (Continued)

* HELICAL SCAN (ROTARY) HEADS *
Options for Rotary Head design:
-1- Ferrite Inductive Write/Read
-2- Metal-In-Gap (MIG) Inductive Write/Read
-3- Thin Film

Ferrite Inductive Write/Read --- This type of head is, by far, the most frequently produced for helical scan devices. The core is ferrite with wire windings and serves both the write and read functions. Ferrite core heads for small trackwidth recorders are intricate to machine and assemble, but because of the enormous production quantities for VHS and other consumer video formats, the cost of heads are very low. However, the ferrite lacks the saturation magnetization to write high coercivity metal particle tape.

Metal-In-Gap (MIG) Inductive Write/Read --- The clever addition of sendust pole tips to the basic ferrite inductive head provides the magnetic saturation needed for writing metal particle tape. However, diffusion at the ferrite-sendust interface effects the magnetic character of the head such that low-level read signals are distorted. This renders the MIG head unsuitable as read head. Much research has gone into finding a suitable amorphous metal suitable for reading as well as writing. Sony has adopted "SOFTMAX", an alloy containing FeRuGaSi. Sony claims the head works both write and read functions and has superior magnetic and hardness properties compared to sendust.

Thin-Film --- Philips has produced helical scan heads of very small trackwidth dimension but without the fragile physical dimensions. In the Philips case, a typical core head is prepared from non-magnetic ceramic (instead of ferrite). The ceramic is halved perpendicular to the magnetic trackwidth dimension. Between the two halves is sandwiched "met-glass", a ribbon of amorphous ferromagnetic material. The halves are then bonded and fitted with a coil. In this configuration, the met-glass forms a complete magnetic circuit and the thickness of the met-glass ribbon determine the magnetic trackwidth. Philips claims this head to be effective from both a recording performance and a wear standpoint at track widths well below 15 microns.

Hitachi S-VHS video recorders provide the second appearance of thin film rotary heads. Hitachi claims to be using a thin film head core of amorphous cobalt alloy with a patterned deposited coil. Both the core pole tips and coil are claimed to be formed by sputtering and etching in vacuum. Sony claims to be using thin film heads in the prototype HDDTV recorder although no specifics have been revealed on head design.

1993 CHALLENGES AND SUMMARY

* CHALLENGES *

Increased data rate and higher areal density will continue to be the major challenge for tape data storage for the 90's. Increases in areal density by increasing linear recording density will require high performance metal particle tape and eventually metal evaporated tape. Significant changes to the head will be required to enable writing iron particles with coercivity almost 3 times that of chrome dioxide. The much higher linear density will also dictate that pole layer recession at the head-tape interface, due to abrasion by tape, must be minimized to a few microinches. Combining these factors, one would look beyond permalloy for a new high saturation ferromagnetic material which will allow very thin poles thickness at the head-tape interface for good wear and corrosion resistance but still provide superior magnetic properties.

Increased areal density will also come by significant reduction in track width. For thin-film heads this will bring challenges to find effective solutions for minimization of Barkhausen noise resulting from magnetic domain instability in structures of such small geometry. Solutions will continue to assure the use of the magnetoresistive sensor which is very well suited for linear tape devices with heads writing and reading multiple tracks concurrently. Such tape devices permit significant data rates with reasonably low tape velocities thereby simplifying the mechanics of the tape transport unit.

* SUMMARY *

Major changes are ahead for high-end tape head producers because of aggressive goals for storage density and data rate. Higher coercivity media (metal particle, metal evaporated) will drive many changes to the write designs. Much smaller track widths will drive many changes to the read designs. The dominant head design is likely to be an integrated shielded MR and buried write head on ferrite substrate. Ferrite is expected because, to quote Hitachi: "Generally metal heads are superior to ferrite heads in recording but ferrite heads are superior to metal heads in reliability" (1). The integrated buried design, using ferrite, combines most benefits of both.

The Japanese appear to be in most favorable position to take the lead because of their established base in 3480 head manufacture combined with aggressive pursuit of improvement and extension to base head technology. In addition, they have significant advantage because of investments in basic research for alternate magnetic materials.

COMPETITIVE TAPE HEADS

o PARTICIPANTS

o TAPE HEAD DESIGNS & MATERIALS

o CHALLENGES FACING TAPE HEADS

COMPETITIVE TAPE HEADS

PARTICIPANTS - TAPE HEADS

- o 3480 TYPE HEADS
  - STK
  - HITACHI
  - FUJITSU
  - MATSUSHITA (KME/PANASONIC)
  - AMC
  - SONY

- o LINEAR HEADS - OTHER
  - GOLD STAR
  - ALPS
  - MATSUSHITA
  - AMC
  - NEC
  - PHILIPS
  - KODAK (SPIN PHYSICS)

- o ROTARY
  - SONY
  - HITACHI
  - MATSUSHITA
  - AMPEX
  - SHARP
  - NEC
  - PHILIPS
  - MITSUBISHI

COMPETITIVE TAPE HEADS

PARTICIPANTS - TAPE HEADS

o PRODUCT LEADERS:

- STK : LINEAR
- SONY: ROTARY

o INNOVATION LEADERS

- HITACHI: LINEAR
- SONY: ROTARY

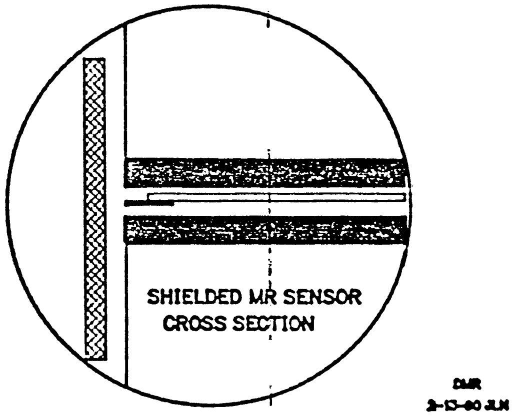
HEAD DESIGNS

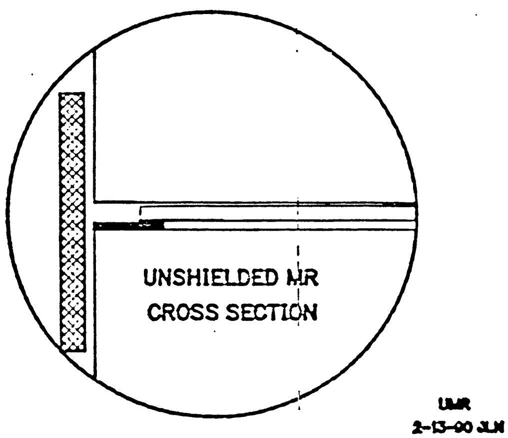
MAGNETORESISTORS

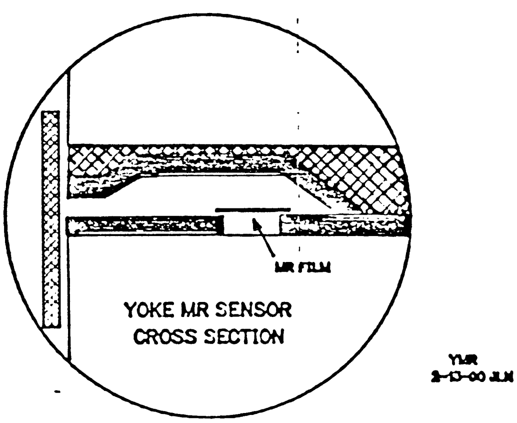
- o SHIELDED, MR SENSOR AT HEAD-TAPE INTERFACE
  - HIGH OUTPUT
  - IDEAL FOR USE WITH LOW TAPE VELOCITY
  - PRECISE LAPPING
  - VULNERABLE TO CORROSION
  - REQUIRES BIASING FOR LINEAR OUTPUT
  - CENTER-TAP REDUCES QUADRATIC DISTORTION
  - SMALL TRACKWIDTH SENSORS REQUIRE ACTIVE BARKHAUSEN NOISE CONTROL

- o UNSHIELDED
  - VERY NARROW PHYSICAL GAP LENGTH MINIMIZES EROSION
  - BIG EQUALIZATION JOB AT HIGH LINEAR DENSITIES

- o YOKE MR
  - REMOTE MR FILM
  - REDUCED DEVICE SENSITIVITY
  - ELIMINATES CORROSION OF MR FILM
  - REQUIRES CAREFUL CONTROL OF FLUX DIRECTING YOKE LAYERS
  - PHILIPS ACTIVE IN THIS DESIGN FOR PAST DECADE


SHIELDED MR SENSOR
CROSS SECTION
2-13-90 JLN


UNSHIELDED MR
CROSS SECTION
UMR
2-13-90 JLN

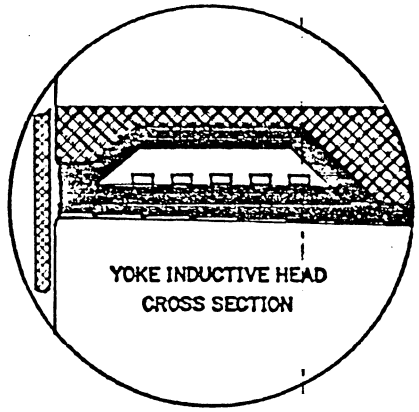

MR FILM
YOKE MR SENSOR
CROSS SECTION
YMR
2-13-90 JLN

COMPETITIVE TAPE HEADS

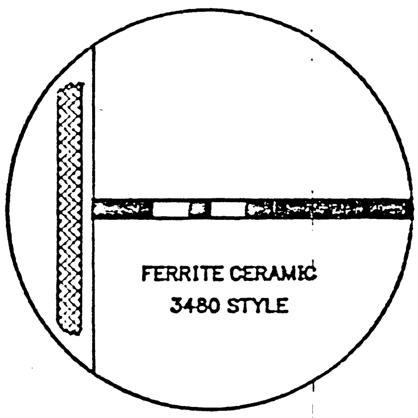
HEAD DESIGNS (Continued)

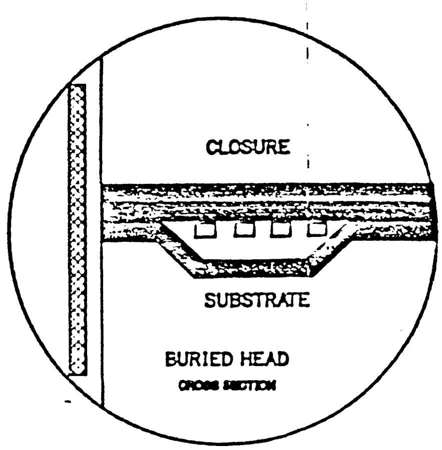
WRITE HEADS

- o DASD, YOKE THIN FILM HEAD
  - REQUIRES PLANARIZING OVERCOAT
  - HAS PHYSICAL GAP OF 15-20 MICRONS
  - SUSCEPTIBLE TO GAP EROSION
- o FERRITE CERAMIC
  - LOW WEAR ON TAPE
  - REDUCED PHYSICAL GAP LENGTH
  - $4\pi M_S$ NOT HIGH ENOUGH FOR METAL PARTICLE TAPE
  - REQUIRES "MIG" FOR METAL PARTICLE TAPES
  - REQUIRES "CUTS" IN FERRITE TO DEFINE MAGNETIC TRACKS
- o BURIED STRUCTURES
  - COILS "BURIED" IN HOLE IN SUBSTRATE
  - MINIMAL PLANARIZATION REQUIRED
  - MODERATE PHYSICAL GAP LENGTH
  - JAPANESE ACTIVE IN THIS AREA


YOKE INDUCTIVE HEAD
CROSS SECTION

YHD


FERRITE CERAMIC
3480 STYLE


CLOSURE
SUBSTRATE
BURIED HEAD
CROSS SECTION

COMPETITIVE TAPE HEADS

HEAD DESIGNS (Continued)

ROTARY HEADS

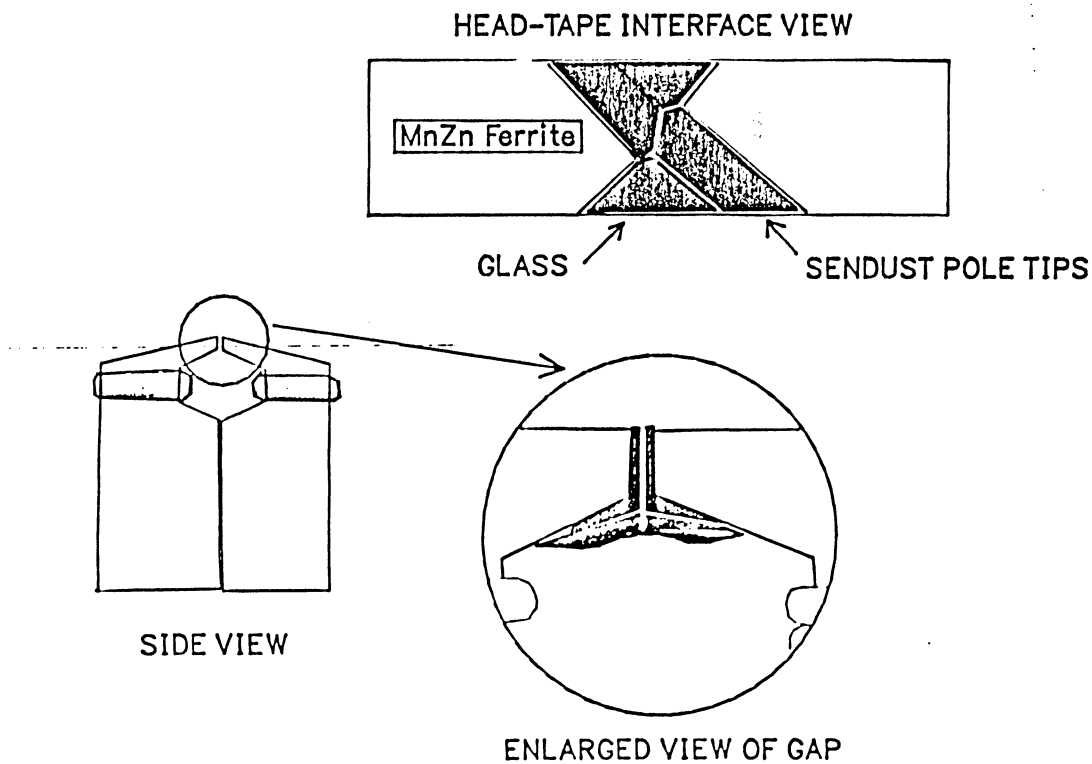
o "MIG" APPROACH

- MAGNETIC FERRITE CERAMIC WITH METAL POLE TIPS
- WOUND COIL ON CORE
- MIXED MECHANICAL / THIN FILM CONSTRUCTION
- SINGLE TRACK
- MULTI-TRACK BY STACKING OF CORES

o THIN FILM HEADS

- AMORPHOUS METAL THIN FILMS
  (CoFeBSi)
  (FeRuGaSi)
- MULTI-TURN INDUCTIVE

CONSTRUCTION OF "MIG" HEAD



MIG1
2-10-90 JLN

TAPE HEAD MAGNETIC MATERIALS

MATERIAL	USE	4PiMs	HEAD PRODUCER	IBM EXPERIENCE
NiZn Ferrite	Core Substrate	3000	3480 "Clones"	IBM 3480
MnZn Ferrite	Core Substrate	5000	Rotary/DASD	DASD Heads
NiFe	Thin Film Head Pole MR Shield	10000	DASD	3380, 3480
Sendust	MIG Pole Tips	11000	Rotary	Sutter-S1
Sofmax	Pole Material	12000	Sony	--
Amorphous (CoZr-X)	Pole Material	14000	Kodak	Exp. DASD Head
Microcrystalline (CoFeBSi)	Pole Material	16000	Japanese	--
Multilayer Films (Fe/Ni, Fe/C, Fe/Ni-Fe, Fe-C/NiFe, Fe-Si-Ru/NiFe)	Pole Material	15-21000	Japanese	ARC Research

COMPETITIVE TAPE HEADS

CHALLENGES

* LEARN TO MERGE THIN FILM HEAD TECHNOLOGY WITH METAL PARTICLE TAPES

  o "MIG" HEAD TECHNOLOGY APPROACH

  - SUCCESSFUL IN ROTARY HEADS
  - FERRITE CERAMIC WITH THIN METAL LAYERS AS POLE TIPS
  - REQUIRES PHYSICAL "CUTS" IN FERRITE TO DEFINE MAGNETIC TRACKS FOR MULTI-TRACK HEAD

  o DASD APPROACH APPLIED TO TAPE HEADS

  - NiFe (PERMALLOY) MUST BE IN THICK LAYERS TO WRITE THICK, METAL PARTICLE TAPE
  - NiFe IS SOFT
    -- ABRADES RAPIDLY
    -- EXCESS HEAD-TAPE SEPARATION
    -- CREATES POCKETS FOR DEBRIS ACCUMULATION
    -- 3380 TYPE YOKE HEAD HAS 15-20 MICRON MECHANICAL GAP LENGTH

COMPETITIVE TAPE HEADS

CHALLENGES

* MAGNETORESISTIVE SENSOR DESIRABLE FOR LOW HEAD-TAPE VELOCITY

  o REQUIRES PRECISE STRIPE LAPPING

  o CONSTANT ABRASION BY TAPE REDUCES STRIPE HEIGHT

  o MR FILM, EXPOSED AT HEAD-TAPE INTERFACE, IS VULNERABLE TO CORROSION

  o SHIELD TO MR SHORTING

* PARALLEL ELEMENTS FOR MULTI-TRACK OPERATIONS AND HIGH DATA RATE

  o REDUCE NUMBER OF HEADS PER WAFER START

  o CABLING COMPLEX DUE TO BONDING & SHIELDING

  o CONTOUR LAPPING SENSITIVE, COMPLEX

  o WRITE VERIFY PROCESS REQUIRES:

    - READ WHILE WRITE

    - TWO OR MORE HEAD MODULES

    - FEEDTHROUGH ENERGY REDUCTION