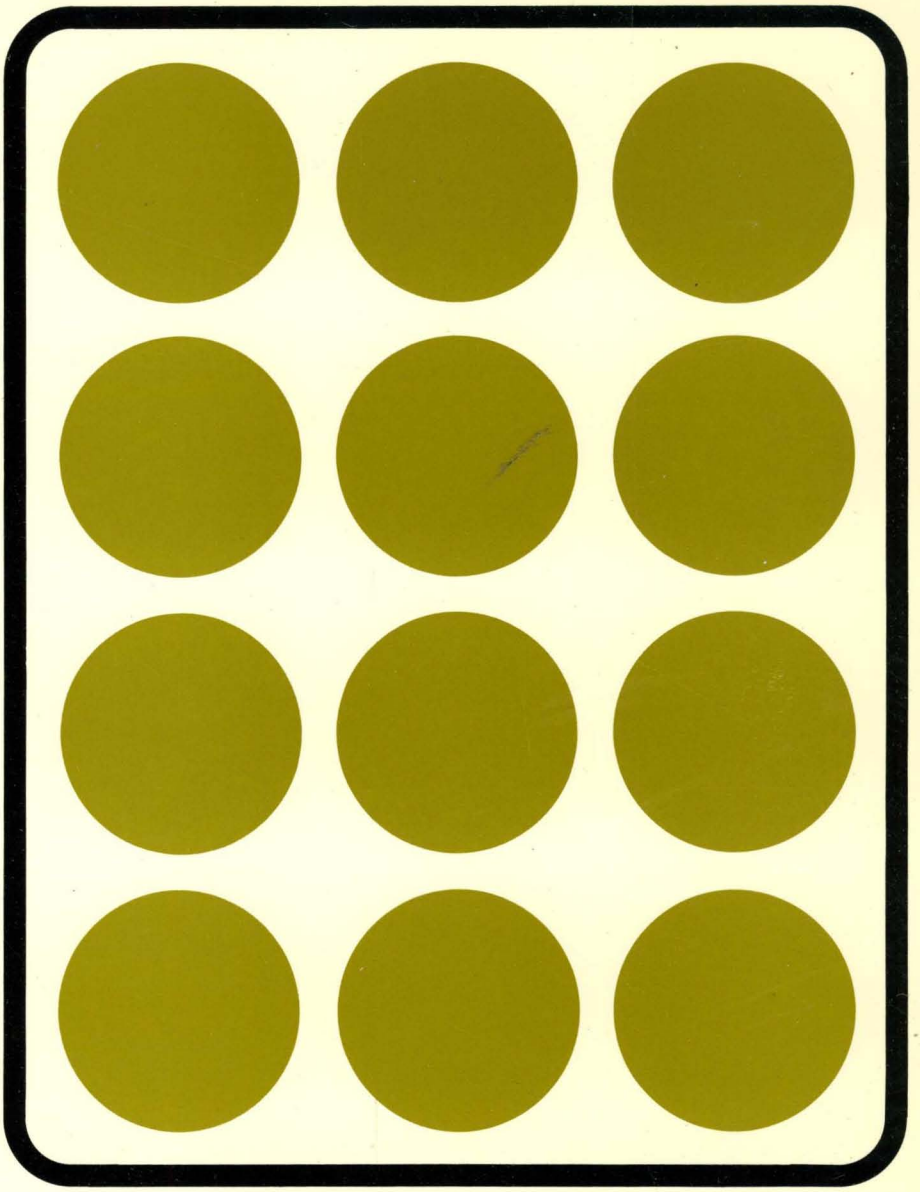
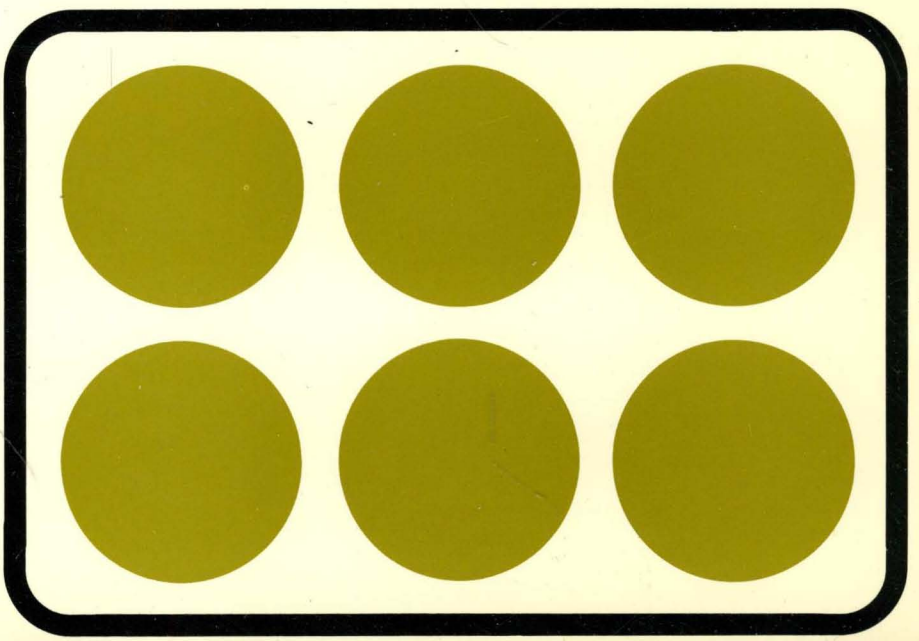


1986 DISK/TREND® REPORT

OPTICAL DISK DRIVES



1986 DISK/TREND® REPORT

OPTICAL DISK DRIVES

July, 1986

DISK/TREND, Inc.
5150 El Camino Real, Suite B-20
Los Altos, California 94022

Telephone: 415/961-6209
Facsimile: 415/969-2560
Telex: 171914

FOREWORD

It is stimulating to observe the formative years of a new industry. The optical disk drive industry is leaving its technological cradle and is beginning to walk. If it can avoid the pitfalls of false expectations, premature product introductions, immature management, and competitive overpopulation, the industrial newcomer should grow into a strong, dynamic part of the data storage products industry.

It won't be easy. The technologies involved, particularly media technology, are changing rapidly. There will be strong competition from other types of data storage and, possibly, from advanced products still in the laboratory. Competitors not yet in the market may crowd out some of the current participants. Those comfortable with the turbulent environment of the magnetic disk drive market will feel right at home in the optical storage market.

We are always willing to help you at any time by providing additional information on the industry which we may have available. And, as always, we welcome and appreciate your suggestions for improvements in the DISK/TREND report.

James N. Porter

Robert H. Katzive

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INTRODUCTION

This is the first year of publication for a separate DISK/TREND report on optical disk drives. The 1985 report on rigid disk drives contained major sections on optical disk storage. These sections have been expanded for the 1986 report.

Readers of the DISK/TREND reports on rigid and flexible disk drives will find the format of this report familiar. For those readers unfamiliar with DISK/TREND reports, a few useful points will help in interpreting the information presented.

* As with other DISK/TREND reports, this report concentrates upon disk drives used with computers, rather than upon media, controllers, or other related topics. Optical disk drives for entertainment, optical tape drives, and optical card drives are not covered.

* All unit totals are given in spindles. At present, all optical disk drives have one spindle, but may have more in future products.

* The values of any leased disk drives are given on an 'if-sold' basis in all DISK/TREND estimates.

* Market share tables are usually included in DISK/TREND reports, but have been omitted for this year's report on optical disk drives because the market is too small and for market share figures to be meaningful.

* This year's report divides optical disk drives into three groups:

    * Read-only optical disk drives

    * Read/write optical disk drives less than 1 gigabyte

    * Read/write optical disk drives more than 1 gigabyte

  The two read/write groups include all drives with the capability to both read and write data on an optical disk, regardless of whether individual drives are intended to operate primarily in a write-once mode, an erasable (reversible) mode, or to have multifunction capabilities.

SUMMARY: OPTICAL DISK DRIVES

Industry size

The optical disk drive industry is expanding in 1986, but while the growth rate of the industry is high, total unit shipments are still low. In 1985, 14,600 optical disk drives were shipped, mostly by non-U.S. manufacturers. In 1989, annual shipments are expected to increase to over one million units. About 60% of the 1989 unit shipments will be CD-ROM read-only drives.

Worldwide revenues will rise from a modest $79.6 million in 1985 to almost $1.3 billion in 1989. Over 75% of the 1989 revenues will be derived from high end read/write drives, because of their higher average prices. While non-U.S. manufacturers currently have almost 88% of total worldwide revenues for optical disk drives, in 1989 U.S. manufacturers will be catching up, and will capture about 38% of worldwide revenues.

In 1989, non-U.S. companies will probably capture over 62% of optical disk drive revenues worldwide. During the forecast period of this report, non-U.S. manufacturers of optical drives are expected to maintain their advantageous position because of their many years of design and manufacturing experience with optical drives. These companies will use many drives in captive systems, accounting for a relatively large fraction, about 77%, of revenue from captive drives in the 1989 worldwide revenue totals.

IBM is not expected to be a manufacturer of optical drives within the forecast period of this report. In the absence of an IBM presence, PCM revenues are expected to be nil.

TABLE 1

CONSOLIDATED WORLDWIDE REVENUES

ALL EXISTING OPTICAL DISK DRIVE GROUPS

REVENUE SUMMARY

	DISK DRIVE REVENUES, BY SHIPMENT DESTINATION ($M)									
	1985		Forecast							
	Revenues		1986		1987		1988		1989	
	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW
U.S. Manufacturers										
IBM Captive	--	--	--	--	--	--	--	--	--	--
Other U.S. Captive	--	--	--	--	24.0	31.2	54.0	66.0	94.0	114.4
TOTAL U.S. CAPTIVE	--	--	--	--	24.0	31.2	54.0	66.0	94.0	114.4
PCM	--	--	--	--	--	--	--	--	--	--
OEM	7.6	9.8	38.4	50.9	79.6	110.9	131.2	184.0	279.6	375.0
TOTAL U.S. NON-CAPTIVE	7.6	9.8	38.4	50.9	79.6	110.9	131.2	184.0	279.6	375.0
TOTAL U.S. REVENUES	7.6	9.8	38.4	50.9	103.6	142.1	185.2	250.0	373.6	489.4
Non-U.S. Manufacturers										
Captive	1.3	51.2	1.3	76.3	5.1	122.0	25.7	225.5	71.3	382.4
PCM	--	--	--	--	--	--	--	--	--	--
OEM	11.2	18.6	27.5	60.4	100.3	122.1	194.9	250.6	315.8	423.6
TOTAL NON-U.S. REVENUES	12.5	69.8	28.8	136.7	105.4	244.1	220.6	476.1	387.1	806.0
Worldwide Recap										
TOTAL WORLDWIDE REVENUES	20.1	79.6	67.2	187.6	209.0	386.2	405.8	726.1	760.7	1,295.4

Marketing channels

Captive shipments by non-U.S. companies accounted for nearly two-thirds of 1985 revenues. The percentage of captive shipments will gradually decay, and in 1989 will be only about 38%. Approximately 23% of the captive revenues will come from U.S. manufacturers.

In 1989, OEM shipments are expected to generate nearly 62% of industry revenues. U.S. manufacturers will hold about 47% of OEM revenues in 1989 as a result of growth in shipments of small diameter optical disk drives and the entry of additional U.S. firms to the high-growth small drive segment.

Users of the DISK/TREND Report should bear in mind that revenues are given in this report at the level of each drive's first public sale. In other words, the price used for each drive is the estimated value at the first time it is sold to a non-affiliated buyer, at captive end user, PCM or OEM levels. Prices are based on disk drives alone, without controllers or other accessories, and leased drives are valued at the price they would command if actually sold.

An understanding of the relative price levels of captive, PCM and OEM drives is important in interpreting DISK/TREND revenue statistics, to avoid an exaggerated impression of the share of the industry's total unit shipments held by captive drives. For most drives, the approximate OEM value of the drive is 1/4 to 1/5 of its captive value.

The marketing channels used by various manufacturers as of mid-1986 are shown in Table 7. OEM channels include dealers, distributors, system integrators, system OEMs and any other channel not explicitly captive or PCM. No PCM shipments are anticipated for the period of this report.

TABLE 2

CONSOLIDATED WORLDWIDE REVENUES
OPTICAL DISK DRIVES

MARKET CLASS REVIEW
REVENUE SUMMARY

WORLDWIDE REVENUES BY MANUFACTURER TYPE	1985 Revenues $M	1985 Revenues %	1986 Forecast $M	1986 Forecast %	1987 Forecast $M	1987 Forecast %	1988 Forecast $M	1988 Forecast %	1989 Forecast $M	1989 Forecast %
U.S. Manufacturers										
IBM Captive	--	--	--	--	--	--	--	--	--	--
	--		--		--		--		--	
Other U.S. Captive	--	--	--	--	31.2	8.0%	66.0	9.0%	114.4	8.8%
	--		--		--		+111.5%		+73.3%	
OEM	9.8	12.3%	50.9	27.1%	110.9	28.7%	184.0	25.3%	375.0	28.9%
	+415.7%		+419.3%		+117.8%		+65.9%		+103.8%	
Total U.S. Manufacturers	9.8	12.3%	50.9	27.1%	142.1	36.7%	250.0	34.3%	489.4	37.7%
	+415.7%		+419.3%		+179.1%		+75.9%		+95.7%	
Non-U.S. Manufacturers										
Captive	51.2	64.3%	76.3	40.6%	122.0	31.5%	225.5	31.0%	382.4	29.5%
	+112.4%		+49.0%		+59.8%		+84.8%		+69.5%	
OEM	18.6	23.4%	60.4	32.3%	122.1	31.8%	250.6	34.7%	423.6	32.8%
	+520.0%		+224.7%		+102.1%		+105.2%		+69.0%	
Total Non-U.S. Manufacturers	69.8	87.7%	136.7	72.9%	244.1	63.3%	476.1	65.7%	806.0	62.3%
	+157.5%		+95.8%		+78.5%		+95.0%		+69.2%	
Worldwide Recap										
Captive	51.2	64.3%	76.3	40.7%	153.2	39.7%	291.5	40.1%	496.8	38.4%
	+112.4%		+49.0%		+100.7%		+90.2%		+70.4%	
OEM	28.4	35.7%	111.3	59.3%	233.0	60.3%	434.6	59.9%	798.6	61.6%
	+479.5%		+291.9%		+109.3%		+86.5%		+83.7%	
Total All Manufacturers	79.6	100.0%	187.6	100.0%	386.2	100.0%	726.1	100.0%	1,295.4	100.0%
	--		+135.6%		+105.8%		+88.0%		+78.4%	

Note: Percentage figures with plus/minus signs refer to year-to-year growth rates.

Product mix

Between 1985 and 1989, read/write drives over one gigabyte will experience the highest growth in revenue due to their relatively high average unit prices. During the same period, the highest revenue growth rates will be achieved by read-only drives and read/write drives under one gigabyte due to rapid growth in unit shipments. As shown in figure 1, high capacity drives will maintain their current status as the leading contributor to revenues. However, they will account for a declining percentage of the total units shipped, dropping from 33.5% in 1985 to 8.5% in 1989.

Throughout the forecast period, read-only optical drives account for a relatively constant 55% to 60% of unit shipments. The big growth in unit shipments will come from read/write drives under one gigabyte, which are expected to increase from 9.6% of unit shipments in 1985 to over 32% of unit shipments in 1989. Revenue growth rates for the smaller read/write drives are also strong, but lower than the growth rate for unit shipments due to declining average prices.

As of mid-1986, there were six manufacturers with 4.72" read-only drives in the market and six manufacturers of write-once 5.25" drives. Some of these drives are announced but not yet in production. Ten manufacturers are offering 12" drives (Nine are write-once and one is read-only), and one manufacturer has made a preliminary announcement of a 3.5" erasable drive. As shown in Table 7, all but one of the 4.72" drive manufacturers and half of the 12" drive manufacturers are Japanese firms, but most of the 5.25" drives are of U.S. origin. Even though new entrants to the market are expected, the association of certain drive sizes with

specific geographical manufacturing areas will probably continue. The U.S. firms will concentrate on 5.25" and 3.5" drives: Japanese and European suppliers will emphasize 4.72" and 12" drives.

Over the long run, the majority of optical disk drives shipped will use smaller disks -- 3.5", 4.72", and 5.25". Until 1988, volume shipments of read/write drives will be write-once configurations, but after 1988, erasable drives are expected to capture a growing share of unit shipments. In the larger diameters, erasability will arrive at a later date because technical difficulties with larger diameter erasable media remain to be resolved. The 3.5" optical disk drives are expected to be almost entirely erasable types, beginning with the formal introduction in 1987 of Eastman Kodak's magneto- optical drives.

The 5.25" and 4.72" drives will be produced in the full size and half high form factors established originally by 5.25" floppy drives. In 1986, full size drives dominate, but in 1987, the trend to half high models will be well under way for read-only optical drives. Read/write optical drives in half-high configurations probably won't be in volume production before 1988. The read/write drives are more complex than the typical read-only drive and will require substantial re-engineering to fit in the half high profile. 3.5" drives may be the first to achieve the slimmer look, as they have been designed from the beginning to fit the 41 mm high standard considered normal for half high 5.25" drives.

Figure 1
CHANGING PRODUCT MIX
CONSOLIDATED WORLDWIDE REVENUES
OPTICAL DISK DRIVES

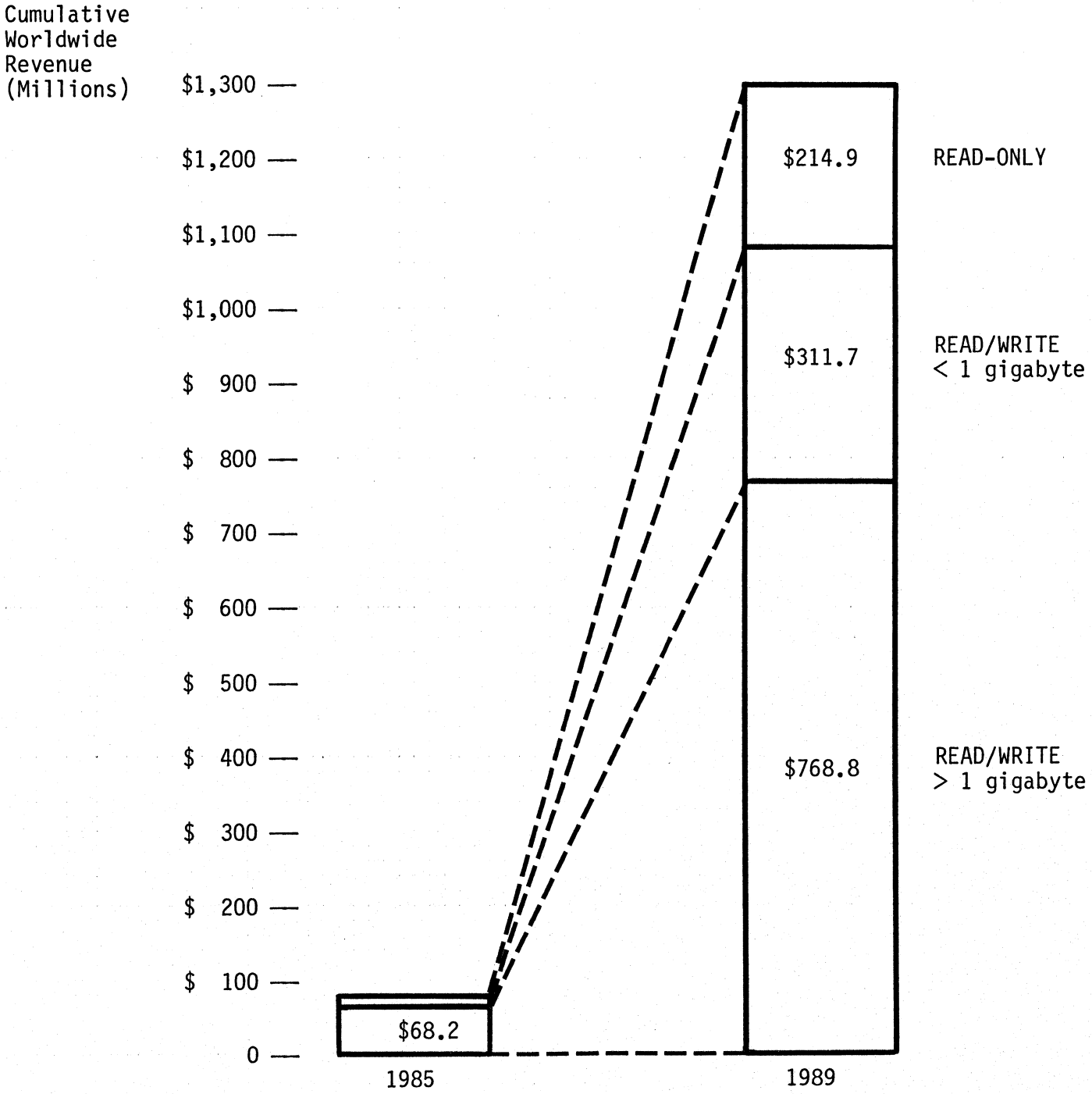

TABLE 3

CONSOLIDATED WORLDWIDE REVENUES
OPTICAL DISK DRIVES
PRODUCT CATEGORY REVIEW

REVENUE SUMMARY

WORLDWIDE REVENUES ALL MANUFACTURERS	1985 Revenues $M	1985 Revenues %	1986 Forecast $M	1986 Forecast %	1987 Forecast $M	1987 Forecast %	1988 Forecast $M	1988 Forecast %	1989 Forecast $M	1989 Forecast %
READ-ONLY	5.6	7.1%	16.7	8.9%	52.4	13.6%	123.8	17.0%	214.9	16.6%
	--		+198.2%		+213.7%		+136.2%		+73.5%	
READ/WRITE less than 1 Gigabyte	5.8	7.3%	32.0	17.2%	75.5	19.5%	165.2	22.8%	311.7	24.1%
	--		+451.7%		+135.9%		+118.8%		+88.6%	
READ/WRITE more than 1 Gigabyte	68.2	85.6%	138.9	73.9%	258.3	66.9%	437.1	60.2%	768.8	59.3%
	+135.1%		+103.6%		+85.9%		+69.2%		+75.8%	
Total Worldwide Revenue	79.6	100.0%	187.6	100.0%	386.2	100.0%	726.1	100.0%	1,295.4	100.0%
	+174.4%		+135.6%		+105.8%		+88.0%		+78.4%	
% U.S. Mfg.	12.3%		27.1%		36.7%		34.4%		37.7%	

Note: Percentage figures with plus/minus signs refer to year-to-year growth rates.

Figure 2
CHANGING PRODUCT MIX
CONSOLIDATED WORLDWIDE SHIPMENTS
OPTICAL DISK DRIVES

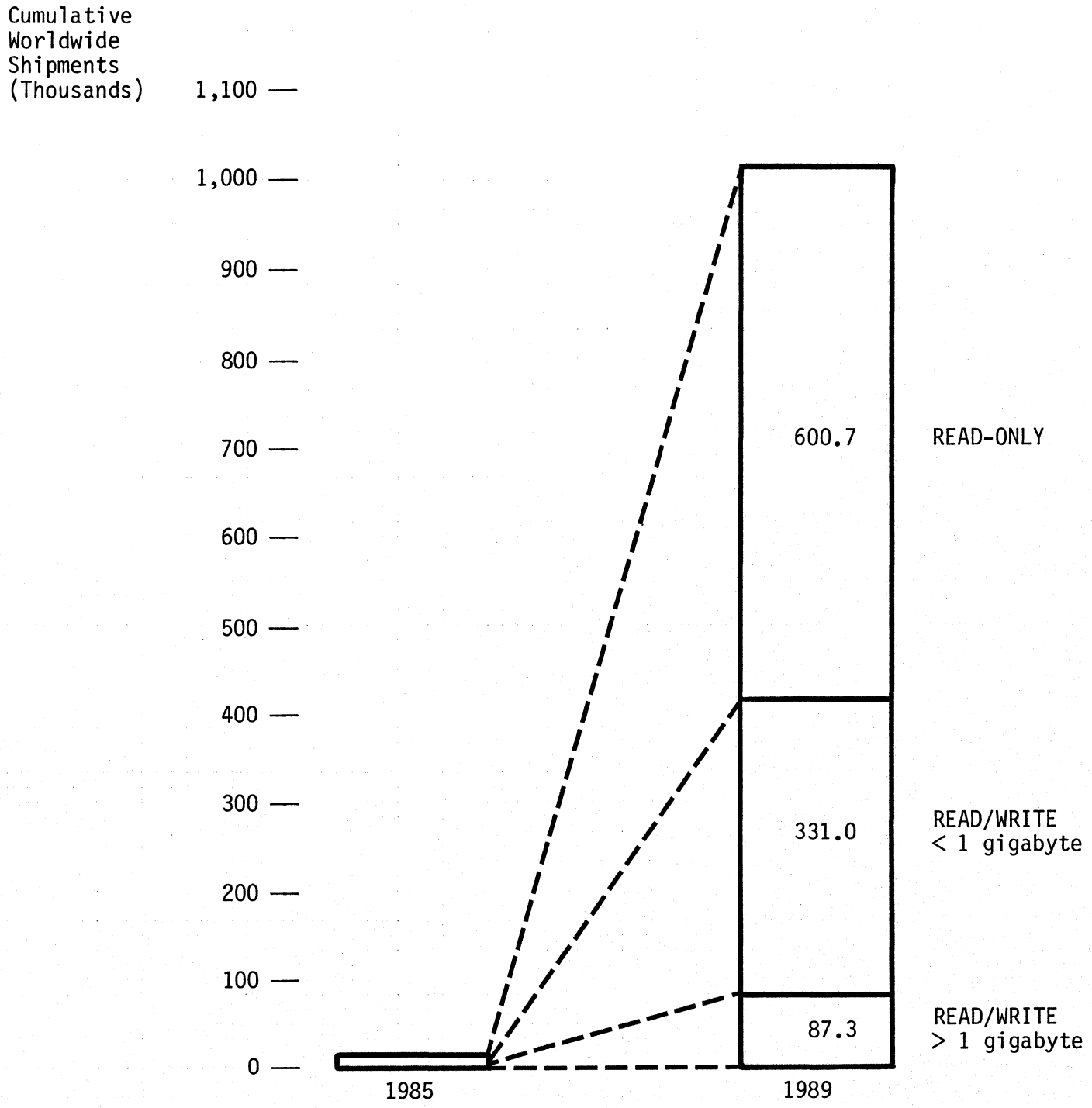

TABLE 4

CONSOLIDATED WORLDWIDE SHIPMENTS
OPTICAL DISK DRIVES
PRODUCT CATEGORY REVIEW

UNIT SHIPMENT SUMMARY

UNIT SHIPMENTS IN THOUSANDS	1985 Shipments Units	1985 Shipments %	Forecast 1986 Units	1986 %	1987 Units	1987 %	1988 Units	1988 %	1989 Units	1989 %
READ-ONLY	8.3	56.9%	30.9	57.5%	110.3	57.2%	290.5	60.4%	600.7	59.0%
	--		+272.2%		+256.9%		+163.3%		+106.7%	
READ/WRITE less than 1 Gigabyte	1.4	9.6%	10.7	19.9%	58.0	30.1%	144.5	30.0%	331.0	32.5%
	--		+664.2%		+442.0%		+149.1%		+129.0%	
READ/WRITE more than 1 Gigabyte	4.9	33.5%	12.1	22.5%	24.6	12.7%	46.5	9.6%	87.3	8.5%
	+145.0%		+146.9%		+103.3%		+89.0%		+87.7%	
Total Worldwide Shipments	14.6	100.0%	53.7	100.0%	192.9	100.0%	481.5	100.0%	1,019.0	100.0%
	+630.0%		+267.8%		+259.2%		+149.6%		+111.6%	
% U.S. Mfg.	13.0%		24.0%		27.3%		22.9%		25.4%	

Note: Percentage figures with plus/minus signs refer to year-to-year growth rates.

OEM market

The OEM market for optical disk drives will evolve to the same volatile state that characterizes the magnetic disk drive market. As optical disk drive technology matures, a pattern will develop characterized by rapid emergence of new product configurations and short product life cycles as major OEM customers shift needs and as the technology evolves.

Most of the new OEM activity will involve the 5.25" and 3.5" disk drives. There will be a significant niche market for write-once drives, but no significant displacement of magnetic disk drives until after erasable optical drives go into production in 1988. System OEMs also have great interest in employing erasable optical disk drives to replace tape drives, reducing system complexity and simultaneously improving performance.

Non-U.S. manufacturers dominate the captive market, but U.S. firms better attuned to the U.S. market will capture and retain most of the OEM market for low capacity read/write drives, due to a head start and the entry of more U.S. firms to the low capacity segment. The high capacity segment will be more of a standoff; there are more non-U.S. firms in this segment already and they benefit from manufacturing efficiencies gained from significant captive production volumes. The read-only optical drive market, which is based largely on the CD-ROM, will be retained by non-U.S. manufacturers; these firms have unassailable strengths in volume manufacturing and experience with optical read-only optical drives.

IBM is expected to become a customer for read-only and small capacity read/write drives during the forecast period. CD-ROM drives were shown in an IBM personal computer exhibit at a major Japanese trade show in 1986.

TABLE 5

OEM WORLDWIDE REVENUES
OPTICAL DISK DRIVES
PRODUCT CATEGORY REVIEW

REVENUE SUMMARY

WORLDWIDE REVENUES	1985		Forecast							
ALL MANUFACTURERS	Revenues		1986		1987		1988		1989	
	$M	%	$M	%	$M	%	$M	%	$M	%
READ-ONLY	5.6	19.7%	16.7	15.0%	40.4	17.3%	74.3	17.1%	124.9	15.6%
	--		+198.2%		+141.9%		+83.9%		+68.1%	
READ/WRITE	3.4	12.0%	27.4	24.6%	64.7	27.8%	118.2	27.2%	243.3	30.5%
less than 1 Gigabyte	--		+705.8%		+136.1%		+82.6%		+105.8%	
READ/WRITE	19.4	68.3%	67.2	60.4%	127.9	54.9%	242.1	55.7%	430.4	53.9%
more than 1 Gigabyte	+546.6%		+246.3%		+90.3%		+89.2%		+77.7%	
Total Worldwide Revenues	28.4	100.0%	111.3	100.0%	233.0	100.0%	434.6	100.0%	798.6	100.0%
	+479.5%		+291.9%		+109.3%		+86.5%		+83.7%	
% U.S. Mfg.	34.5%		45.7%		47.5%		42.3%		46.9%	

Note: Percentage figures with plus/minus signs refer to year-to-year growth rates.

TABLE 6

OEM WORLDWIDE SHIPMENTS
OPTICAL DISK DRIVES
PRODUCT CATEGORY REVIEW

UNIT SHIPMENT SUMMARY

UNIT SHIPMENTS	1985		Forecast							
IN THOUSANDS	Shipments		1986		1987		1988		1989	
	Units	%	Units	%	Units	%	Units	%	Units	%
READ-ONLY	8.3	70.4%	30.9	62.8%	100.3	58.0%	235.5	58.3%	480.7	56.1%
	--		+272.2%		+224.5%		+134.7%		+104.1%	
READ/WRITE	1.3	11.1%	10.5	21.3%	56.0	32.4%	134.7	33.3%	313.0	36.5%
less than 1 Gigabyte	--		+707.6%		+433.3%		+140.5%		+132.3%	
READ/WRITE	2.2	18.5%	7.9	15.9%	16.8	9.6%	34.5	8.4%	64.7	7.4%
more than 1 Gigabyte	--		+259.0%		+112.6%		+105.3%		+87.5%	
Total Worldwide Shipments	11.8	100.0%	49.3	100.0%	173.1	100.0%	404.7	100.0%	858.4	100.0%
	--		+317.7%		+251.1%		+133.7%		+112.1%	
% U.S. Mfg.	16.1%		26.1%		29.5%		26.4%		29.4%	

Note: Percentage figures with plus/minus signs refer to year-to-year growth rates.

TABLE 7

CURRENT PRODUCT LINES
MANUFACTURERS OF OPTICAL DISK DRIVES

Codes: C = Captive
O = OEM
E = Erasable

DISK/TREND PRODUCT GROUP:		10	11	12
U.S. Manufacturers (8)	Type	Read-Only Optical Drives	Read/Write Optical Drives <1 GB	Read/Write Optical Drives >1 GB
Cherokee Data Systems	O		5.25	
Information Storage, Inc.	O		5.25	
Laserdrive, Ltd.	O		5.25	
Optical Storage International	O			12
Optimem	O			12
Optotech	C		5.25	
Reference Technology, Inc.	O	12		
Verbatim	O		3.5 E	
Japanese Manufacturers (10)				
Fujitsu, Ltd.	C,O			12
Hitachi, Ltd.	C,O	4.72		12
Matsushita Electric	C,O	4.72		
Matsushita Graphics Comm.	C,O		8	
NEC	C			12
Nippon Columbia	O	4.72		
Pioneer Electronic Corp.	O		8	
Ricoh Co., Ltd.	O		5.25	
Sony Corporation	C,O	4.72	8	12
Toshiba Corporation	C,O	4.72	5.25	12
European Manufacturers (3)				
Alcatel Thomson Gigadisc	O			12
N. V. Philips	O	4.72		
Van Der Heem	O			12

Numbers in table are diameters in inches.

TECHNICAL REVIEW

Optical disks represent a new class of solutions to storage problems. Within the class of optical disks, there are three classes of technology competing for assignments in various applications. These are:

* Read-only optical disk drives
* Write-once (non-reversible) optical disk drives
* Erasable (reversible) optical disk drives

All of the optical technologies offer high storage capacity relative to physical size and at least moderately fast access times. Several storage cabinets full of paper-based files can be replaced with an optical disk system requiring little floor space and less human handling of physical records. The reduced search time and reduced filing time offer potentially large cost savings to users of automated optical storage technology, when compared to the cost of manual operations. Additional unique capabilities, such as the capability to store images, data, and text in one document open up new possibilities for advances in training and education. These inherent advantages enable optical disk storage technology to compete, with varying degrees of success, against technologies not based upon optical disks. These include:

* Magnetic tape drives
* Optical card drives
* Microfilm storage
* Bubble memories
* Magnetic disk drives
* Optical tape drives
* Printed paper

The printing, microfilm and magnetic technologies are well developed; the optical technologies are just beginning to move into commercial production.

Optical disks

Those optical storage technologies with outstanding strengths for specific applications will be successful in developing selected niche markets in the short term. Larger markets will develop as product capabilities, industry infrastructure, and product costs improve. Today's leading candidates for commercial success are discussed in the following sections.

* Read-only optical disks: The read-only optical disk category is dominated by the CD-ROM. Storage capacities of 550 to 600 megabytes are typical of these products. CD-ROM technology borrows heavily from the designs of the 4.72" CD audio players now in volume production. CD-ROM acceptance benefits from industry agreement on the CD standards developed jointly by Sony and Philips. In addition to the 4.72" CD-ROM, which is limited in performance, high performance 12" read-only drives are being shipped by Reference Technology.

  It is possible to use read-only media with write-once drives. 3M and other companies have proposed such media in a 5.25" format, but the low costs of the CD-ROM relative to read-write drives make it unlikely that read/write drives will significantly inhibit the growth of the CD-ROM market.

  Most read-only optical drives will be used with small systems to provide personal access to large amounts of information. The success of read-only optical disks, in general, depends upon the existence and timely development of a data base publishing industry willing to make use of the CD-ROM format to support its clients. As of mid-1986, there were relatively few titles available on CD-ROM, and of these, none seemed likely to be a major success.

  Another significant factor is the need to have a common standard for recording format that allows disks to be interchanged between systems. While none yet exists, an ad hoc group of companies has prepared such a standard and submitted it to the appropriate standards commitees.

* Non-reversible optical disks: The first optical disk recording systems to enter the market are "non-reversible" or "write-once" systems. After many years of costly development programs undertaken by several European and Japanese manufacturers, such devices are beginning to be introduced as shippable products.

Because they have track densities approaching 16,000 tracks per inch, write-once drives are capable of higher areal densities than magnetic recording techniques now in use. Some planned systems provide several gigabytes on a single removable disk. Other products are being used in mass storage systems which access large numbers of optical disks under system control.

Although not yet demonstrated, advocates of the various types of optical disk media technologies believe that their disks will provide archival lives which equal or exceed those of magnetic media, with 10 years being a commonly encountered specification for archival life of the media. Lifetime is limited by the gradual appearance of defects on the recording layer due to the corrosive effects of water and oxygen on the metal films used in the recording layers of the media. The termination point of media lifetime occurs when the error correction capability of the drive is no longer capable of coping with the gradually increasing media defect density. Some recently introduced media based on dye-polymer designs have no metallic films and may offer improved stability.

In broad terms, two kinds of systems will be offered: Document storage and data storage systems. Systems intended to store images of documents were early entries to the market in Japan, offered by Toshiba, Matsushita Electric, and others. The early emphasis on optical document storage systems in the Japanese market is explained by the extremely complicated character of the written Japanese language. Since most business communication and records are in handwritten characters, the Japanese emphasis first on copying machines, then facsimile transmission, and now optical document storage systems is understandable. At this time, it does not appear that optical document storage systems will be able to compete on a price per image basis with microfilm for bulk storage of images. However, the fast and convenient access to stored images provided by optical disk systems will probably create a major place for them in the emerging office automation market for large-scale specialized applications.

Data storage systems have been later to develop, partly because of more stringent demands upon the media and the difficulty of developing a drive with performance suitable for data processing applications. Optical data storage systems and disk drives from a variety of firms, including Optical Storage International, Optotech, Optimem, ISI, Alcatel Thomson Gigadisc, Hitachi, Toshiba, NEC and Sony are now being shipped in modest numbers. These firms have identified a number of target applications involving databases which are infrequently or never updated, and for which a write-once system would not be at a disadvantage -- such as stock market history, legal files, seismic data, banking transaction logs and law enforcement records. Replacement of magnetic tape for general archival storage is also high on the target list. While Storage Technology Corporation was unsuc-

cessful in bringing its high performance 7640 product to market, it did succeed in setting expectations for the functionality of a high-end, DP-oriented optical storage product. The STC project has been cancelled and is now up for sale.

The write-once systems now available or entering the market use comparable, but differing technologies, with capacities per disk in the range of one hundred megabytes to three gigabytes. The smaller capacity products are being marketed initially as OEM drives for use in small systems; larger capacity drives are being used in captive systems and by a few OEM purchasers.

Obviously, the market for this generation of optical disk systems will be limited to the niches which can tolerate nonreversibility. These niches do exist and the low cost per byte of optical storage will start to open selected markets to optical disk systems. In some applications, the ability of write-once storage systems to maintain an audit trail or indicate whether or not stored data has been modified is a significant benefit.

Large automated libraries that provide random access to tens or hundreds of disks make the use of large scale optical storage potentially very attractive for banks, insurance companies and other organizations with massive records that must be easily accessed. But the markets will be specialized, with system manufacturers slow to act. Little displacement of magnetic disk drives will result in the foreseeable future. Some displacement of tape in archival applications is probable.

* Erasable optical disks: The possibility for real inroads into the market for magnetic disk drives exists with reversible optical disk systems, when either of the principal proposed technologies reaches the status of a reliable production product. Magneto-optical recording has seen development activity for more than twenty years, and "phase change" optical recording has attracted considerable attention during the past few years.

Low-end erasable optical drives offer the promise of higher capacities and access times equivalent to those offered by many of today's small magnetic rigid drives. Such drives should be more reliable than magnetic disk drives due to the decreased chance of head crashes obtained through more head/disk separation. High end erasable drives await the availability of larger diameter erasable media, which is difficult to fabricate within the current state of the art.

Especially impacted will be magnetic tape. The ability to add an optical disk for backup using the same controller used for other system disks offers the system OEM an attractive opportunity to reduce system complexity and cost while simultaneously improving performance.

Most current magneto-optical development programs involve using a low power laser to change the magnetic state of the active layer on a disk. The laser raises the temperature of the active layer into the range of the Curie point while a magnetic field is present, causing individual magnetic domains on the disk to align with the direction of the external field. Changes in magnetic orientation are detected during reading, as the affected spot on the disk causes a small rotation in the polarized light reflected from the surface or transmitted through the disk. However, magneto-optical disks have not yet shown the ability to overwrite in place: A complete sector must be erased before the sector can be rewritten.

Phase change optical recording involves a different type of amorphous coating, in which individual spots on the disk are changed by polarized light from a crystalline state, during which light is reflected, to a noncrystalline state, during which light is absorbed. Fujitsu has revealed a comparable process in which different crystalline states are used to vary reflectivity.

A third technology, potentially the least expensive to manufacture, is erasable dye/polymer. As of yet, only limited success has been obtained with this technique because developers have not been able to demonstrate an adequately large number of write/erase cycles. Individual firms are also working on other proposed reversible optical recording technologies, but none of these are known to have overcome all of the problems, which have included: Slow completion of the reversal cycle, limitations on the number of reversals before degradation, poor shelf life, and low recording density.

Magneto-optical storage is close to being in a manufacturable status, although some additional work needs to be done to insure that the media is adequately resistant to corrosion caused by exposure to air, water and atmospheric pollutants. Most of the technical problems have been overcome by some of the U.S., Japanese or European companies working in the area, and a few of these firms have committed to the heavy investment required to establish volume production capability. Technology announcements of products in 3.5" and 5.25" formats have been made by Verbatim, 3M, and several Japanese firms, and several firms are preparing to manufacture magneto-optical drives and media in volume by 1988. Phase change media production could follow in a few years if acceptable stability and producibility are feasible.

Competing technologies

In making technology comparisons, it is important to remember that all technologies evolve and must be considered as "moving targets". Almost all forms of data storage have shown consistently improving bit storage density, track density, lower power requirements, faster access times, more intelligence and smaller size. Much of the experience gained in developing magnetic disk drives is applicable to the design of optical disk drives, and it appears that some techniques used by optical drive designers may be applicable to the design of magnetic disk drives. This type of cross-fertilization hastens the development of both technologies.

Because development is a slow process and acceptance of a new product does not occur overnight, displacement of existing products by the new optical products will be far from instantaneous, even where the optical product is highly suitable for a given task. The following sections review the various contenders and discuss expected progress in the years ahead.

Magnetic disk drives

* Rigid disk drives: Rigid magnetic disk drives are the mainstay of today's auxiliary storage devices. Except on the lower end of the capacity and performance range, they appear relatively immune from serious displacement by optical drives over the next few years. The relatively high mass of the optical drive head makes it quite difficult for optical drives to match the access time performance of today's voice coil magnetic drives. However, improvements in head technology should make it possible to meet or improve upon the access time performance of most stepping motor rigid drives soon. Another factor to consider is that the typical optical drive has only one data surface under the head at any one time, while a typical magnetic drive has several surfaces available, reducing the time required to access data.

By the time optical drives have improved performance to the point where they can offer 30 millisecond average access time on a 100 megabyte drive, magnetic drives will have evolved to the point where sub-20 millisecond times on drives of the same capacity are common. It is unlikely, therefore, that the magnetic drive will be seriously threatened in its role as a high performance system disk. Low end, lower performance magnetic drives may be seriously impacted. For some applications where the economics of using an optical disk drive to perform the combined functions of a tape drive and a rigid system disk drive outweigh performance considerations, the erasable optical disk will make inroads on the uses of rigid magnetic disks.

* High capacity flexible disk drives: It is within the capabilities of today's technology to fabricate a floppy disk drive offering over 30 megabytes of storage capacity by using media capable of 40,000 fci recording density and 2,7 RLL coding. Although such a product is not expected soon, when available, it could compete with the very low end of potential optical disk drive products. The market for personal computers has grown at a rapid rate, and shipments of small disk drives are keeping pace, creating a market segment large enough to attract new product types.

  The 12 megabyte 5.25" floppy disk drive announced by Eastman Kodak will develop markets with specialized systems and in the personal computer add-on market. Future products may double capacities to 24 megabytes. Iomega has already announced a 5.25", 20 megabyte Bernoulli disk drive. But capacities in this range are only the beginning of the potential expansion of floppy drive capabilities. Two other more significant rival technologies are waiting in the wings to boost floppy capacity.

  Perpendicular recording for flexible disks has received considerable attention in recent years, and has the potential to increase capacity for a 5.25" drive to 5-10 MB without significant increases in track density. Toshiba is preparing to ship a 4 megabyte, 3.5" drive based on barium ferrite as the recording material. By using a sputtered thin film on a Mylar substrate, disks for perpendicular recording could achieve linear densities of at least 50,000 BPI. The increased track densities of today, exceeding 300 tpi, could yield an additional factor of three or more.

  It is likely that the largest limitation to the development of markets for such a drive will be media availability. Success would require that media be produced by the millions of units, which would be difficult with today's batch sputtering processes, and durability remains a problem for thin film media used with head in-contact floppy disk drives. In addition to Toshiba, Sony and Matsushita Electric have revealed programs to develop 3.5" drives and media using perpendicular recording.

Another technology with yet unrealized promise for improving floppy capacities involves use of very small magnetic particles, not much longer than they are wide. Use of such particles in coatings with conventional binder systems could result in "isotropic" magnetic recording, in which many more flux changes per inch could be obtained than with conventional recording. The big advantage for this technique may be producibility of the media, with little to change in existing floppies but the magnetic particles. Presumably, existing coating lines operated by the several major floppy media suppliers could be used. The principal difficulty with isotropic media to date has been oversensitivity to thermal change, with the potential under some circumstances to lose recorded data. As a result, activity in the area of isotropic media is low at present.

* Stretched surface recording: SSR, as this technique is commonly known, was devised by the 3M corporation over the last several years. It employs a disk composed of magnetically coated plastic film stretched across concentric cylindrical rings. The chief characteristic of this technology is that it allows a head to fly on an air cushion backed by a deformable surface that bulges slightly in the region under the head. This provides close head-media separation needed for high capacity but also makes the product head crash proof. Disk drives using this design technique could be produced in either fixed or removable format and can offer the same capacity as a small Winchester or optical drive. The media, however, will have a cost only 1/3 to 1/4 that of the rigid disk media in current or projected use. The cost compared to optical media is even lower. Several firms have worked with 3M on various versions of products using SSR. If adequately supported and promoted by 3M, SSR has the potential to be a major commercial technology.

Alternative optical devices: cards and tape

* Optical cards: The optical card, announced in 1981 by Drexler Technology Corporation, offers up to 4 megabytes of read-only or write-once storage contained on a credit card sized plastic substrate. The cards will most frequently be used by insurance or medical organizations for client/patient record keeping. The card format allows ready transportation and read back of large volumes of information. The card is capable of withstanding considerable handling and is suitable for transport by individual patients. Other applications include software distribution, security/access control, and programming of numerical control machines and other industrial automatic equipment. Because of its relatively limited capacity, the optical card is not a competitor to the optical disk drive.

  An experimental program using an optical card with 2 megabyte capacity is underway at Health Management Services, a subsidiary of Maryland Blue Cross/Blue Shield. Drives for this program

will be made by Canon. Canon, Matsushita Electric Industries and Toshiba have all indicated that they would offer an optical card reader as a peripheral device for small computers. These three firms and seventeen others are all licensees of Drexler Technology. Most other major prospective users, however, are likely to wait to see how the Maryland program goes before making major commitments to the use of optical cards.

The write-once format and limited capacity of the card will limit it to specialized applications. The cost of the drive is unlikely to decrease below the cost of a floppy disk drive, so the optical card is unlikely to displace the large number of floppy disk drives widely used for software distribution. The optical card will make its mark in the development of new applications rather than in the penetration of existing uses of storage devices.

* Optical tape: Optical tape drives, still in a developmental stage, represent another potential solution for those needing a way to stably store large amounts of archival data. So far, only write-once technology has been shown to be feasible for these devices. While tape devices are inherently less capable of fast access to data than are disks, they do provide substantially greater capacity than tape in a single media unit, eliminating the need to handle as many media units per volume of data accessed. So far, only a few firms have been active in the optical tape field. The best known are Docdata N.V., which has been developing a 6.2 Gigabyte tape drive for use with IBM compatible tape controllers, and Laserstore, which has been working on a 2.5 gigabyte product. The Laserstore product will have a SCSI interface and be packaged in an 8" form factor.

Magnetic tape drives

* High performance tape drives

Magnetic tape drives are shifting away from the reel-to-reel format in favor of cartridge formats. The IBM 3480 is setting a new standard for high end tape drives and imitators are beginning to appear. 3480 class products are competitive with the lower end of the optical disk product lines in terms of capacity, but are inferior in terms of average access time. At present, they can offer erasability, which the optical disk drive cannot. However, as erasable optical disk drives become available, they have the potential to displace a significant fraction of the tape drives used for save/restore applications.

High speed reel-to-reel tape drives will remain in use in some installations where libraries of reel tapes exist that the user does not wish to convert to cartridge or optical disk format. These devices have relatively slow average access times and take up considerable space relative to cartridge or optical tech-

niques. The media is relatively bulky compared to tape cartridge or optical disk formats, and are not as well suited to automated handling by automated library devices. For these reasons, reel-to-reel tape is expected to phase out and be replaced by tape cartridge devices such as the IBM 3480 or by optical disk storage in high-end applications. Most installations will retain some reel type drives for purposes of data or program interchange or for backward compatibility, but they will receive relatively low usage.

* Low performance tape drives

Cartridge tape products have been increasing in capacity and performance since their introduction in the 1970s. Three tape widths are in use: .15", .25", and .5". Capacities range from 4 to 100 megabytes in the .25" and smaller formats, and new products are evolving to 125 megabyte capacities in 5.25" form factors. The .5" tape cartridge drives will offer 240 megabytes in a 5.25" form factor. Some manufacturers are adopting the physical format of the 3480 cartridge in their drives but not the recording format; such products will be less expensive than the 3480 but will not offer media interchangeability with IBM systems.

These products are threatened to some degree by write-once technology, and will definitely be threatened by small erasable optical disks offering similar or greater capacity at equivalent prices. The disk products also have the advantage of being able to share a controller with the disk drive being backed up, resulting in overall cost savings for system OEMs. Given the early state of optical technology, displacement effects won't be felt for several years.

The primary use of low-end cartridge tape products is to back up rigid disk drives. They are also occasionally used for software distribution, especially for multi-user microcomputer based systems. Because the price of optical media is expected to be several times that of cartridge tape media, the use of optical media for software distribution will be retarded until media costs are approximately equivalent. Since software distribution tasks rarely require the entire capacity of the media unit, the extra capacity of optical disks is not necessarily an advantage. Most programs load from the distribution media sequentially, and random access is not as important a consideration as it would be in general purpose storage/retrieval operations.

Low performance reel-to-reel tape drives are currently used for data logging, for program and data interchange, and for hard disk backup on minicomputers and some multi-user microcomputers. These products are relatively expensive and bulky, and are vulnerable to gradual displacement as optical storage devices and high capacity tape cartridge devices come into wide use. The tape devices will continue to prevail where access time is

not a major consideration: Access time insensitivity is characteristic of data logging applications.

Bubble memories

Bubble memories today are not serious competition to optical memories. 4 megabit chips are available today, with 16 megabit chips expected by 1988. 64 megabit chips are expected to be the next step, but a period of several years will be required to work out all of the manufacturing technology. They are unlikely to be available until after 1990. Chips of this capacity conceivably could be used in arrays that might eventually be capacity competitive with low-end optical and magnetic disk memories, although it is highly unlikely that bubbles can compete on a cost per bit basis.

Bubble technology bit density theoretically can be extended beyond that achievable with optical or magnetic technology if VBL (Vertical Bloch line) storage proves to be feasible as a manufacturable technology. Much of the fundamental exploratory work on VBL is being performed at Carnegie-Mellon University. Feasibility demonstrations are being done, but much remains to be accomplished: It will probably be at least 10 years before this technology is used in very large capacity arrays. If feasible, however, the inherently parallel organization of bubble memories promises to bring the equivalent of head per track performance to very large capacity storage devices. Such devices would be formidable competition to low end optical and magnetic disk storage.

Optical disk drive enhancements

Most of the major technology innovations now in use in the disk drive industry have come from IBM. IBM developed all the basic disk recording technology, and independent firms merely adapted heads, disks and other components to the specific drive configurations desired. However, due to IBM's lack of activity in development of small disk drives for several years, many variations in the technology have been introduced by others. In optical recording, IBM has contributed little to date, although the firm has an active development program. Japanese firms, such as Toshiba, Hitachi, NEC, Sony and Fujitsu have developed the bulk of the optical technology in use today. In the U.S., Xerox, Control Data, Storage

Technology and 3M have been the leaders in optical technology; Philips has led the way in Europe. Several firms, including Alcatel-Thomson Gigadisc and Optimem, are pursuing optical disk drive designs that can accept write-once, erasable, or read-only media. These products, often called "universal drives" will be initially implemented in 5.25" form factor. If successfully developed, they are expected to be available in production quantities in 1988.

Other key enhancements to optical drive performance are likely in the following areas.

* Recording heads: The optical recording head is a relatively complex device incorporating the laser, detector, optics, and, frequently, a fine positioning mechanism. The inclusion of all of this functionality results in a relatively massive head assembly, which, in turn, either slows access time or increases the power required to position the head. For the first generation of write-once optical drives, which were used with document storage systems, the long average access time, typically in excess of 125 milliseconds, was not a critical factor. However, the desire of many firms to use the optical drives in data processing systems is creating pressure for faster average access time and less massive heads. Considerable work is underway at many firms aimed at reducing the mass of optical head assemblies, and is expected to bear fruit in products introduced in the next few years that may have access times in the range of fifty milliseconds or less.

  Molded glass aspheric lenses will be used in smaller drives. These lenses, some of which are molded using plastic rather than glass, substantially reduce the cost and complexity of the optical path in the head. Some advanced techniques currently being explored at Osaka University have the potential to result in a monolithic assembly in which laser and lens are fabricated as a single unit.

  Work is also being done with heads using composite laser assemblies that are capable of emitting separate read, write and erase beams through a common optical channel. These assemblies are intended to permit direct read-after-write operations in which the read beam can interrogate the disk immediately after a bit is written to insure that a write error was not made. Composite assemblies of this type are very difficult to fabricate and align. As error correction techniques improve, they may not be necessary to achieve adequate performance.

* Lasers: The amount of power available from the laser in the optical drive is a limit on how fast a spot on the disk can be written, and thus, a limit on the rotation speed and data transfer rate that can be obtained. For example, Optotech is using a 20 milliwatt laser that is able to write at a data rate of 5 megabits/second. Semiconductor lasers now in development appear able to double or triple the available power of lasers in use in current products. If these new laser products are found to be economically and technically suitable, a significant increase in data transfer rates and a significant decrease in latency should be obtainable within a few years. As a result, optical disk drives are expected to be able to match the 10 megabit/second data transfer rates of small rigid disk drives in a few years.

  A second limitation related to the laser is the spot size, which is a function of laser wavelength, among other factors. Work on shorter wavelength lasers may result in smaller spot sizes and an increase in bit density. Doubling the frequency halves the spot size, which results in a theoretical quadrupling of storage density. However, large improvements are not anticipated in the near future due to the difficulty of producing a semiconductor laser that will operate at near blue wavelengths with adequate power and stability. A promising indirect approach is the use of a frequency doubler as reported by Matsushita Electric. This technique has yet to be shown suitable for volume production.

* Recording disks: During 1985, optical media was generally in short supply. The manufacturing capacity problem is beginning to be resolved as new facilities go into production. Most of the optical disks made to date have used complex multi-layer designs and sputtering techniques to deposit the various layers. Manufacturing facilities have operated on a pilot scale until recently, and the manufacturing techniques used have not been universally successful in creating a disk that can withstand the range of temperatures and humidities likely to be experienced without media degradation.

  Media manufacturers have yet to fully characterize the distribution of media defects so that designers of error correction electronics can design optimum chips. Media life is still a concern. Accelerated life tests indicate that media can be expected to have a useful life of 10 years or more, but there is no experience of actual lifetimes of this duration: The field is still too new. Protection of the active layer of erasable media to achieve adequate lifetimes still requires further improvement. Such problems will probably be resolved by late 1987. Some innovative products, such as the dye/polymer disks offered for use with the Pioneer write-once optical drive, offer potentially lower costs and improved environmental stability because the active layer has no metal components subject to corrosion.

Most of the substrates used so far have been plastic. However, the ability of glass to provide smoothness, freedom from distortion at high rotation rates, minimal optical dispersion and superior environmental protection is causing this material to be seriously evaluated as a substrate material, especially for erasable optical disks that are not intended to be removed from the drive and for which handling related damage is not a user-perceived issue. However, glass substrates are expected to be much more expensive than plastic, a factor discouraging use.

* Head positioning methods: The track density achieved on an optical drive is much higher than that obtainable on a magnetic disk drive because most optical drive designs use the pregrooved substrate as a device to provide tracking information to the head positioning servo. Some designs, such as that used in the Alcatel Thomson Gigadisc product, use an embedded servo technique for fine tracking as well. At the present time, it does not appear that there will be major increases in track density in the next few years. For most products, it will remain in the range of 15,000 to 20,000 TPI. However, as manufacturers go to higher rotation rates to improve latency and transfer rates, it will be necessary to redesign tracking and focusing servo systems to operate at higher bandwidths.

* Packaging: Most small optical drives are being packaged to fit into a standard 5.25" form factor so that they can be mounted in a personal computer easily. The next generation will offer half-height profiles. The first such products will be CD-ROM units, such as the one recently introduced by Matsushita Electric, but half-high write-once and erasable optical drives are expected eventually. The Eastman Kodak/Verbatim 3.5" drive will fit into a standard 41 mm high space. There is less packaging pressure on larger diameter products.

  Many of these are table-top or rack mounted. The form factor for 14" diameter products expected from Kodak and others may be a floor standing profile. 12" products are typically rack mounted as are the 8" units now beginning to appear on the market. 8" drives may displace 12" drives in some document storage systems, but the 8" form factor will not be popular with small system manufacturers. Suppliers of larger data systems and subsystems will prefer to remain with the 12" size because of its larger capacity per media unit. This leaves a relatively narrow niche for the 8" form factor at present.

  Several firms are working on write-once drives using the 4.72" CD-ROM format. The existence of such a product is looked upon with disfavor by many potential CD-ROM publishers, who are concerned that piracy will become a problem if copying is made too easy. The experience of the software industry suggests that these fears are valid, and the availability of a writable CD format product may discourage publishers and slow industry growth. Nevertheless, drive manufacturers will continue to

investigate the CD format and one manufacturer, TDK, has stated that it is interested in providing write-once media for the CD format. Products may go into production in 1987.

* Interface: The most common interface encountered on optical drives is an interface to the IBM PC. SCSI is also frequently offered on larger drives intended for use with multi-user or document storage systems, and there has been some work done on a modification of the ESDI interface to support optical drives. Drives used in proprietary systems--largely of Japanese manufacture--have frequently used a proprietary interface, but as these and other drives make their way into OEM markets, the standardized interfaces will be the most common.

* Software: Erasable optical disk drives will appear to a system much the same as a magnetic disk drive, so the preparation of system software that supports an erasable optical disk is a routine task. However, software support for a write-once drive is a task of formidable magnitude. Lack of appropriate software is one of the factors that has slowed the acceptance of write-once optical drives. While drive manufacturers will be expected to supply such basic software items as routines that link the drive to major operating systems, manufacturers of complete systems or storage subsystems will find that they must do the bulk of the software themselves or contract the work to a third party.

  Software for CD-ROM is becoming available. In many cases, the software will be loaded on the CD-ROM along with the published material. As much of the base of CD-ROM published works will be of a textual or database nature, publishers must obtain appropriate and efficient text search or database search software. A few software specialty houses, such as TMS, Inc., and Activenture have begun to make such programs available.

* Standards: Physical standards for CD and for CD-ROM were set by Sony and Philips. In early 1986, the two firms released an additional specification called CD-I (CD-Interactive) which defines a free-standing appliance rather than a computer peripheral. No hardware is expected until at least 1987. The announcement of the new standard confused the market, especially the publishing segment, and delayed the release of published materials in the CD-ROM format.

  Physical standards for other types of optical drives are not as advanced, and lack of standardization will delay acceptance of optical drives by some OEMs. The ANSI X3B11 technical subcommittee is well along on an unrecorded media standard for 5.25" disks: A release of the draft specification is expected in early 1987 that will define the parameters necessary to achieve physical interchange among drives of erasable, write-once and read only media. This assumes resolution in 1986 of differences regarding the method of clamping the disk to the spindle hub.

At present, there is little standardization in any other size. There are already so many 12" drive designs in the field that standardization of this size is unlikely in the near future. Although there have been some efforts, notably the convergence of the Optimem and Alcatel Thomson Gigadisc designs for commonly usable media, the diversity of existing designs makes it difficult for most manufacturers to agree to changes because of the major costs of product redesign. New generations of 12" drives may be standardized to a greater degree.

Recorded media standards permitting media interchange across drives of a given physical format will also be necessary for all media sizes if the market potential of the optical drive is to be reached. Recording format standards for CD-ROM have been prepared under the aegis of the High Sierra Group, an ad hoc organization consisting of several firms concerned with CD-ROM. This proposed standard was submitted in mid-1986 to ANSI to begin the formal process of standards development. The format defined is applicable to both CD-ROM and CD-I, and the commonality provided should encourage publishers to resume their CD-ROM publishing efforts which were delayed by the uncertainties caused by the CD-I announcement.

A recorded format standard for read/write drives is not expected until at least 1988, as work in this area has proceeded slowly.

* Libraries: Random-access libraries, commonly called "juke-boxes", are devices that automatically pick, load, unload and refile media units for an optical disk drive. While not part of the drive, they are frequently associated with the drive in high-end archival systems where very large amounts of data must be accessed and maintained on line. A library unit may store from ten to over 200 disk units: Typical retrieval and load time are in the order of a few seconds. Some of these devices have multiple picking assemblies so that access/load operations can be overlapped. Libraries are currently too expensive to be attractive for use with lower capacity optical drives. However, as small optical drives begin to be used in departmental systems, it is likely that less expensive, lower performance libraries will become available to support them. It is quite likely that a random access disk library will be developed for CD players: If so, this product will migrate to the computer world as an accessory for the CD-ROM.

* Error correction: Error correction and detection (EDAC) will continue to be required to deal with the relatively high defect density of optical media. The techniques and designs developed to deal with this problem in optical storage may also migrate to the magnetic storage arena as storage densities increase and the impact of small physical defects on magnetic media become proportionately greater. Error correction can be implemented in chip form. This is the case for CD-ROM already, and ECC chips for other optical drives are being prepared by several firms.

There is still some controversy as to which algorithms should be used for the ECC function. At the present time, standards efforts in the U.S. lean towards endorsing the use of long-distance Reed-Solomon codes for the purpose of error detection and correction in read/write drives. Some Japanese firms have favored product codes, a method of performing error correction on a multi-dimensional data array, and the issue is still unresolved. At least two firms in the U.S., Cyclotomics and Data Systems Technology, are developing algorithms and chips that will perform the bulk of the error detection and correction process, so the implementation of these functions should not be onerously expensive. Both of these firms are using Reed-Solomon codes.

DEFINITIONS

Many basic terms have varying meanings within the computer industry, depending upon the role of the person speaking. In this report, such terms are used in the way most disk drive manufacturers use them.

MARKET CLASSIFICATION

Market class is used here, arbitrarily, to differentiate captive, PCM and OEM disk drive marketing activities.

Captive: Disk drives manufactured internally or by a subsidiary of a computer manufacturer or system OEM, and sold or leased primarily for use with systems offered by the manufacturer. Note that the term is used to describe the products, not the manufacturer; drives sold to PCM or OEM market classes are classified accordingly. Most DISK/TREND statistics separate data between IBM captive and "other captive", but the term still pertains to the disk drives involved, not the manufacturer.
Examples:

* Drives sold by Fujitsu to its computer system users are considered captive, if internally manufactured.

* In the case of a joint venture disk drive manufacturer such as Optical Systems International, a joint venture of N. V. Philips and Control Data, OSI drives sold by Philips are considered captive, and OSI drives sold by Control Data are considered captive, PCM or OEM as appropriate.

Non-captive: Any public sale or lease by any disk drive manufacturer, except sales or leases of internally manufactured drives by computer manufacturers or system OEMs primarily for use with their own systems. Both OEM and PCM shipments are included in the non-captive category.
Examples:

* Shipments by Hitachi are non-captive, except for drives sold with systems made by the parent company or other subsidiaries.

PCM: Disk drives sold or leased by "plug compatible manufacturers" directly to end users; shipments of internally manufactured drives by computer manufacturers or system OEMs are not included unless supplied in plug compatible configurations for installation with systems supplied by other manufacturers. This category is not limited to plug compatible drives installed on IBM systems. It includes any drives which are suitably equipped to be connected without additional hardware to systems of all types, including minicomputers and small business systems.

OEM: Disk drives sold through any non-captive distribution channel except PCM. (See also the definition of "Distribution channel"). Drives are normally sold to OEMs to be included in complete systems or subsystems; such drives are included in OEM totals whether or not the OEM actually manufactures the remainder of the system or subsystem, or merely assembles components and adds software. Sales by a disk drive manufacturer to a second drive manufacturer for resale are included only in shipment totals for the originating drive manufacturer, except when drives are produced on a contract manufacturing basis with a design supplied by the disk drive manufacturer which finally sells the drive to a third party. Distributors and dealers are arbitrarily defined as included in OEM totals.

GEOGRAPHIC CLASSIFICATION

Geographic analysis is based upon two regions: the U.S. and non-U.S. Together, these two regions comprise the worldwide market.

U.S. vs. Worldwide SHIPMENTS: Shipments are classified U.S. or worldwide depending on the shipment destination of a drive's first public sale. Examples:

* An OEM shipment by a U.S. drive manufacturer to a European system manufacturer is included in worldwide totals.

* An OEM shipment by a Japanese drive manufacturer to a U.S. system manufacturer is included in U.S. totals.

U.S. vs. Non-U.S. MANUFACTURERS: Manufacturers are classified U.S. or non-U.S., depending on the location of the firm's headquarters, regardless of the location of individual manufacturing plants.
Examples:

* ISI and Optotech are considered U.S. manufacturers, even though each firm plans to manufacture some of its disk drives in non-U.S. locations.

* Laserdrive Ltd. is considered a non-U.S. manufacturer, since it is a subsidiary of a non-U.S. firm.

UNITS OF MEASUREMENT

Spindles: The basic unit in counting disk drives. One spindle or spindle disk assembly consists of the disk drive mechanism required to utilize a single disk or disk stack. All DISK/TREND unit totals are counted in spindles, even though some drive configurations may include more than one spindle.

Revenue: Based on sales of disk drives alone, as normally sold by individual manufacturers. Controllers sold as separate units are not included, nor are spare parts or service. When individual disk drive models include

integral control functions, such as may be required for the first drive on a string of drives, the actual value of the complete unit is used.

Sale prices are estimated public sale transaction prices, whether at captive end user, PCM or OEM levels. Prices used for leased drives are on an "if sold" basis, at captive or PCM levels, as appropriate. All prices are in 1986 constant dollars.

Forecasts: Expected shipments and revenues for current or announced products in new production. Evolutionary improvements within existing formats are included, but completely new configurations or technologies are not included. Examples:

* Enhancements such as double surface versions of existing single surface configurations and revised encoding schemes are anticipated in DISK/TREND forecasts.

* Innovations such as non-standard size disks or new physical configurations may require establishment of new DISK/TREND product groups.

DISTRIBUTION CHANNEL CLASSIFICATION

Shipments of non-captive drives (OEM and PCM market classes) are analyzed by each of the following distribution channels:

Mainframe computer manufacturers: The major computer manufacturers, sometimes popularly known as "mainframers". In the U.S. this group consists of IBM, Sperry, Honeywell, Burroughs, Control Data, and NCR.

Mini/micro computer manufacturers: Computer manufacturers primarily oriented to the minicomputer class, such as DEC, Hewlett-Packard, and Data General, and the manufacturers of microprocessor-based systems, such as Intel and National Semiconductor.

System OEMs/systems houses: (1) OEMs which manufacture a system requiring disk drives, such as Plexus Computers, Lockheed Electronics and Arete Systems. (2) System houses, of any size, which combine finished components and software into complete systems.

Independent peripherals suppliers: Specialized manufacturers which add controllers, interfaces and other equipment or software, and offer plug compatible subsystems to end users, system OEMs and systems houses. Examples: Tallgrass, Cygnet, Tecmar, Filenet, and Emulex.

Distributors, dealers, end users: (1) Sales of plug compatible (PCM) disk drives with any other necessary hardware directly to end users by disk drive manufacturers, whether or not title to the equipment is to be held by end users themselves or by lessors. (2) Distribution of OEM or PCM drives through wholesalers, such as Hamilton Avnet, Arrow, or dealers of any type.

READ-ONLY OPTICAL DISK DRIVES

1986 DISK/TREND REPORT

READ-ONLY OPTICAL DISK DRIVES

Coverage

Examples of coverage in this group include:

4.72" disk diameter (CD-ROM)

Hitachi	CDR-1502S, CDR-2500
Matsushita Electric	SQ-D1, SQ-D100
Nippon Columbia (Denon)	DRD-550
Philips	CM-100, CM-110
Sony	CDU-100, CDU-5002
Toshiba	XM-2000

12" disk diameter

Reference Technology	2000

A read-only optical drive is equipped only to read an optical disk. It does not have a laser capable of developing write power or a method to switch the laser into a writing mode. The optical read-only drive is sometimes referred to generically as OROM (Optical Read-Only Memory).

Optical read-only memories are expected to be the first category of optical disk drives to be used in high volume. The 4.72" CD-ROM, which is the dominant product type in this group, benefits from the design, manufacturing and standards infrastructure that was developed for the very successful CD (Compact Disk) consumer products. The first CD-ROM products offered displayed their consumer-oriented background. Packaging was not consistent with computer industry practice; early products were free standing or top loading types. More recent products are packaged in the standard full height or half height configurations that have become standard for small computer systems.

Market status

In 1985, approximately 8,300 drives were shipped, mostly by Hitachi, Philips, and Sony. Several other Japanese firms, such as Nippon Columbia and Toshiba, will begin production in 1986. Reference Technology, a U.S. firm, is shipping in small quantities a read-only memory in a 12" format that offers more capacity and faster access times than CD-ROMs. This firm also remarkets the Hitachi CD-ROM.

Digital Equipment Corporation is the first major system manufacturer to offer a CD-ROM as a system peripheral. The Philips CD-ROM is available as a peripheral device for the Micro-Vax II product line. Other system suppliers are expected to introduce CD-ROMs as part of their product lines in 1986 and 1987.

Standards issues are largely resolved. The physical format for CD-ROM was established through the joint action of Sony and Philips. More recently, an ad hoc committee known as the High Sierra Group has proposed a recorded standard format that has been submitted to standards groups for formal approval and which has the status of a de facto standard. Unfortunately, the announcement of a supplementary standard, CD-I (Compact Disk-Interactive), by Sony and Philips in the spring of 1986 has created confusion among potential CD-ROM suppliers. CD-I is aimed at defining a product for the home and education markets, and does not modify the definition of the CD-ROM as a computer peripheral. The primary impact of the CD-I announcement upon the computer industry will be to delay the availability of CD-ROM published materials while publishers and system suppliers convince themselves that the scope and timing of CD-I products do not impact their markets.

The market for read-only disk drives is driven by publishers. Success for hardware manufacturers depends upon the availability and market acceptance of a wide variety of materials published in the CD-ROM format. At present, only a limited number of titles is available, and none of these appear to have the potential to attract a large business-oriented following. Other titles with wider appeal are in preparation by a number of publishers and are expected to be available by mid-1987.

Facilities for mastering and replicating read-only media are available and adequate, although most publishers would prefer to have shorter lead times available to them. The cost of preparing the master copy from which CD-ROM replica copies are made has decreased to under $5,000, an affordable level for even smaller firms. Replicated disk prices at the OEM level are $4-5 per disk. From a cost standpoint, the stage is set for rapid growth.

Marketing trends

Most of the CD-ROMs produced will be made by large producers of CD audio equipment enjoying an experience and cost advantage over other competitors. 1986 worldwide unit shipments of about 31,000 units will rise rapidly to over 600,000 units in 1989. This increasing volume will probably attract numerous fringe competitors, tending to depress prices much as the prices of floppy disks are now depressed as a result of over competition. The CD-ROM, while more complex than a floppy disk drive, is not so difficult to make as to discourage an ambitious market entrant--and Japanese firms, in particular, are always interested in new export opportunities.

CD-ROM product prices will decline rapidly, with early average OEM prices in the $600 to $700 range, declining to the $400 range in 1987 and to the $250 range in 1989.

Personal computers and single user workstations will provide the dominant attachment opportunities for CD-ROMs in the next few years. Significant captive sales will take one or two years to develop; early sales will be from system manufacturers (such as DEC, and, possibly, IBM) and from the publisher or aftermarket subsystem manufacturer offering a package consisting of drive, software, published material and interface. As many of the drives will come equipped with an IBM PC interface, many retail dealers will also be interested in offering the product once sufficient database and supporting software products become available. With the majority of the PC market in the U.S., CD-ROM sales will show a similar pattern.

Although cost factors are not a limiting factor for market development, a factor that might delay market development is the current saturation of media replication facilities with entertainment products. The replication facilities shortage will ease significantly over the next year as new facilities go into production, and is not expected to be a major problem.

Applications

Applications for read-only memory drives relate primarily to distribution of information and represent a form of electronic publishing. Databases such as Department of Commerce statistics, drug side effects, legal research materials, construction materials catalogs, and selected

professional publications are typical possible contents. Text oriented databases are especially suitable for implementation on read-only memory. These include legal cases, encyclopedias and other educational materials, news files, technical papers and all types of reference works. CD-ROM also has the inherent capability to store and recover digitized images and audio, but most workstations and personal computers do not have the capability at this time to fully use these features because of deficiencies in either hardware or software. A further obstacle is the lack of an inexpensive, easy to use mechanism for transferring images or audio material to a CD-ROM document, but availability of inexpensive scanning/editing systems for that purpose is expected within a year or two.

The dissemination of large amounts of static or slowly changing data in machine readable format is a logical role for optical drives, especially for the CD-ROM format. The low cost of mass replicated media and the ability of the drive to fit into the user and operating environments of personal computers and other small systems make this an attractive option.

Read-only drives will appear primarily on micro-based systems, including individual personal computers, workstations, and attached to network file servers. CD-ROMs will be connected to large processors through microcomputer based file servers to provide access to CD-ROM data bases for mainframe and mini-computer users.

CD-ROM may also find a market in on-board vehicle navigation and dispatching systems. Several Japanese firms are investigating such an application, which could be useful for sales staffs, public sevice personnel, taxi drivers, urban planners, and public utilities.

Electronic publishers must face the same site licensing and copy protection issues that are currently debated by software providers. Some

publishers may defer product availability until they can define their multi-user access policies. Others will attempt (probably unsuccessfully) to prevent unauthorized access through copy protection schemes. The best protection may be the nature of the data: If it must be updated frequently to be useful, copiers may not find it worth the time and bother.

Materials likely to appear in CD-ROM format will be concentrated in one of two application groups:

Electronic publishing

* Large publicly available databases, such as those compiled by economists for use with econometric models.
* Indexed textual databases, such as information on drug toxicology, legal case citations, or bibliographies.
* Maps, including those used for on-board vehicle navigation. Such systems could be used eventually in personal vehicles as well as commercial aircraft, ships and military vehicles.

Intracompany data distribution

* Directories, etc. for large organizations
* Catalogs, parts lists and product data
* Training materials and service manuals

Technical trends

The technology in this product group is relatively stable, as it derives from the consumer CD player for the most part. The areas receiving the most attention are:

* Standards for file formats, so that disks can be used on any small computing system.
* Average access times, which will decrease to the .5 second range in 1986.
* Improved error correction, capable of 10^{-12} bit error rates

* Programmable library units for CD-ROM drives. These may be based upon units being developed for automotive CD player systems.

* Packaging of the CD-ROM disk in a carrier, or cartridge, that provides protection from scratches and prevents excessive vertical disk motion while the drive is in operation.

* Development of software to support use with major operating systems and application programs. Software for efficient searching of large data bases and text files is necessary to generate large sales of CD-ROM and is beginning to appear.

* Cost reduction programs. Molded lenses, for instance, are replacing ground lenses. Some of these lenses are plastic instead of glass.

* Packaging of drives in half height format.

* Development of SCSI and IBM personal computer interfaces.

* Development of document preparation and other support software and systems for publishers preparing CD-ROM materials.

The existence of the Sony/Philips de facto standard for CD-ROM establishes a basis for CD-ROM physical disk interchangeability and provides a mechanism for identification of a disk and files upon the disk. The High Sierra Group, an ad hoc task force consisting of a group of companies interested in CD-ROM has prepared a proposed recording standard and submitted it to ANSI and ECMA for initiation of the formal standards-making process. The National Information Standards Organization (ANSI Z39) is working on format interchange standards for CD-ROM, and it is this group that will consider the High Sierra Group proposal. Because the High Sierra Group had broad industry participation, most companies will consider its proposal a de facto standard and expect relatively quick approval by the ANSI group. Nevertheless, some publishers may hold back until there is a definite indication that the proposed standard will be approved without major changes.

The packaging of CD-ROM drives will change rapidly over the next few years. At present, most of the drives shipped are not compatible with the full height and half high form factors that have been adopted for 5.25" products. The drives going into production in 1986 are either full height or half high models: Matsushita Electric exhibited a half high CD-ROM at the 1986 NCC conference and the other major suppliers are expected to shortly do the same. Another packaging issue relates to the use of a cartridge to hold the disk in place within the drive, preventing loss of focus due to vibration, shock, or mounting in other than a horizental position. Such a cartridge would permit the drive to be used in vehicles or to be mounted in a vertical position within a system enclosure. Several Japanese firms are considering adoption of such a cartridge.

Most CD-ROMs will be offered with SCSI interfaces and host adapters to the IBM PC family. DEC is already offering the Philips CD-ROM as a peripheral for the Micro-VAX processor line, and other system manufacturers are expected to offer interfaces to CD-ROMs on various systems.

Some manufacturers are considering a read/write version of the CD-ROM. The prospects for such a product are reviewed in the discussion of read/write drives with under 1 gigabyte capacity.

Forecasting assumptions

1. CD-ROM players will be in production status at Sony, Matsushita, Hitachi, Toshiba and Philips by the end of 1986. The form factor will evolve to a half high de facto standard by the end of 1987.

2. The formatted disk interchange standard for CD-ROM will be processed relatively quickly by ANSI and will be approved by 1988. Until approval seems certain, distribution of data bases on CD-ROM will be deferred by some publishers.

3. Non-U.S. suppliers will dominate the CD-ROM hardware market. There will be no significant U.S. production.

4. Increasing production volume and competition will reduce the quoted CD-ROM average OEM price (less controller and software) to $200 by 1989. Most drives will have on-board controllers, adding $50 to $100 to the price.

5. There will be a significant demand for CD-ROMs by system and subsystem integrators who will add them to specialized workstations, file servers, and memory subsystems.

6. CD-ROMs will appear on approximately 3% of the installed business oriented PC base and on less than 1% of the installed base of home and educational systems by the end of 1989.

7. The CD-I format will impact primarily the home and education markets. Hardware will not appear until the latter part of 1987 and there will be additional shipment delays while programs and published materials are prepared. CD-I will have relatively minor impact on the CD-ROM in the business market.

8. Media mastering and replicating capacity will be adequate and will not be a restriction on growth for read-only optical memory markets.

TABLE 8

READ-ONLY OPTICAL DISK DRIVES

REVENUE SUMMARY

	DISK DRIVE REVENUES, BY SHIPMENT DESTINATION ($M)									
	1985		Forecast							
	Revenues		1986		1987		1988		1989	
	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW
U.S. Manufacturers										
IBM Captive	--	--	--	--	--	--	--	--	--	--
Other U.S. Captive	--	--	--	--	--	--	--	--	--	--
TOTAL U.S. CAPTIVE	--	--	--	--	--	--	--	--	--	--
PCM	--	--	--	--	--	--	--	--	--	--
OEM	.9	.9	1.6	1.6	2.4	2.4	3.0	3.8	3.5	4.9
TOTAL U.S. NON-CAPTIVE	.9	.9	1.6	1.6	2.4	2.4	3.0	3.8	3.5	4.9
TOTAL U.S. REVENUES	.9	.9	1.6	1.6	2.4	2.4	3.0	3.8	3.5	4.9
Non-U.S. Manufacturers										
Captive	--	--	--	--	2.4	12.0	9.9	49.5	22.5	90.0
PCM	--	--	--	--	--	--	--	--	--	--
OEM	3.8	4.7	12.8	15.1	32.4	38.0	56.4	70.5	90.0	120.0
TOTAL NON-U.S. REVENUES	3.8	4.7	12.8	15.1	34.8	50.0	66.3	120.0	112.5	210.0
Worldwide Recap										
TOTAL WORLDWIDE REVENUES	4.7	5.6	14.4	16.7	37.2	52.4	69.3	123.8	116.0	214.9
OEM Average Price ($000)	.662	.675	.539	.540	.407	.403	.315	.315	.259	.260

TABLE 9

READ-ONLY OPTICAL DISK DRIVES

UNIT SHIPMENT SUMMARY

	DISK DRIVE UNIT SHIPMENTS, BY SHIPMENT DESTINATION (000)									
	1985		Forecast							
	Shipments		1986		1987		1988		1989	
	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW
U.S. Manufacturers										
IBM Captive	--	--	--	--	--	--	--	--	--	--
Other U.S. Captive	--	--	--	--	--	--	--	--	--	--
TOTAL U.S. CAPTIVE	--	--	--	--	--	--	--	--	--	--
PCM	--	--	--	--	--	--	--	--	--	--
OEM	.1	.1	.2	.2	.3	.3	.4	.5	.5	.7
TOTAL U.S. NON-CAPTIVE	.1	.1	.2	.2	.3	.3	.4	.5	.5	.7
TOTAL U.S. SHIPMENTS	.1	.1	.2	.2	.3	.3	.4	.5	.5	.7
Non-U.S. Manufacturers										
Captive	--	--	--	--	2.0	10.0	11.0	55.0	30.0	120.0
PCM	--	--	--	--	--	--	--	--	--	--
OEM	7.0	8.2	26.5	30.7	85.2	100.0	188.0	235.0	360.0	480.0
TOTAL NON-U.S. SHIPMENTS	7.0	8.2	26.5	30.7	87.2	110.0	199.0	290.0	390.0	600.0
Worldwide Recap										
TOTAL WORLDWIDE SHIPMENTS	7.1	8.3	26.7	30.9	87.5	110.3	199.4	290.5	390.5	600.7
Cumulative Shipments										
IBM	--	--	--	--	--	--	--	--	--	--
Non-IBM	7.1	8.3	33.8	39.2	121.3	149.5	320.7	440.0	711.2	1,040.7
WORLDWIDE TOTAL	7.1	8.3	33.8	39.2	121.3	149.5	320.7	440.0	711.2	1,040.7

TABLE 10

READ-ONLY OPTICAL DISK DRIVES

WORLDWIDE REVENUES ($M)

BREAKDOWN BY DISK DIAMETER

	1985 Revenues		Forecast 1986		1987		1988		1989	
	12"	4.72"	12"	4.72"	12"	4.72"	12"	4.72"	12"	4.72"
U.S. MANUFACTURERS										
IBM Captive	--	--	--	--	--	--	--	--	--	--
Other U.S. Captive	--	--	--	--	--	--	--	--	--	--
OEM	.9	--	1.6	--	2.4	--	3.8	--	4.9	--
TOTAL U.S. REVENUES	.9	--	1.6	--	2.4	--	3.8	--	4.9	--
NON-U.S. MANUFACTURERS										
Captive	--	--	--	--	--	12.0	--	49.5	--	90.0
OEM	--	4.7	--	15.1	--	38.0	--	70.5	--	120.0
TOTAL NON-U.S. REVENUES	--	4.7	--	15.1	--	50.0	--	120.0	--	210.0
WORLDWIDE RECAP										
Captive	--	--	--	--	--	12.0	--	49.5	--	90.0
	--	--	--	--	--	--	--	+312.5%	--	+81.8%
OEM	.9	4.7	1.6	15.1	2.4	38.0	3.8	70.5	4.9	120.0
	--	--	+77.7%	+221.2%	+50.0%	+151.6%	+58.3%	+85.5%	+28.9%	+70.2%
Total Revenues	.9	4.7	1.6	15.1	2.4	50.0	3.8	120.0	4.9	210.0
	--	--	+77.7%	+221.2%	+50.0%	+231.1%	+58.3%	+140.0%	+28.9%	+75.0%
ANNUAL SHARE, BY DIAMETER	16.1%	83.9%	9.6%	90.4%	4.6%	95.4%	3.1%	96.9%	2.3%	97.7%

TABLE 11

READ-ONLY OPTICAL DISK DRIVES

WORLDWIDE SHIPMENTS (000)

BREAKDOWN BY DISK DIAMETER

	1985		Forecast							
	---Shipments----		------1986------		------1987------		------1988------		------1989------	
	12"	4.72"	12"	4.72"	12"	4.72"	12"	4.72"	12"	4.72"
U.S. MANUFACTURERS										
IBM Captive	--	--	--	--	--	--	--	--	--	--
Other U.S. Captive	--	--	--	--	--	--	--	--	--	--
OEM	.1	--	.2	--	.3	--	.5	--	.7	--
TOTAL U.S. SHIPMENTS	.1	--	.2	--	.3	--	.5	--	.7	--
NON-U.S. MANUFACTURERS										
Captive	--	--	--	--	--	10.0	--	55.0	--	120.0
OEM	--	8.2	--	30.7	--	100.0	--	235.0	--	480.0
TOTAL NON-U.S. SHIPMENTS	--	8.2	--	30.7	--	110.0	--	290.0	--	600.0
WORLDWIDE RECAP										
Captive	--	--	--	--	--	10.0	--	55.0	--	120.0
	--	--	--	--	--	--	--	+450.0%	--	+118.1%
OEM	.1	8.2	.2	30.7	.3	100.0	.5	235.0	.7	480.0
	--	--	+100.0%	+274.3%	+50.0%	+225.7%	+66.6%	+135.0%	+40.0%	+104.2%
Total Shipments	.1	8.2	.2	30.7	.3	110.0	.5	290.0	.7	600.0
	--	--	+100.0%	+274.3%	+50.0%	+258.3%	+66.6%	+163.6%	+40.0%	+106.8%
ANNUAL SHARE, BY DIAMETER	1.2%	98.8%	.6%	99.4%	.3%	99.7%	.2%	99.8%	.1%	99.9%

TABLE 12

READ-ONLY OPTICAL DISK DRIVES

DISTRIBUTION CHANNEL SUMMARY
U.S. Non-Captive Disk Drives

Distribution channel	1985 U.S. Net Shipments Units (000)	1985 U.S. Net Shipments %	FORECAST 1986 %	1987 %	1988 %	1989 %
Mainframe computer manufacturers	--	--	--	6.0	16.0	20.0
Mini/micro computer manufacturers	3.9	54.9	20.0	13.0	8.0	5.0
System OEMs/systems houses	3.0	42.3	75.0	71.0	62.0	56.0
Independent peripherals suppliers	.2	2.8	5.0	6.0	5.0	4.0
Distributors, dealers, end users	--	--	--	4.0	9.0	15.0
TOTAL	7.1					

READ/WRITE OPTICAL DISK DRIVES UNDER 1 GIGABYTE

1986 DISK/TREND REPORT

READ/WRITE OPTICAL DISK DRIVES LESS THAN 1 GIGABYTE

Coverage

Examples of optical disk drives in this group include:

3.5" disk diameter

Verbatim	Mod-1 (Erasable)

5.25" disk diameter

Cherokee Data Systems	Pathfinder
Information Storage Inc.	525WC
Laserdrive	LD33
Optotech	5984
Ricoh	RO-5040WL
Toshiba	WM-D050

8" disk diameter

Matsushita Electric	LD-10
Pioneer	DD-8001
Sony	WDD-2000

Two types of drives fit into this group: Write Once Read Many, (WORM) and Erasable. Products in this group will typically be used with small computer systems of the mini and micro class and with many intelligent workstations. Although all of the drives presently in this group that are actually in current production are of the write-once type, lower capacity erasable optical drives will be included as they go into production.

Provided that a drive is capable of writing and reading, it is classified in this group even if it can also be used with read-only media.

Market status

1985 unit shipments were under 1,500 units, with production from ISI the only significant contribution to the figures. Optotech began production shipments in mid 1986, and Cherokee Data Systems and Laserdrive are preparing to ship products in 1987. While 1986 will see increased shipment levels of write-once products, design-in cycles, software development time, and OEM preference for erasable storage will postpone high volume shipments until after 1987. Media availability was a factor limiting possible shipment growth in 1985, but in 1986 sufficient capacity is available to remove this restriction.

Erasable products are still in a prototype status, so almost all products shipped through 1987 will be write-once types. Drives using erasable media based upon magneto-optical technology are expected to begin production quantity shipments in 1988 at the earliest. Even where announcements have been made (Verbatim's 3.5" drive is an example), these releases describe erasable drive technology capability, rather than specific products.

Marketing trends

Shipments of disk drives in this class will begin modestly with approximately 11,000 units in 1986. By 1989, shipments will grow to almost 330,000 units. The preponderance of early sales will go to the add-on market; sub-system integrators will provide a market for the 5.25" drives that make up the majority of products in this category.

Most of the 5.25" units will be provided by U.S. firms. Because initial demand is modest, Japanese firms, while developing and announcing 5.25" optical disk drive products, will make relatively small efforts to

develop the U.S. market until demand is stronger. Half a dozen Japanese firms are expected to make product announcements of 5.25" optical drives by the end of 1986, and some 12 to 15 eventual competitors are anticipated. Most, if not all, will offer their products in the U.S. to insure recognition as the market develops. Some Japanese producers have concentrated on 8" drives in the under one gigabyte range that can be used in office automation systems, but the thrust of the majority of Japanese firms is toward 5.25" drives with 300-400 megabytes capacity per side.

Japanese firms will also have to contend with existing U.S. competitors plus firms beginning to enter the low capacity market segment. Two suppliers of high capacity optical drives, Optimem and O.S.I. have indicated their intent to offer 5.25" optical disk drives. Maxtor, one of the most formidable competitors in the high capacity 5.25" magnetic disk drive market, began an optical disk drive development program in mid-1986. Further entrants are expected. Some of the new players have substantial financial resources and can be expected to be very effective competitors.

By 1988, disk drives using erasable media will probably begin to ship in significant numbers, diverting growth from write-once disk drives. These will include both 3.5" and 5.25" product configurations. 3.5" drives will capture about 25% of the market in 1989.

During the next three years, it is unlikely that IBM will be in production of any optical disk drive. However, it is possible that IBM may choose to remarket a product in this class for use with personal computers and specialized workstations.

Some firms are considering offering a read/write drive in the CD-ROM physical format. Such a product, if based on the present CD-ROM mechanisms, would offer modest performance, high capacity and low cost.

However, they will not offer any significant packaging advantage over the 5.25" products, once these are available in half height form, as is expected. Performance will not match that available from the typical 5.25" drive. Finally, publishers of data bases, fearing a recurrance of the piracy that has plagued the personal computer software publishers, may discourage the development and marketing of a read/write drive in CD-ROM format. Regardless of any perceived disadvantages, the writeable CD-ROM, or CD-PROM as it is sometimes called, may be on the market in 1987. Its low price will make it an attractive add-on for those small computer users who need to save and restore large data bases.

Applications

Write-once optical drives under 1 gigabyte will find their first applications as save-restore devices in microcomputer and minicomputer systems where tape interchange isn't required.

Follow-on applications will include reference level storage, a new level in the storage hierarchy. Reference storage is defined as files that change infrequently but must be occasionally updated. On smaller systems, as much as 70% of disk file contents may fit this definition. Optical drives, slower than rigid magnetic disk drives but with tape-like capacity, fit this niche well.

Departmental level systems for document storage or image storage will use the lower capacity read/write drives. It is likely that some applications will require the use of small library units with five to twenty five media units to contain all the required records in a conveniently accessible form. These systems will be found in office automation,

medical, law enforcement, CAD/CAM, and smaller financial applications.

Erasable optical storage is expected to significantly displace tape storage devices, when available, as prices decline and customer confidence in the new technology increases. However, the high end user price of the media ($100 to $200 compared to $15 to $20 for a tape reel or cartridge) will limit initial acceptance.

An optical disk offering 30-60 megabyte of capacity at an end user media price approximating $50 might be very competitive against tape cartridges media for archival storage: Most tape users consume only a fraction of tape capacity and store only one dataset per media unit. This practice may carry over as optical memory comes into use, but it is more likely that the random access features of optical disks will encourage users to more completely use the media units. If this occurs, actual user media costs may not be higher than those associated with tape cartridge media.

Small erasable disk drives will also find significant use as system disks in low end applications. Average access times of these small drives are expected eventually to be competitive with those of today's 20 to 50 megabyte rigid magnetic disk drives. For some applications, removability is a very attractive feature: Even with modest access time, an optical disk coupled with a rigid magnetic disk drive could perform all required backup storage requirements, yet not require additional controllers or special software. System users in the military and aerospace segments of the industry who are subject to strict security controls will find appealing the ability to store the media in a vault or other secure facility.

The price/performance characteristics of 5.25" and 8" optical drives are consistent with use on both micro and mini-based systems. Some of the

larger capacity units may see service as peripherals on smaller mainframes and mini-computers if suitable controllers are developed.

Specific applications include:

Save-restore operations

* Save-restore disk data backup.

* Archival storage of files.

Reference level storage

* Storage of programs, freeing up fixed magnetic disk drives for data.

* Storage of data bases frequently used but infrequently changed.

Document storage

* Storage of images for use in departmental or small organizational CAD/CAM, medical, law enforcement, and financial record systems.

* Office automation systems at the departmental level.

Data distribution

* Production and distribution of data bases in quantities too small to warrant mass replication costs or where replication delays are too long for timeliness.

System disk

* Function as system disk where moderate performance is adequate and high capacity is needed.

Technical trends

Major issues for the small drives include media technology, access times, media lifetime error rates, erasability, and software. Other significant issues are track following and servo control and substrate materials. Most of these are issue areas for larger drives as well, so this section also applies to larger drives, unless otherwise noted.

Media technology: A variety of optical media technologies and constructions are in use, creating interchange problems and confusion. At present, pit forming or bubble forming writing methods are in the majority. In the future, writing using the phase change between amorphous and crystalline state may become common. A write-once dye/polymer based media design went into use in mid-1986.

Interchangeable media designs will eventually evolve. The creation of interchange standards will promote market acceptance. The surviving designs will be those with low manufacturing cost solutions.

Access times: One of the major limitations of optical drives is average access time, which exceeds 100 milliseconds on all products yet announced except the cancelled Storage Technology 7640 and the Cherokee Data Systems 5.25" drive. Magneto-optical drives will have an additional latency for writing operations caused by the need to erase a sector before writing. This lack of overwrite capability requires that an additional complete rotation be performed before the drive is ready to write in the selected sector. Such long access times in today's optical disk drives make them unattractive as competitors for magnetic disks in most system applications.

Manufacturers of smaller drives are targeting access times of under 100 milliseconds for future products. Evolving optical head designs of lower mass, plus the relatively short head travel distances used on small diameter drives, offer the prospect of average access times in the 50 millisecond range by 1987.

Because most optical drives have both fine and coarse head positioning mechanisms, the average access time to data within the range of the fine head positioner may be very competitive with the average access times of small magnetic disk drives for similar amounts of data. For instance, a Sony drive can access a band of 200 tracks from the fine positioner's nominal center position. About 9.6 megabytes lie within this range, and any point in the range can be reached within 53 milliseconds, including latency. This suggests that suitable software could improve the throughput of optical drives, much as the use of cache improves the performance of magnetic disk drives.

Even when head positioning times improve, the amount of data quickly accessible from an optical disk drive will not match that quickly accessible on magnetic disks. Magnetic disks have multiple surfaces and make a cylinder of data available (with a short delay for head switching) from which data can be accessed. Optical drives, which today typically can access a single surface, must always move the head to reach additional tracks -- a more time consuming operation. As heads shrink in mass and cost, optical drives will appear that offer on-line access to both sides of the disk. Multi-disk designs also appear inevitable and should begin to appear by 1989.

Another factor impacting average access time is latency. Optical disk drives rotate at lower speeds than do typical magnetic disk drives. Improvements in media materials, laser power, and tracking and focusing servos should eventually enable optical disk latency to match magnetic disk latency.

Media lifetime: While accelerated life tests seem to indicate that media lifetimes of 10 years or more are achievable, this aspect of media performance will remain unproven until actually demonstrated, limiting the use of optical recording for archival records.

Error rate: Error correcting codes are used to compensate for the high raw error rate of optical media. The codes used, typically long distance Reed-Solomon codes, are able to deal with the higher defect density that occurs at the end of media life. While there is a reduction of data capacity on the disk to accomodate the redundancy needed by ECC methods, the loss may be as little as 8%, depending upon the ECC technique used.

Erasability: There are several technologies contending for acceptance in erasable optical media, but magneto-optical media appears to be the only near term practical product capable of meeting user demands for sensitivity, erasability, and stability. Magneto-optical techniques may not be the long range solution. While progress in commercializing erasable phase change and other types of erasable recording trails progress in magneto-optical recording, the high cost of fabricating the required multi-layer structures makes magneto-optical a dubious long term choice as the preferred erasable media technology.

Provided that an adequate number of erase cycles can be demonstrated, it is likely that the second generation of erasable media will make use of phase change techniques. Phase change media may permit the interchange of write-once and erasable media on a single drive, something that is not inherent to magneto-optical recording. The large scale use of erasable phase change media may begin as early as 1988.

Another form of media, dye/polymer, may eventually become a commercially significant erasable optical disk. Now in R&D status, this type of media is less subject to degradation problems and uses inexpensive materials. However, it requires more development to provide an adequate number of write/erase cycles. Dye/polymer media is likely to be solvent coatable and relatively inexpensive to produce, and may operate with existing drives (except those configured for magneto-optical media). Obtaining an adequate number of write/erase cycles is technically difficult, and dye/polymer erasable media will not be commercially available until 1990 or later. Dye/polymer media's relative immunity to environmental influences enhances its desirability as a low cost solution to the erasability problem.

Packaging: Optical disk drives using 4.72" or 5.25" disks will be packaged to conform with the envelope of a full height 5.25" floppy disk drive, permitting use in most personal computers. Half height designs are planned and may be available in 1987.

Military interest is spurring the design of ruggedized optical drives. At least 3 firms are actively engaged in pursuing this product line.

Track following: Most optical disk drive units make use of a pre-grooved substrate surface to establish track location. The desire for minimal media cost may eventually result in the wide use of drives capable of using grooveless media, even though the drive will be more expensive. ISI is the first firm to market such a product.

Substrates: Glass has given way to plastic in order to reduce media cost and improve manufacturability. Polycarbonate appears to be the future material of choice, displacing PMMA. PMMA is permeable to water vapor which, in turn, can cause corrosion of the active layer. Epoxy casting, which offers low optical distortion, is also being evaluated as a substrate fabrication technique.

While casting polycarbonate with low birefringence (a form of optical distortion) is difficult, proper formulation and control of the molding process has been shown by some substrate manufacturers to permit fabrication of substrates adequate for 5.25" media. The job of making polycarbonate 12" substrates is more difficult, but at least one Japanese manufacturer claims to have solved the problems and is now providing samples.

Standards: There are not yet any optical media or drive standards, but ANSI X3B11, ECMA TC31, ISO TC91/SC23 are all involved in standardization programs for unrecorded media. Standardization efforts are currently concentrated upon the 130 mm media size, and an unrecorded standard may be in place by 1987. It is unlikely that there will be early standardization of the 300 mm media size due to the variety of existing designs already in production.

No standard device level interface for optical drives exists, but there is a grass roots effort to prepare an optical drive version of the ESDI standard. At the system level, SCSI appears to have the status of a de facto standard, and the IBM PC interface will have this status for both CD-ROM and read/write small drives.

Software: Read-write optical disk drives require specific supporting software, including drivers, operating system utilities, and application programs.

Basic software must address problems presented by the nature of the optical disk drive:

* More storage capacity is available than unmodified small computer operating systems can handle.

* Write-once disks require nonstandard file management utilities and drivers. File updates may result in degraded performance if files and directories are dispersed across the disk.

* Magneto-optical disks require modified system software to handle the overwrite requirement, or must have this function performed by the disk electronics or controller.

Driver and operating system utilities specific to optical disk drives will be provided by drive vendors for widely used systems such as the IBM PC. System integrators and OEMs will provide system support on less widely used processors.

Application programs frequently will be supplied in the form of object code that is resident on the optical disk itself. The large capacity of the optical disk may permit the inclusion of program versions for several types of popular machines. Software suppliers will probably have to face the choice of distributing source code to system integrators and OEMs, or remastering (for CD-ROM), or maintaining a significant ongoing effort to provide support for a complete range of systems. Most will choose to let other organizations bear support costs.

All of the above represent development that requires time, making software one of the factors that will delay high volume shipments of optical drives until 1987 or later.

Forecasting assumptions

1. IBM will not announce an internally manufactured optical disk drive in this class until after 1989.

2. Erasable media will be available in production quantities in 1988; write-once media will be readily available in 1986.

3. Japanese 5.25" drives will become available on an OEM basis in 1986, but U.S. producers of 3.5" and 5.25" drives will represent the bulk of production through 1989. After 1988, increasing demand will inspire higher levels of Japanese production and marketing efforts; the large number of Japanese producers will begin to shift the balance.

4. Basic system software support on the IBM PC family will be supplied by manufacturers of drives in 1986. Support on mini-computers will follow in 1987.

5. Most media interchange specifications will be standardized by 1987.

6. The small system add-on market will be the earliest large major distribution opportunity for this class of drive.

7. 4.72" read/write drives will be in production by late 1987.

TABLE 13

READ/WRITE OPTICAL DISK DRIVES, LESS THAN 1 GIGABYTE

REVENUE SUMMARY

	DISK DRIVE REVENUES, BY SHIPMENT DESTINATION ($M)									
	1985		Forecast							
	Revenues		1986		1987		1988		1989	
	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW
U.S. Manufacturers										
IBM Captive	--	--	--	--	--	--	--	--	--	--
Other U.S. Captive	--	--	--	--	--	--	--	--	--	--
TOTAL U.S. CAPTIVE	--	--	--	--	--	--	--	--	--	--
PCM	--	--	--	--	--	--	--	--	--	--
OEM	1.0	1.3	8.7	13.5	27.9	39.9	48.5	67.6	123.4	164.6
TOTAL U.S. NON-CAPTIVE	1.0	1.3	8.7	13.5	27.9	39.9	48.5	67.6	123.4	164.6
TOTAL U.S. REVENUES	1.0	1.3	8.7	13.5	27.9	39.9	48.5	67.6	123.4	164.6
Non-U.S. Manufacturers										
Captive	--	2.4	--	4.6	1.1	10.8	3.8	47.0	15.2	68.4
PCM	--	--	--	--	--	--	--	--	--	--
OEM	.6	2.1	1.4	13.9	13.9	24.8	28.6	50.6	47.7	78.7
TOTAL NON-U.S. REVENUES	.6	4.5	1.4	18.5	15.0	35.6	32.4	97.6	62.9	147.1
Worldwide Recap										
TOTAL WORLDWIDE REVENUES	1.6	5.8	10.1	32.0	42.9	75.5	80.9	165.2	186.3	311.7
OEM Average Price ($000)	2.0	2.6	1.8	2.6	1.0	1.2	.8	.9	.7	.8

TABLE 14

READ/WRITE OPTICAL DISK DRIVES, LESS THAN 1 GIGABYTE

UNIT SHIPMENT SUMMARY

	DISK DRIVE UNIT SHIPMENTS, BY SHIPMENT DESTINATION (000)									
	1985		Forecast							
	Shipments		1986		1987		1988		1989	
	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW
U.S. Manufacturers										
IBM Captive	--	--	--	--	--	--	--	--	--	--
Other U.S. Captive	--	--	--	--	--	--	--	--	--	--
TOTAL U.S. CAPTIVE	--	--	--	--	--	--	--	--	--	--
PCM	--	--	--	--	--	--	--	--	--	--
OEM	.7	1.0	5.2	8.5	29.4	42.0	64.3	90.5	165.4	222.0
TOTAL U.S. NON-CAPTIVE	.7	1.0	5.2	8.5	29.4	42.0	64.3	90.5	165.4	222.0
TOTAL U.S. SHIPMENTS	.7	1.0	5.2	8.5	29.4	42.0	64.3	90.5	165.4	222.0
Non-U.S. Manufacturers										
Captive	--	.1	--	.2	.2	2.0	.8	9.8	4.0	18.0
PCM	--	--	--	--	--	--	--	--	--	--
OEM	.1	.3	.3	2.0	10.5	14.0	33.0	44.2	71.0	91.0
TOTAL NON-U.S. SHIPMENTS	.1	.4	.3	2.2	10.7	16.0	33.8	54.0	75.0	109.0
Worldwide Recap										
TOTAL WORLDWIDE SHIPMENTS	.8	1.4	5.5	10.7	40.1	58.0	98.1	144.5	240.4	331.0
Cumulative Shipments										
IBM	--	--	--	--	--	--	--	--	--	--
Non-IBM	.8	1.4	6.3	12.1	46.4	70.1	144.5	214.6	384.9	545.6
WORLDWIDE TOTAL	.8	1.4	6.3	12.1	46.4	70.1	144.5	214.6	384.9	545.6

TABLE 15

READ/WRITE OPTICAL DISK DRIVES, LESS THAN 1 GIGABYTE

WORLDWIDE REVENUES ($M)

BREAKDOWN BY DISK DIAMETER

	1985 Revenues				Forecast 1986				1987				1988				1989			
	8"	5.25"	4.72"	3.5"	8"	5.25"	4.72"	3.5"	8"	5.25"	4.72"	3.5"	8"	5.25"	4.72"	3.5"	8"	5.25"	4.72"	3.5"
U.S. MANUFACTURERS																				
IBM Captive	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Other U.S. Captive	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
OEM	--	1.3	--	--	--	13.5	--	--	--	39.9	--	--	--	57.4	--	10.2	--	91.0	--	73.6
TOTAL U.S. REVENUES	--	1.3	--	--	--	13.5	--	--	--	39.9	--	--	--	57.4	--	10.2	--	91.0	--	73.6
NON-U.S. MANUFACTURERS																				
Captive	2.4	--	--	--	4.6	--	--	--	--	10.8	--	--	--	47.0	--	--	--	68.4	--	--
OEM	2.1	--	--	--	13.0	.9	--	--	11.6	6.0	7.2	--	21.0	12.8	16.8	--	31.5	18.0	24.0	5.2
TOTAL NON-U.S. REVENUES	4.5	--	--	--	17.6	.9	--	--	11.6	16.8	7.2	--	21.0	59.8	16.8	--	31.5	86.4	24.0	5.2
WORLDWIDE RECAP																				
Captive	2.4	--	--	--	4.6	--	--	--	--	10.8	--	--	--	47.0	--	--	--	68.4	--	--
	--	--	--	--	+91.6%	--	--	--	-100.0%	--	--	--	--	+335.1%	--	--	--	+45.5%	--	--
OEM	2.1	1.3	--	--	13.0	14.4	--	--	11.6	45.9	7.2	--	21.0	70.2	16.8	10.2	31.5	109.0	24.0	78.8
	--	--	--	--	+519.0%	--	--	--	-10.7%	+218.7%	--	--	+81.0%	+52.9%	+133.3%	--	+50.0%	+55.2%	+42.8%	+672.5%
Total Revenues	4.5	1.3	--	--	17.6	14.4	--	--	11.6	56.7	7.2	--	21.0	117.2	16.8	10.2	31.5	177.4	24.0	78.8
	--	--	--	--	+291.1%	--	--	--	-34.0%	+293.7%	--	--	+81.0%	+106.7%	+133.3%	--	+50.0%	+51.3%	+42.8%	+672.5%
ANNUAL SHARE, BY DIAMETER	77.7%	22.3%	--	--	55.1%	44.9%	--	--	15.4%	75.2%	9.4%	--	12.7%	71.0%	10.2%	6.1%	10.1%	57.0%	7.7%	25.2%

TABLE 16

READ/WRITE OPTICAL DISK DRIVES, LESS THAN 1 GIGABYTE

WORLDWIDE SHIPMENTS (000)

BREAKDOWN BY DISK DIAMETER

	1985 Shipments				Forecast: 1986				1987				1988				1989			
	8"	5.25"	4.72"	3.5"	8"	5.25"	4.72"	3.5"	8"	5.25"	4.72"	3.5"	8"	5.25"	4.72"	3.5"	8"	5.25"	4.72"	3.5"
U.S. MANUFACTURERS																				
IBM Captive	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Other U.S. Captive	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
OEM	--	1.0	--	--	--	8.5	--	--	--	42.0	--	--	--	82.0	--	8.5	--	130.0	--	92.0
TOTAL U.S. SHIPMENTS	--	1.0	--	--	--	8.5	--	--	--	42.0	--	--	--	82.0	--	8.5	--	130.0	--	92.0
NON-U.S. MANUFACTURERS																				
Captive	.1	--	--	--	.2	--	--	--	--	2.0	--	--	--	9.8	--	--	--	18.0	--	--
OEM	.3	--	--	--	1.7	.3	--	--	2.0	6.0	6.0	--	4.2	16.0	24.0	--	7.0	30.0	48.0	6.0
TOTAL NON-U.S. SHIPMENTS	.4	--	--	--	1.9	.3	--	--	2.0	8.0	6.0	--	4.2	25.8	24.0	--	7.0	48.0	48.0	6.0
WORLDWIDE RECAP																				
Captive	.1	--	--	--	.2	--	--	--	--	2.0	--	--	--	9.8	--	--	--	18.0	--	--
	--	--	--	--	+100.0%	--	--	--	-100.0%	--	--	--	--	+390.0%	--	--	--	+83.6%	--	--
OEM	.3	1.0	--	--	1.7	8.8	--	--	2.0	48.0	6.0	--	4.2	98.0	24.0	8.5	7.0	160.0	48.0	98.0
	--	--	--	--	+466.6%	+780.0%	--	--	+17.6%	+445.4%	--	--	+110.0%	+104.1%	+300.0%	--	+66.6%	+63.2%	+100.0%	--
Total Shipments	.4	1.0	--	--	1.9	8.8	--	--	2.0	50.0	6.0	--	4.2	107.8	24.0	8.5	7.0	178.0	48.0	98.0
	--	--	--	--	+375.0%	+780.0%	--	--	+5.2%	+468.1%	--	--	+110.0%	+115.6%	+300.0%	--	+66.6%	+65.1%	+100.0%	--
ANNUAL SHARE, BY DIAMETER	28.7%	71.3%	--	--	17.8%	82.2%	--	--	3.4%	86.3%	10.3%	--	2.9%	74.7%	16.6%	5.8%	2.1%	53.9%	14.5%	29.5%

TABLE 17

READ/WRITE OPTICAL DISK DRIVES, LESS THAN 1 GIGABYTE

DISTRIBUTION CHANNEL SUMMARY
U.S. Non-Captive Disk Drives

Distribution channel	1985 U.S. Net Shipments Units (000)	%	FORECAST 1986 %	1987 %	1988 %	1989 %
Mainframe computer manufacturers	.4	50.0	5.0	4.0	4.0	4.0
Mini/micro computer manufacturers	.2	25.0	25.0	17.0	12.0	8.0
System OEMs/systems houses	.2	25.0	50.0	55.0	57.0	59.0
Independent peripherals suppliers	--	--	15.0	16.0	18.0	19.0
Distributors, dealers, end users	--	--	5.0	8.0	9.0	10.0
TOTAL	.8					

READ/WRITE OPTICAL DISK DRIVES MORE THAN 1 GIGABYTE

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Coverage

Examples of the drives included in this group are given below.

12" disk diameter

Alcatel Thomson Gigadisc	GD1001
Fujitsu	F6441B1
Hitachi	OD 301-1
NEC	N7911/N6329-21
Optical Storage International	Laserdrive 1200
Optimem	1000
Sony	WDD 3000
Toshiba	DF-0450
Van Der Heem	DOR-RI

These products are most likely to be used with large mini-computers and mainframes or in specialized imaging, document storage, or archiving applications. They are frequently used with library devices to make random access mass storage subsystems capable of handling hundreds of gigabytes of storage on-line. At present, all of the available products in this class use 12" media. However, 14" media will also be used in the future by some products in this group, notably Eastman Kodak's optical drive when it is introduced. The Storage Technology Corporation 7640, currently in abeyance while the company seeks a buyer for the project, also used 14" media. 8" media may appear in a product in this category, but whereas the 12" and 14" drives currently all use a single disk per drive, the 8" units will use multiple disks per drive unless manufacturers design drives capable of accessing both sides of the disk simultaneously.

Market status

Unit shipments in 1985 were predominantly Japanese products used in captive systems, but about 6% of the 4,900 units sold were produced by U.S. firms, mostly for specialized image processing applications. In 1986, the Japanese producers are expected to continue to manufacture the majority of this product class because of its suitability for use in systems capable of storing documents produced in Asian character sets. But the U.S. producer share of the worldwide market is increasing, as optical storage units begin to work their way into on-line retrieval applications in large organizations.

The first announced drive in the high capacity storage class with performance optimized for mainframes was the Storage Technology 7640. Due to financial constraints, STC halted development work and indicated interest in selling off the project. If STC is soon successful in finding a buyer for its optical storage program, the new owners might have the product on the market by late 1988.

In 1986, Sperry became the first mainframe manufacturer to support optical disk storage as a mainframe peripheral. Sperry is offering the Hitachi optical disk drive and a Filenet library subsystem as peripherals for its 1100 series systems. While Sperry does not have a large portion of the mainframe market, its product introduction is the first significant chance to test demand for write-once optical storage in the mainframe market. Whether Sperry will get the chance to proceed with its plans is somewhat uncertain; Sperry's acquisition by Burroughs may result in an unexpected shift of plans.

Marketing trends

Because this class of optical disk drive will be used primarily on larger systems or in more specialized applications, shipment growth will be smaller for this category than for other optical drisk drive categories. Unit shipments will increase from about 4,900 units in 1985 to almost 87,000 units in 1989. While about 60% of the market is currently in Japan, by 1989, two thirds of the market will be in the U.S. Applications will continue to be concentrated in image processing and archiving, where the higher price and lower performance of current products is acceptable.

At least one U.S. firm, Eastman Kodak, is expected to be in limited production of a 14" write-once disk drive in 1987. This unit will probably be used by Eastman Kodak in its own line of image processing systems on a captive basis. Eastman Kodak may also offer the product on an OEM or PCM basis if performance is suitable for use in a mainframe EDP environment and suitable marketing arrangements can be made.

While IBM has an acknowledged optical disk drive development program underway, no production is anticipated prior to 1990. IBM has made no official specific statements about its optical disk drive product, which will probably be positioned by IBM as a mass storage system to replace the 3850 tape-based mass storage system. It is unlikely that IBM would find write-once technology attractive, given the relatively short time until erasable technology is available. It is also unlikely that a single disk product would provide the capacity needed. The most probable product is a multi-disk, multi-head configuration using magneto-optical erasable media, associated with a library mechanism.

An IBM introduction, if it occurs within the forecast span of this report, could enhance shipments of large capacity drives.

Applications

Optical drives in the over 1 gigabyte class will be used mostly for medical or industrial imaging, archival storage with mainframes, or to accumulate transaction data that must be stored for future reference but is not needed for current operations. The high capacity drive will also have a major role in acquiring high volume digitized data from real time inputs and storing it for subsequent analysis.

Most early usage will be in imaging systems, in document filing systems or within government bodies such as taxing agencies, law enforcement, and military/intelligence agencies. Drive library units (jukeboxes) are available for use with high capacity optical disk drives, allowing the creation of on-line mass storage subsystems that are attracting the attention of insurance companies, banks, and other large organizations that must have ready recall of large amounts of account related data.

Mainframes and minicomputers will become hosts for the large optical drives, as they have the capability needed to process or distribute the large amounts of data stored on optical drives. Tape and microfilm systems currently used in mainframe environments may be heavily impacted by the large capacity optical drives now becoming available.

Microcomputers will be the typical hosts for large capacity optical drives used for document storage in an office automation environment and for most medical system usage. Microcomputers with large capacity optical disk drives will also be used for systems that store and manipulate engineering drawings, technical specifications and reference materials. The electronic form of storage permits distribution electronically, saving time and reducing the possibility of errors.

Typical specific usage will include:

Engineering and manufacturing systems

* Centralized drawing/document storage and distribution.
* Document storage for computer integrated manufacturing.
* Document storage and dissemination for construction projects.

Record management

* Personnel records.
* Tax records and tax rolls.
* X-ray and scanner images.
* Social Security and other government records.
* Large library index files.

Save-restore operations

* Disk backup.
* Archival storage.

Office automation

* Storage and dissemination of office documents.
* Storage of legal documents incorporating signatures and other personal identification.

Transaction audit trails

* Records of reservations, bank transactions, etc.
* Secure area access records.

Data acquisition

* Capture of data from scanners, seismic detectors or other imaging devices.
* Capture of data having military or intelligence significance.

Technical trends

Many of the technical issues discussed in the section on optical disk drives under 1 gigabyte capacity also apply to the larger capacity drives. The issues are reviewed here as they pertain specifically to the higher capacity drives.

Almost all of the released products in this group currently use complex optical head assemblies, resulting in excessive average access times. Considerable work is being done by manufacturers to reduce product complexity and to improve access time. Even so, it may be several years before typical average access times are below 100 milliseconds for these drives.

Most of the effort in the over 1 gigabyte group is aimed at the 12" diameter disk class, but 14" diameters are also going to be represented. The Eastman Kodak and Storage Technology programs were mentioned earlier; if these firms are successful, other firms will offer similar products.

Standards for very high capacity media will take several years to materialize, because the initial products' incompatibility prevents media interchange and the initial product designs are already established. The ANSI X3B11 group, which has the charter to develop such a standard, does not expect any significant progress on a standard for 12" or 14" media for some years to come. IBM could change this situation by making a product announcement and creating a de facto standard, but as already noted, an early IBM announcement is unlikely, leaving the standards situation for this product group unresolved for some years to come.

Large drives will frequently be part of disk library subsystems that permit the contents of many optical disks to be available on-line. These subsystems are intended to perform the functions of a mass storage

subsystem and are the logical successor to the tape-based IBM 3850 mass storage subsystem. From 10 to over 200 disks can be available to a single drive equipped with a library subsystem; average access times will be approximately 1/10 to 1/2 minute. Some libraries will be equipped with multiple drives and pickers that can operate independently of each other, minimizing access time.

Other technical issues specifically impacting larger capacity drives are discussed below:

* Software: The software required to integrate a write-once optical disk into the operating system environment of a mainframe computer represents a major project, in many cases requiring man years of effort. The integration of erasable disks should be easier, but even these will present some problems. It is possible that those aspects of the drive unique to optical storage may be buried inside the drive or controller so that the optical storage subsystem appears as a standard magnetic disk to the operating system.

* Packaging: The larger capacity disk drives will typically have a rack mount configuration. Because these devices will often be used with library devices, there will be interest in defining a standardized mechanical interface that would permit any drive to be used with any library load/unload mechanism.

  For the next few years, the 12" form factor will remain the most frequently encountered form factor in this product group. Eventually, multi-disk configurations fabricated with smaller diameter disks will appear in this product group. Both 5.25" and 8" diameters are likely to be represented in these multi-disk configurations. Single disk 14" diameter drives in this group are likely to appear in 1987 when Eastman Kodak's drive goes into production.

* Track Following: Pregrooving of the media continues to be the primary method of providing tracking information to the tracking servo for this product group. There has been some interest in using sector servo techniques to improve tracking. Alcatel Thomson Gigadisc has done substantial development work with this technique and has incorporated it into the design of the ATG 12" drive. ATG believes that its technique improves the ability of the drive to accept write-once, erasable, and read-only media on the same drive and makes the drive less sensitive to variations in groove shape and depth. This approach has been proposed by ATG as a point of departure in the preparation of a standard for 12" optical media.

* Interface: SCSI is the most commonly encountered interface on the large capacity optical drives. This is likely to remain the case unless IBM introduces optical drive products with a different interface. Even then, SCSI is likely to remain the preferred choice because of design commitments or until drives with higher performance are technically possible. It is not clear that there will be a standard or semi-standard device level interface for this product class. For most drives, proprietary interfaces are used at the device level at the present time.

  For a 12" drive operating at 1800 RPM, a practical data transfer rate limit is about 10 megabits/second, limited by the spot size of the laser. As lasers improve or as RPM increases, the interface will have to cope with significantly higher data transfer rates. A future 12" drive equipped with a green semiconductor laser and spinning at 3600 rpm could generate a data transfer rate exceeding 37 megabits/second.

* Media: Larger diameter media requires substrates that will not deform at high rotation rates and will maintain consistent optical properties over the usable area of the disk. The latter point is especially significant for magneto-optical media in which distortion caused by locked-in or dynamic stresses in the substrate creates signal degradation. These mechanical problems may be a significant obstacle to improving the performance of high end optical drives, although one Japanese supplier claims to have a substrate suitable for 12" erasable media available in limited quantities.

  The current limit on rotational velocity for larger diameter disks is created by the performance of focus and tracking servos, rather than by material failure. 1800 RPM is considered today's state of the art; there are expections of achieving 2800 to 3600 RPM as a practical matter in the future as a result of using non-mechanical focusing techniques and improved substrate materials.

  In general, erasable media for large capacity disks is not available except in sample quantities, and, given the current emphasis on small diameter media by media suppliers and standards groups, the availability date of production volumes is probably later than 1989.

Forecasting assumptions

1. No IBM-produced units will be shipped until after 1989.

2. Technical difficulties will delay availability of erasable media for this product group until 1989 or later.

3. There will be an adequate supply of write-once media for most products in this group by mid 1986.

4. Generally recognized media interchange standards for this product group will not exist until after 1988 unless IBM introduces an optical drive in the group before that time.

5. Products in this class will be used primarily with mainframes, large minicomputers, and document storage systems.

6. System support software for write-once products will be developed by system manufacturers. Most software projects will be time consuming, delaying the widespread appearance of optical memory on mainframes until 1987, or later.

TABLE 18

READ/WRITE OPTICAL DISK DRIVES, MORE THAN 1 GIGABYTE

REVENUE SUMMARY

	DISK DRIVE REVENUES, BY SHIPMENT DESTINATION ($M)									
	1985		Forecast							
	Revenues		1986		1987		1988		1989	
	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW
U.S. Manufacturers										
IBM Captive	--	--	--	--	--	--	--	--	--	--
Other U.S. Captive	--	--	--	--	24.0	31.2	54.0	66.0	94.0	114.4
TOTAL U.S. CAPTIVE	--	--	--	--	24.0	31.2	54.0	66.0	94.0	114.4
PCM	--	--	--	--	--	--	--	--	--	--
OEM	5.7	7.6	28.1	35.8	49.3	68.6	79.7	112.6	152.7	205.5
TOTAL U.S. NON-CAPTIVE	5.7	7.6	28.1	35.8	49.3	68.6	79.7	112.6	152.7	205.5
TOTAL U.S. REVENUES	5.7	7.6	28.1	35.8	73.3	99.8	133.7	178.6	246.7	319.9
Non-U.S. Manufacturers										
Captive	1.3	48.8	1.3	71.7	1.6	99.2	12.0	129.0	33.6	224.0
PCM	--	--	--	--	--	--	--	--	--	--
OEM	6.8	11.8	13.3	31.4	54.0	59.3	109.9	129.5	178.1	224.9
TOTAL NON-U.S. REVENUES	8.1	60.6	14.6	103.1	55.6	158.5	121.9	258.5	211.7	448.9
Worldwide Recap										
TOTAL WORLDWIDE REVENUES	13.8	68.2	42.7	138.9	128.9	258.3	255.6	437.1	458.4	768.8
OEM Average Price ($000)	8.9	8.8	8.3	8.5	7.6	7.6	7.0	7.0	6.7	6.7

TABLE 19

READ/WRITE OPTICAL DISK DRIVES, MORE THAN 1 GIGABYTE

UNIT SHIPMENT SUMMARY

	DISK DRIVE UNIT SHIPMENTS, BY SHIPMENT DESTINATION (000)									
	1985		Forecast							
	Shipments		1986		1987		1988		1989	
	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW
U.S. Manufacturers										
IBM Captive	--	--	--	--	--	--	--	--	--	--
Other U.S. Captive	--	--	--	--	1.2	1.6	2.7	3.4	5.3	6.6
TOTAL U.S. CAPTIVE	--	--	--	--	1.2	1.6	2.7	3.4	5.3	6.6
PCM	--	--	--	--	--	--	--	--	--	--
OEM	.6	.8	3.3	4.2	6.4	8.9	11.3	16.0	22.1	30.1
TOTAL U.S. NON-CAPTIVE	.6	.8	3.3	4.2	6.4	8.9	11.3	16.0	22.1	30.1
TOTAL U.S. SHIPMENTS	.6	.8	3.3	4.2	7.6	10.5	14.0	19.4	27.4	36.7
Non-U.S. Manufacturers										
Captive	.1	2.7	.1	4.2	.1	6.2	.8	8.6	2.4	16.0
PCM	--	--	--	--	--	--	--	--	--	--
OEM	.8	1.4	1.7	3.7	7.2	7.9	15.7	18.5	27.4	34.6
TOTAL NON-U.S. SHIPMENTS	.9	4.1	1.8	7.9	7.3	14.1	16.5	27.1	29.8	50.6
Worldwide Recap										
TOTAL WORLDWIDE SHIPMENTS	1.5	4.9	5.1	12.1	14.9	24.6	30.5	46.5	57.2	87.3
Cumulative Shipments										
IBM	--	--	--	--	--	--	--	--	--	--
Non-IBM	1.7	7.6	6.8	19.7	21.7	44.3	52.2	90.8	109.4	178.1
WORLDWIDE TOTAL	1.7	7.6	6.8	19.7	21.7	44.3	52.2	90.8	109.4	178.1

TABLE 20

READ/WRITE OPTICAL DISK DRIVES, MORE THAN 1 GIGABYTE

WORLDWIDE REVENUES ($M)

BREAKDOWN BY DISK DIAMETER

	1985 Revenues			Forecast											
	1986			1987			1988			1989					
	14"	12"	8"	14"	12"	8"	14"	12"	8"	14"	12"	8"	14"	12"	8"
U.S. MANUFACTURERS															
IBM Captive	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Other U.S. Captive	--	--	--	--	--	--	6.0	25.2	--	30.0	36.0	--	50.0	64.4	--
OEM	--	7.6	--	--	35.8	--	--	68.6	--	2.0	110.6	--	20.0	185.5	--
TOTAL U.S. REVENUES	--	7.6	--	--	35.8	--	6.0	93.8	--	32.0	146.6	--	70.0	249.9	--
NON-U.S. MANUFACTURERS															
Captive	--	48.8	--	--	71.7	--	--	99.2	--	--	129.0	--	--	224.0	--
OEM	--	11.8	--	--	31.4	--	--	59.3	--	--	129.5	--	--	224.9	--
TOTAL NON-U.S. REVENUES	--	60.6	--	--	103.1	--	--	158.5	--	--	258.5	--	--	448.9	--
WORLDWIDE RECAP															
Captive	--	48.8	--	--	71.7	--	6.0	124.4	--	30.0	165.0	--	50.0	288.4	--
	--	+102.4%	--	--	+46.9%	--	--	+73.5%	--	+400.0%	+32.6%	--	+66.6%	+74.7%	--
OEM	--	19.4	--	--	67.2	--	--	127.9	--	2.0	240.1	--	20.0	410.4	--
	--	+295.9%	--	--	+246.3%	--	--	+90.3%	--	--	+87.7%	--	+900.0%	+70.9%	--
Total Revenues	--	68.2	--	--	138.9	--	6.0	252.3	--	32.0	405.1	--	70.0	698.8	--
	--	+135.1%	--	--	+103.6%	--	--	+81.6%	--	+433.3%	+60.5%	--	+118.7%	+72.5%	--
ANNUAL SHARE, BY DIAMETER	--	100.0%	--	--	100.0%	--	2.3%	97.7%	--	7.3%	92.7%	--	9.1%	90.9%	--

TABLE 21

READ/WRITE OPTICAL DISK DRIVES, MORE THAN 1 GIGABYTE

WORLDWIDE SHIPMENTS (000)

BREAKDOWN BY DISK DIAMETER

	1985 Shipments			Forecast											
	1986			1987			1988			1989					
	14"	12"	8"	14"	12"	8"	14"	12"	8"	14"	12"	8"	14"	12"	8"
U.S. MANUFACTURERS															
IBM Captive	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Other U.S. Captive	--	--	--	--	--	--	.2	1.4	--	1.0	2.4	--	2.0	4.6	--
OEM	--	.8	--	--	4.2	--	--	8.9	--	.2	15.8	--	2.0	28.1	--
TOTAL U.S. SHIPMENTS	--	.8	--	--	4.2	--	.2	10.3	--	1.2	18.2	--	4.0	32.7	--
NON-U.S. MANUFACTURERS															
Captive	--	2.7	--	--	4.2	--	--	6.2	--	--	8.6	--	--	16.0	--
OEM	--	1.4	--	--	3.7	--	--	7.9	--	--	18.5	--	--	34.6	--
TOTAL NON-U.S. SHIPMENTS	--	4.1	--	--	7.9	--	--	14.1	--	--	27.1	--	--	50.6	--
WORLDWIDE RECAP															
Captive	--	2.7	--	--	4.2	--	.2	7.6	--	1.0	11.0	--	2.0	20.6	--
	--	+68.7%	--	--	+55.5%	--	--	+80.9%	--	+400.0%	+44.7%	--	+100.0%	+87.2%	--
OEM	--	2.2	--	--	7.9	--	--	16.8	--	.2	34.3	--	2.0	62.7	--
	--	+450.0%	--	--	+259.0%	--	--	+112.6%	--	--	+104.1%	--	+900.0%	+82.7%	--
Total Shipments	--	4.9	--	--	12.1	--	.2	24.4	--	1.2	45.3	--	4.0	83.3	--
	--	+145.0%	--	--	+146.9%	--	--	+101.6%	--	+500.0%	+85.6%	--	+233.3%	+83.8%	--
ANNUAL SHARE, BY DIAMETER	--	100.0%	--	--	100.0%	--	.8%	99.2%	--	2.6%	97.4%	--	4.6%	95.4%	--

TABLE 22

READ/WRITE OPTICAL DISK DRIVES, MORE THAN 1 GIGABYTE

DISTRIBUTION CHANNEL SUMMARY
U.S. Non-Captive Disk Drives

Distribution channel	1985 U.S. Net Shipments Units (000)	1985 U.S. Net Shipments %	FORECAST 1986 %	1987 %	1988 %	1989 %
Mainframe computer manufacturers	--	--	2.0	5.0	8.0	11.0
Mini/micro computer manufacturers	.2	14.3	16.0	18.0	20.0	20.0
System OEMs/systems houses	.5	35.7	40.0	42.0	44.0	46.0
Independent peripherals suppliers	.7	50.0	42.0	35.0	28.0	23.0
Distributors, dealers, end users	--	--	--	--	--	--
TOTAL	1.4					

OPTICAL DISK DRIVE SPECIFICATIONS

OPTICAL DISK DRIVE SPECIFICATIONS

Coverage

The following pages list optical disk drives intended for computer data storage which are now announced or in new production. They are arranged alphabetically by manufacturer. In a few cases, products are listed for which only preliminary announcements have been made. They are included because they are judged to be significant indicators of industry direction in the production period indicated. In all cases, the product specifications and prices given are those in effect at the time of report publication. They are subject to change without notice by manufacturers.

Recording medium

The composition of the active layer of optical media varies according to manufacturer. The formulation given is the one described by the drive manufacturer. Other formulations of other manufacturers may not operate properly. Recording formats also differ: In products announced to date, recorded media is generally not interchangable between systems.

Interface

Specific interfaces are listed for most of the drives. As this area is subject to frequent change, consult the manufacturers' most current specifications to insure you have accurate data.

Speed control

Two abbreviations are used : CAV=constant angular velocity.
CLV=constant linear velocity.

Capacities

Capacities are listed as "U" for unformatted and "F" for formatted. In general, optical drives are preformatted, so the capacity given will be the formatted capacity. Track capacity in CLV drives is variable, so this parameter is given only for CAV drives.

Positioner type

Many optical drives have a multi-stage head positioner. A coarse movement positions the head in the general vicinity of the track to be located. A fine, or vernier, actuator then moves the head to the desired track. Where appropriate, the abbreviation "Crs." is used for "coarse".

OEM prices

The 100 unit price is given for most OEM drives sold in the United States. These prices are often changed by the manufacturers without notice and should be considered as guidelines only.

Accuracy

All of the information in this section has been checked for accuracy. However, it is anticipated that some errors may exist due to the rapid state of change within this category and because published specifications do not always cover all of the items listed, requiring verbal inquiries and updates.

1986 DISK/TREND optical disk product groups

For the 1986 report, products are classified in three groups.

Group 10: Read-only optical disk drives.

Group 11: Read/write disk drives, less than 1 gigabyte.

Group 12: Read/write disk drives, more than 1 gigabyte.

MANUFACTURER	ALCATEL THOMSON GIGADISC	ALPS ELECTRIC	CHEROKEE DATA SYSTEMS	FUJITSU, LTD.	FUJITSU, LTD.
DRIVE	GD1001	CD-ROM	PATHFINDER	F6441B1	M2501A1
DISK/TREND GROUP	12	10	11	12	12
MARKET	OEM	OEM	OEM	Captive	OEM
MEDIA: Nominal disk diameter	12"	200 mm	130 mm	12"	12"
Recording medium	Au-Pt-Polymer	Aluminum	--	Te Alloy	Te Alloy
Track format	Spiral	Spiral	Spiral,concent.	Concentric	Concentric
Recording method	Bubble	Mastering	Pit	Phase change	Phase Change
DRIVE: Operating mode	Write Once	Read Only	Write Once	Write Once	Write Once
Interface	SCSI/Prop.	Proprietary	ESDI	Modified 3350	SCSI
Speed control	CAV	CLV	CAV	CAV	CAV
CAPACITY/RECORDING DENSITY					
Total capacity (MBytes)	F: 1,000	F: 550	F: 315	F: 1,376	F: 1,376
Capacity per track (Bytes)	F: 25,600	F: N/A	F: 20,754	F: 30,720	F: 30,720
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	40,000	40,640	15,178	44,800	44,800
Track density (TPI)	14,432	15,875	15,000	15,875	15,875
Maximum linear density (BPI)	14,500	27,600	15,000	24,144	24,144
Rotational speed (RPM)	1121.5	530-200	2941	900	900
PERFORMANCE					
Positioner type	Crs: Voice Coil Fine: Solenoid	Rack and pinion	Crs: Voice Coil Fine: Solenoid	Crs: Voice Coil Fine: Lens Actuator	Crs: Voice Coil Fine: Lens Actuator
Average positioning time (msec)	200	490	43	216.7	216.7
Average rotational delay (msec)	27	110	10.3	33.3	33.3
Average access time (msec)	227	600	53.3	250	250
Data transfer rate (KBytes/sec)	625	153	1250	783	783
FIRST CUSTOMER SHIPMENT	3Q84	--	1987	3Q85	3Q85
U.S. OEM PRICE FOR 100 UNITS	$6,933	--	--	N/A	N/A
COMMENTS	Also works with 3M media	Stand-alone type	Ruggedized drive.	Available only in Japan. F6441A1 has SCSI interface. F6442B2 is 32 disk library.	Available only in Japan. M2501B1 has modified 3350 interface.

MANUFACTURER	HITACHI, LTD.	HITACHI, LTD.	INFORMATION STORAGE INC.	LASERDRIVE LTD.	MATSUSHITA ELECTRIC CO.
DRIVE	CDR 1502S CDR 2500	OD 301-1	525 WC	LD33	SQ-D1
DISK/TREND GROUP	10	12	11	11	10
MARKET	OEM	Captive/OEM	OEM	OEM	Captive/OEM
MEDIA: Nominal disk diameter	120 mm	12"	130 mm	130 mm	120 mm
Recording medium	Aluminum	Te-Se-Pb	Te Alloy	Te-Se	Aluminum
Track format	Spiral	Spiral	Concentric	Spiral	Spiral
Recording method	Mastering	Pit	Pit	Pit	Mastering
DRIVE: Operating mode	Read Only	Write Once	Write Once	Write Once	Read Only
Interface	PC/SCSI	SCSI/GPIB/SMD	ESDI/SCSI/PC	Prop./SCSI	SCSI/PC
Speed control	CLV	CAV	CAV	CLV	CLV
CAPACITY/RECORDING DENSITY					
Total capacity (MBytes)	F: 552	F: 1,310	F: 122	F: 350	F: 540
Capacity per track (Bytes)	F: N/A	F: 31,700	F: 8192	F: N/A	F: N/A
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	40,640	41,300	14,901	--	40,600
Track density (TPI)	15,875	16,000	15,875	15,875	15,875
Maximum linear density (BPI)	27,600	19,500	11,500	15,875	27,600
Rotational speed (RPM)	429-200	600	1800	400-950	530-200
PERFORMANCE					
Positioner type	Crs: Stepping Motor Fine: Galvonom.	Crs: Voice Coil Fine: Galvonom.	Crs: Stepping Motor Fine: Galvonom.	Crs: Voice Coil Fine: Solenoid	Crs: Voice Coil Fine: Voice Coil
Average positioning time (msec)	190	200	150	170	540
Average rotational delay (msec)	110	50	16.7	60	110
Average access time (msec)	300	250	166.7	230	650
Data transfer rate (KBytes/sec)	176	440	300	212.5	150
FIRST CUSTOMER SHIPMENT	2Q85	2Q84	3Q85	1987	3Q86
U.S. OEM PRICE FOR 100 UNITS	$650	$12,500	$800	--	--
COMMENTS	Has built in ECC. Model CDR 2500 mounts in PC. Price $600.	Price includes controller	Grooveless tracking system I.S.I. will certify media.	Preliminary specification	41 mm high. Operates in horizontal or vertical position.

MANUFACTURER	MATSUSHITA ELECTRIC CO.	MATSUSHITA ELECTRIC CO.	MATSUSHITA GRAPHIC COMMUNICATION	NEC	NIPPON COLUMBIA
DRIVE	SQ-D100	SQ-D101	LD-10	N6329-21 N7911	DRD-550 DRD-551 DRD-552 DRD-553
DISK/TREND GROUP	10	10	11	12	10
MARKET	Captive/OEM	Captive/OEM	Captive/OEM	Captive	OEM
MEDIA: Nominal disk diameter	120 mm	120 mm	200 mm	12"	120 mm
Recording medium	Aluminum	Aluminum	Te-Ox	3M	Aluminum
Track format	Spiral	Spiral	Spiral	Spiral	Spiral
Recording method	Mastering	Mastering	Phase Change	Pit	Mastering
DRIVE: Operating mode	Read Only	Read Only	Write Once	Write Once	Read Only
Interface	SCSI/PC	SCSI/PC	Proprietary	Modified SASI	SASI/SCSI
Speed control	CLV	CLV	CAV	CAV	CLV
CAPACITY/RECORDING DENSITY					
Total capacity (MBytes)	F: 600	F: 540	F: 700	F: 1,016	F: 553
Capacity per track (Bytes)	F: N/A	F: N/A	F: 32,000	F: 32,768	F: N/A
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	41,250	40,600	23,330	31,000	40,640
Track density (TPI)	15,875	15,875	23,333	15,900	15,475
Maximum linear density (BPI)	27,600	27,600	15,394	20,000	26,008
Rotational speed (RPM)	500-250	530-200	900	900	535-194
PERFORMANCE					
Positioner type	Crs: Stepping Motor Fine: Voice Coil	Crs: Voice Coil Fine: Voice Coil	Linear, Voice Coil	Linear, Voice Coil	Linear, Voice Coil
Average positioning time (msec)	295	540	200	270	190
Average rotational delay (msec)	105	110	180	33.3	110
Average access time (msec)	400	650	380	303.3	300
Data transfer rate (KBytes/sec)	153	150	675	785	159
FIRST CUSTOMER SHIPMENT	2Q86	3Q86	4Q85	4Q83	4Q85
U.S. OEM PRICE FOR 100 UNITS	--	--	--	$14,350	--
COMMENTS	Standalone and slot mount versions available.	Free standing with integral power supply		N7921 is drive library unit. 48 disk capac.	DRD 550 & 551 mount in full height slot. DRD 550 & 552 have SCSI interface.

MANUFACTURER	OPTICAL STORAGE INTERNATIONAL	OPTIMEM	OPTOTECH	PHILIPS	PIONEER
DRIVE	LASERDRIVE 1200	1000 1000/S	5984	CM100 CM110	DD-8001
DISK/TREND GROUP	12	12	11	10	11
MARKET	OEM	OEM	OEM	OEM	OEM
MEDIA: Nominal disk diameter	12"	12"	130 mm	120 mm	203 mm
Recording medium	Te Alloy	Au-Pt-Polymer	Te-Se	Aluminum	Dye-polymer
Track format	Spiral	Spiral	Spiral/Concent.	Spiral	Spiral
Recording method	Pit	Bubble	Pit	Mastering	Pit
DRIVE: Operating mode	Write Once	Write Once	Write Once	Read Only	Write Once
Interface	SCSI/ISI	SCSI/SASI/Prop.	SCSI/PC	Prop.	SCSI
Speed control	CAV	CAV	CAV	CLV	CAV
CAPACITY/RECORDING DENSITY					
Total capacity (MBytes)	F: 1,000	F: 1,000	F: 202	F: 600	F: 750
Capacity per track (Bytes)	F: 32,800	F: 25,000	F: 10,752	F: N/A	F: 32,432
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	32,000	40,000	18,826	41,250	23,125
Track density (TPI)	15,875	14,432	15,625	15,875	15,875
Maximum linear density (BPI)	14,111	15,300	14,620	27,600	15,875
Rotational speed (RPM)	480	1121.5	1200	500-200	450
PERFORMANCE					
Positioner type	Linear, Voice Coil	Crs: Voice Coil Fine: Galvonom.	Crs: Stepping Motor Fine: Voice Coil	Rotary Galvonometer	Linear, Voice coil
Average positioning time (msec)	150	150	170	890	184
Average rotational delay (msec)	62.5	27.5	25	110	66
Average access time (msec)	213	177.5	195	1000	250
Data transfer rate (KBytes/sec)	313	475	275	176	308
FIRST CUSTOMER SHIPMENT	3Q83	2Q84	3Q85	1Q85	4Q85
U.S. OEM PRICE FOR 100 UNITS	$8,400	$6,900	$2,300	--	--
COMMENTS	Has direct read after write.	Also uses 3M media in pit forming mode. 1000/S includes host adaptor for PC.		CM110 has SCSI interface.	Recording layer is cyanine dye.

MANUFACTURER	REFERENCE TECHNOLOGY	RICOH	SONY	SONY	SONY
DRIVE	2000	RO-5040WL	CDU-100 CDU-5002	WDD 2000	WDD 3000
DISK/TREND GROUP	10	11	10	11	12
MARKET	OEM	Captive/OEM	OEM	OEM/Captive	OEM/Captive
MEDIA: Nominal disk diameter	12"	130 mm	120 mm	120 mm	12"
Recording medium	Aluminum	Dye-polymer	Aluminum	Se-Sb/Bi-Te	Se-Sb/Bi-Te
Track format	Spiral	Spiral	Spiral	Spiral	Spiral
Recording method	Mastering	Pit	Mastering	Phase change	Phase change
DRIVE: Operating mode	Read Only	Write Once	Read Only	Write Once	Write Once
Interface	SCSI	SCSI	Prop./PC	SCSI/Prop.	SCSI/Prop.
Speed control	CAV	CLV	CLV	CLV	CAV/CLV
CAPACITY/RECORDING DENSITY					
Total capacity (MBytes)	F: 1,000	F: 400	F: 540	F: 500	F:1,100/1,600
Capacity per track (Bytes)	F: 19,600	F: N/A	F: N/A	F: N/A	F: 25,600
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	51,000	37,500	40,640	18,750	43,750
Track density (TPI)	14,896	15.875	15,875	12,700	15,875
Maximum linear density (BPI)	24,000	30,238	27,600	25,391	24,937
Rotational speed (RPM)	1800	668-334	500-200	900-535	720/720-360
PERFORMANCE					
Positioner type	Crs: Voice coil Fine: Galvonom.	Crs: Voice Coil Fine: Voice Coil	Linear, Voice Coil	Linear, Voice Coil	Linear, Voice Coil
Average positioning time (msec)	125	108	665	250	250/620
Average rotational delay (msec)	16.7	60	86	44.7	42/62.5
Average access time (msec)	151	168	750	295	292/682.5
Data transfer rate (KBytes/sec)	1000	300	176	300	300
FIRST CUSTOMER SHIPMENT	4Q84	4Q86	3Q85	4Q84	2Q85
U.S. OEM PRICE FOR 100 UNITS	$8,900	--	$575	$5,300	$7,200
COMMENTS		Preliminary specification Recording layer is methine dye.	CDU-5002 fits full-height PC slot, CDU-100 free-standing: SCSI version available.	Controller is $4000.	Controller is $4000. 50 disk library unit available.

MANUFACTURER PROFILES

1986 DISK/TREND REPORT

MANUFACTURER PROFILES

All manufacturers now producing optical disk drives, or which are expected to enter the market, are listed in this section. DISK/TREND normally estimates the annual volume of disk drive sales by manufacturers. Because no company had a high level of optical disk drive sales in 1985, this figure is not reported explicitly in this year's report. "1985 total net sales" covers the fiscal year ending in 1985 for each firm unless noted otherwise, or for the parent company if the disk drive manufacturer is a subsidiary. The fiscal year of listed firms ends on December 31, 1985, unless otherwise noted.

Exchange rates

The exchange rates used in converting the financial data of non-U.S. manufacturers to dollars are given below. The average exchange rate for 1985 is used, as cited by the Federal Reserve Bulletin and rounded to 3 significant figures.

Country	Currency	Currency units/U.S. dollar
France	Franc	8.98
Japan	Yen	238.00
Netherlands	Guilder	3.32

U.S. Manufacturers

CHEROKEE DATA SYSTEMS
1880 S. Flatiron Court
Boulder, CO 80301

Cherokee was founded in March, 1984. Key founders include managers previously with Storage Technology Corporation and Sperry Corporation. The firm is designing a 300 megabyte ruggedized 5.25" write-once drive that it expects to supply to customers in the defense and mineral resources industries. Shipments are expected to begin in the first quarter of 1987. The first major customer for the Cherokee product appears to be Lockheed Corporation, which announced in April of 1986 that it had invested $2,000,000 in Cherokee and intended to modify the product for potential use in airborne electronic navigation systems for fighter aircraft. Lockheed has estimated its requirements at 1500 units per year, beginning in 1987. Plasmon Data Systems is among the known suppliers of media for the Cherokee product.

DIGITAL EQUIPMENT CORPORATION
146 Main Street
Maynard, MA 01754

1985 total net sales: $6,686,000,000 (FY ending 6/30/85) Net income: $447,000,000

DEC is not actively producing an optical drive at present, but is one of the first major system suppliers to offer the CD-ROM as a system peripheral. The product is based upon a drive supplied by Philips, and is interfaced and supported on the highly successful micro-VAX product line. DEC is also active in groups concerned with setting standards for CD-ROM. A long-time manufacturer of both rigid and floppy magnetic disk drives, DEC is a logical candidate for internal production of its own optical drives at some future time.

EASTMAN KODAK COMPANY
343 State Street
Rochester, NY 14650

1985 total net sales: $10,631,000,000 Net profit: $332,000,000

While not yet in production, Eastman Kodak has acknowledged that it is developing at least two optical disk drives; one a very high capacity write-once optical disk drive and the other a low-end magneto-optical drive. The latter product originated at Verbatim Corporation, acquired by Eastman Kodak in 1985. Neither product is expected to be available before 1987. The write-once, high-end drive will use a 14" diameter format and may employ proprietary dye/polymer media. The product will probably be used in Eastman Kodak's document storage product lines and may also be offered on an OEM or PCM basis as a computer peripheral.

HEWLETT-PACKARD COMPANY
3000 Hanover Street
Palo Alto, CA 94303

1985 total net sales: $6,505,000,000 (FY ending 10/31/85) Net income: $489,000,000

Hewlett-Packard has been examining the possibility of manufacturing an optical disk drive, and is capable of so doing if it chooses. Hewlett-Packard has an disk drive manufacturing operation at Boise, Idaho, established in 1977 and since expanded. The Boise facility was supplemented in mid-1983 with a new $50 million facility in Bristol, England, and by production of 3.5" Winchester drives at Greeley, Colorado. H-P makes disk cartridge, disk pack, and fixed Winchester disk drives at Boise, which is also the firm's development facility for its advanced head and disk technology. The Greeley facility is actively exploring possible opportunities for optical disk drives.

INFORMATION STORAGE, INC.
2768 Janitell Road
Colorado Springs, CO 80906

ISI was started in 1983 by executives from Optical Peripherals Laboratory, the Philips and Control Data joint venture for optical drive development which later became part of Optical Storage International. Among the early investors in ISI were CPT and Tallgrass. Sperry also is a significant investor, and has acquired rights to ISI technology. ISI is supplying drives to Sperry, but Sperry will make its own drives for military applications. The initial ISI product is a 5.25" write-once drive of 122 megabyte capacity, and is aimed at the personal computer and small system peripherals market. Limited production began in the fourth quarter of 1985. A funds shortage in early 1986 required scaling back the size of the company, but ISI was successful in attracting additional investment from local and foreign sources. Single sided media for the ISI drive is being supplied by Sumitomo Chemical. Daicel will supply double sided media. ISI has announced that it is also developing a 400 megabyte, 5.25" write-once drive for delivery at some unspecified time in the future. The ISI customer base includes a number of small system suppliers, but no major firm is known to be purchasing production large volumes as of mid-1986.

INTERNATIONAL BUSINESS MACHINES CORPORATION
Route 22
Armonk, NY 10504

1985 total net sales: $50,065,000,000 Net income: $6,555,000,000

While IBM is known to have an active program underway to develop optical disk drives, the company is believed to be a long way from making any product announcement concerning internally manufactured drives. In May,

1986, IBM demonstrated a CD-ROM subsystem for use with the 5550, the firm's personal computer sold in the Pacific Basin market area. A CD-ROM subsystem for use with the personal computer XT and AT families may appear within the next year. It is expected that these requirements will be filled with outside purchases of OEM CD-ROM drives.

LASERDRIVE LTD.
1101 Space Park Drive
Santa Clara, CA 95054

Laserdrive was founded in 1984 with financial support from Acorn Computer and BSR International. Olivetti also holds about a 25% of ownership. The firm's first product, a 5.25" write-once drive with 400 megabyte capacity, will be formally introduced in 1987. Production of the drive mechanism will be done in Japan under contract. The electronics and final assembly will be done in the U.S., as will the research and engineering functions. Laserdrive is receiving considerable financial and management support from Olivetti, which purchased 80% of Acorn Computer in mid-1985.

OPTICAL STORAGE INTERNATIONAL
Joint venture of N. V. Philips and Control Data
1050 S. Academy Boulevard
Colorado Springs, CO 80910

Formed in April, 1984, OSI is a joint venture of Philips and Control Data. While Philips now holds the majority interest, the organization originally was managed by Control Data. OSI combines two earlier joint ventures, Optical Peripherals Laboratory in Colorado and Optical Media Laboratory in the Netherlands. The entire U.S. operation, at one time split between California and Colorado, was consolidated at the Colorado facility in early 1986. In the spring of 1986, Philips assumed management responsibility for a CDC-Philips joint venture that includes OSI. OSI products currently include a 12" write once drive, with a 5.25" unit in development. Image processing has been the most significant application to date of the firm's products. Media is obtained from an OSI manufacturing operation sharing Philips media manufacturing facilities at Blackburn in the UK.

OPTIMEM
Subsidiary of Cipher Data Products, Inc.
435 Oakmead Parkway
Sunnyvale, CA 94086

1985 total net sales: $169,000,000 Net income: $14,700,000

Optimem began in 1980 as a development program managed by Shugart Associates, at that time the leading manufacturer of small disk drives. Optimem is one of the few U.S. based firms that is shipping a production version of an optical disk drive. 3M and Alcatel Thomson Gigadisc are sources for media. The Optimem product is a 12", 1 gigabyte drive. A

5.25" drive capable of using read-only, write-once or magneto-optical erasable media is being developed in a joint effort with 3M. Production is planned for 1987. The 12" Optimem product has found applications in image processing and in document storage and retrieval systems. In mid-1986, control of Optimem was acquired from Xerox by Cipher Data Products. Xerox retains a 10% minority ownership position.

OPTOTECH,INC.
770 Wooten Road
Colorado Springs, CO 80915

Founded in 1984, Optotech is one of the early suppliers of 5.25 inch, 400 megabyte write-once drives. Initial production began in mid-1986 in Colorado, but Optotech has stated that its eventual plan is to have its drives manufactured offshore. Small systems suppliers and add-on subsystem suppliers will be Optotech's target market. Optotech currently is supplying drives to Miltope, Lancore Technologies, Tallgrass Technologies (also an investor is ISI) and several other small firms. Optotech has expanded its facilities in Colorado in order to accomodate its initial production.

REFERENCE TECHNOLOGY, INC
1832 North 55th Street
Boulder, CO 80301

Reference Technology's products include a 12" read-only unit, but the firm has also begun to remarket the Hitachi CD-ROM. Replication services for media are available through 3M. Reference Technology has entered into marketing agreements with database publishers aimed at providing complete subsystem packages to the ultimate end users. The 12" media used is a video laserdisk which can be used for either data or images. Reference Technology has begun to shift its emphasis more into the area of systyem integration; its product line now includes hardware and software to interface optical disk drives to small systems.

STORAGE TECHNOLOGY CORPORATION
2270 South 88th Street
Louisville, CO 80028

1985 total net sales: $673,000,000 Net profit: ($44,000,000)

Storage Technology is best known as a producer of plug compatible tape and disk drives, but also invested over $100 million in the development of a 4 gigabyte high performance optical drive and media, including $40 million in a limited R&D partnership. The STC development program began in 1981 when STC purchased the Exxon Corporation's Star Systems Division optical disk drive development program. At its height, the optical program employed a staff of over 450 people and occupied a building with 500,000 square feet of space. Losses caused by overexpansion caused the firm to file for Chapter 11 in late 1984. At that time, STC transferred

its media technology to DuPont and negotiated an agreement for DuPont to manufacture media for the STC drive. While the optical program was continued at a reduced scale for another year, continuing financial pressures resulted in termination of the program in late 1985. The company is currently searching for a purchaser for its development work to date and related equipment.

VERBATIM CORPORATION
Subsidiary of Eastman Kodak
323 Soquel Way
Sunnyvale, CA 94086

1985 total net sales: $10,631,000,000 Net profit: $332,000,000

Verbatim is known primarily as a maker of floppy disk media, but has had an active program of erasable optical disk drive development under way since early 1983. Based upon technology developed at Philips, the Verbatim design, a 3.5" magneto-optical erasable drive, was announced in preliminary form at the NCC in 1985. In its final form, the drive is expected to be a low cost, moderately fast drive that will use Kerr effect technology and offer at least 50 megabytes of capacity. Eastman Kodak, which acquired Verbatim in 1985, has continued to support the development of the product at a high level, and has brought in several key employees from its operations in Rochester, NY, to strengthen the program. A non-operating prototype was demonstrated at the 1986 NCC. The drive will be produced by Eastman Kodak; media for the drive will be produced by Verbatim.

Japanese Manufacturers (All fiscal years end in March, 1985, unless otherwise noted.)

FUJITSU, LIMITED
1-6-1, Marunouchi
Chiyoda-ku, Tokyo 100

1985 total net sales: $6,564,118,000 Net income: $374,067,000

Fujitsu is Japan's largest producer of computer systems and also manufactures a wide variety of other electronic equipment. Computer products represent about 70% of Fujitsu's sales. The firm announced a write-once drive for use in document storage systems in 1984. The product is currently marketed only in Japan. In 1986, the company added a similar product for sale in Japan on an OEM basis. The head for the drive was developed in a joint effort with Olympus Optical Company, the industry's leading supplier of optical read/write heads. Media was developed in a joint program with Asahi Chemical. Fujitsu has a very active development program for erasable optical disk drives and media, and has made a technology announcement of erasable media using phase change techniques.

HITACHI, LTD.
6-2, Otemachi 2-chome
Chiyoda-ku, Tokyo 100

1985 total net sales: $21,064,270,000 Net income: $883,038,000

Hitachi is Japan's largest manufacturer of electrical and electronic equipment and the third largest Japanese producer of computer systems, which account for about 10% of sales. It manufactures rigid disk drives and other peripherals as well as processors. Hitachi is one of the earlier entrants in the optical disk drive market. CD-ROM and write-once products are available in the U.S. as well as in Japan. Hitachi's write-once 12" optical disk drive has a capacity of 1.3 gigabyte and began shipping in 1984. The CD-ROM product began shipping in 1985. In early 1986, Sperry announced that the Hitachi write-once optical drive was available as a peripheral device on its mainframes--the first optical drive offered by a mainframe vendor. A 5.25" optical drive family is also under development for probable announcement in 1986. Hitachi also offers an automated library storage unit based upon its 12" write-once drive. Media for the Hitachi drives is made by Hitachi Maxell. Hitachi also has an active program to develop erasable media.

MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.
1006, Kadoma City
Osaka, 571

1984 total net sales: $19,834,270,000 (FY ending 11/30/84) Net profit: $1,001,533,000

MEI's Panasonic, National, Technics, and Quasar brands are among the most widely known in the world for appliances, consumer electronics, and communications equipment. MEI is offering a CD-ROM and has developed an 8" write-once drive that is now manufactured by Matsushita Graphics Communication Systems and used in captive document storage systems. The company also has an active program in erasable optical drives and media, and is noted for its advanced work in erasable phase change media. At the 1986 NCC, the firm displayed working half height CD-ROMS, the first time such a product has been displayed.

MATSUSHITA GRAPHIC COMMUNICATION SYSTEMS
3-8 Shimomeguro 2-chome
Meguro-ku, Tokyo 104

1984 total net sales: $259,020,000 (FY ending 11/30/84) Net profit: $8,920,000

MGCS is best known for facsimile systems, but has, for the past two years, marketed a line of office automation equipment. These include document storage systems using an 8" write-once optical drive developed by MGCS' parent, Matsushita Electric Industrial Company. MCGS manufactures the drive itself for use in the Panafile series of systems.

NEC CORPORATION
5-33-1, Shiba
Minato-ku, Tokyo 108

1985 total net sales: $9,488,970,000 Net profit: $282,088,000

NEC has defined its product area as communications and computers, with computer products accounting for about 30% of annual revenues. The firm has the largest share of the Japanese personal computer market. NEC makes a variety of disk products, including floppy, rigid and optical disk drives. The optical drive is a 1 gigabyte, 12" unit used primarily for NEC captive document storage systems but also sold on an OEM basis. 3M supplies the media for the NEC drive. A fingerprint tracking system using optical storage is sold by NEC and has achieved some success in the U.S. The largest such system installed has 28 NEC optical drives and may be further expanded.

NIPPON COLUMBIA CO, LTD.
4-14-14, Akasaka
Minato-ku, Tokyo 107

1985 total net sales: $329,038,000 Net profit: $1,504,000

Primarily known as a producer of phonograph records, consumer electronics and audio equipment, Nippon Columbia is leveraging its CD audio player experience to gain an entry in the CD-ROM market. The firm's product is unusual in that it can operate in a vertical or horizontal position, affording packaging flexibility to manufacturers of small systems. CD-ROM hardware production in limited quantities began in the fourth quarter of 1985. The company is also developing phase change technology write-once media, but has not yet committed to development of a write-once drive.

PIONEER ELECTRONIC CORPORATION
4-1, Meguro 1-chome
Meguro-ku, Tokyo 153

1985 total net sales: $1,433,109,000 (FY ending 9/30/85) Net profit: ($10,307,000)

Pioneer and Ricoh have had a joint development program on an 8" 750 megabyte optical write-once disk drive, with Ricoh being Pioneer's most significant customer for the product. First shipments began in late 1985, and Pioneer has established a separate division to make and sell the product. Pioneer is also known to be developing a 5.25" write-once drive and has shown media for it at the Japan COMDEX show in early 1986. The media used in the these drives is an unusual dye/polymer type that appears to offer superior resistance to corrosion. The active layer is placed on the PMMA substrate by spin coating, a relatively inexpensive production process. Pioneer's media is the first commercial version of dye/polymer media to be brought to market.

RICOH CO., LTD.
15-1, Minami-Aoyama 1-chome
Minato-ku, Tokyo 107

1985 total net sales: $2,292,151,000 Net profit: $70,420,000

Copiers, photographic equipment, and sensitized papers provide the bulk of Ricoh's revenues, but the firm also produces a growing line of data processing equipment. This product line, which was started in 1979, includes floppy disks and a cartridge-type rigid disk licensed from DMA Systems. Ricoh has been Pioneer's partner in the development of an 8" write-once optical drive which Ricoh uses in a document storage system. Ricoh has indicated its intent to produce its own optical drives at some time in the future, and showed a prototype 8" write-once drive at the 1986 NCC show. However, Ricoh is expected to concentrate upon developing new products in the 5.25" form factor rather than expend significant effort marketing the 8" product.

SONY CORPORATION
6-7-35, Kitashinagawa
Shinagawa-ku, Tokyo 141

1985 total net sales: $21,064,270,000 (FY ending 10/31/85) Net profit: $306,811,000

Sony is well recognized as a leader in consumer electronics and has also earned a position as the major supplier of 3.5 inch floppy disk drives. Sony is fielding a product line of CD-ROM and write-once optical drives, and is actively involved in research on erasable media. The write-once products are available in 8" and 12" sizes. Sony is vertically integrated and supplies its own media. Because of its strong position in the audio CD player market, Sony is expected to be very competitive in the CD-ROM marketplace with products aimed at the personal computer and small systems market. Sony, together with Philips, has been a moving force in establishing standards for CD and CD-ROM devices. Sony's latest CD-ROM products have been modified to conform to the commonly used 5.25" form factor used by floppy and small rigid disk drives, thus making them physically compatible with personal computer packaging. To support its write-once drives, Sony offers an automated library unit, first shown at COMDEX in the fall of 1985.

TOSHIBA CORPORATION
1-1-1, Shibaura
Minato-ku, Tokyo 105

1985 total net sales: $14,045,470,000 Net profit: $361,845,000

Toshiba is a major factor in consumer electric and electronic products, and also has a leading position in the office computer market in Japan. Floppy, rigid, and optical drives all are produced by Toshiba; the firm was one of the first to offer a commercial 12" write-once drive. Toshiba has also made product announcements of CD-ROM and 5.25" write-once optical disk drives, and began shipping samples of its 400 megabyte 5.25" write-once drive in 1986. CD-ROM shipments are expected to begin in mid-1986. Most of Toshiba's write-once optical disk drives have been used in captive document storage systems, but they have also seen use in medical imaging systems.

European Manufacturers

ALCATEL THOMSON GIGADISC
La Boursidiere - R.N. 186
F-92350 Le Plessis Robinson
France

Beginning as the optical disk operation of Thomson-CSF, ATG was formed when the organization was transferred in 1984 to Alcatel, a maker of image processing systems. A major drive and media production facility in Toulouse was brought on-stream in early 1986. ATG was one of the first firms to get into limited production of optical drives, but media shortages have hampered its growth. The new facility is expected to alleviate this problem. Optimem and ATG share technology; the two firms' drives can use the same media. The current product line is based upon 12" write-once products using an unusual media developed by ATG. The drive will also operate with 3M media if properly adjusted. Most of the ATG drives have been used in image processing applications.

OLIVETTI PERIPHERAL EQUIPMENT
Subsidiary of Ing. C. Olivetti & C., S.p.A.
via Torino, 603
10090 S. Bernardo d'Ivrea (Torino)
Italy

1985 total net sales: $2,398,098,000 Net profit: $186,494,000

Under Olivetti's current management, the firm has undertaken numerous changes to modernize the company's product lines and drop out of older lines. The Olivetti Peripheral Equipment organization represented a consolidation of the firm's printer and disk memory activities in 1980. This organization has established production for 5.25" Winchester disk drives at Ivrea, with both captive and OEM markets in mind. The biggest impact on Olivetti's lifestyle during the past few years was purchase of a 25% share in the company by American Telephone and Telegraph, and adoption of an Olivetti-designed personal computer for distribution by AT&T. Production of small disk drives for this program has been underway at Ivrea, resulting in rapid growth in rigid disk drive production. The company bought 80% of Acorn Computer in 1985. Because Acorn had a major ownership position in Laserdrive, Ltd, Olivetti now owns about 25% of Laserdrive. Olivetti has proceeded only to the research stage in terms of its own internal optical drive development, but technology assistance agreements recently concluded with Toshiba may increase the pace of Olivetti activity in the optical drive field.

N.V. PHILIPS
5600 MD Eindhoven
The Netherlands

1985 total net sales: $16,215,793,000 Net income: $335,443,000

The Philips organization has been active for many years in the development of optically based information systems. Initial development work was spun off to joint ventures with Control Data. Other Philips subsidiaries, such as Van Der Heem, continue to produce specialized products. Philips' major digital optical product is the CM-100 CD-ROM, which has the distinction of being the first CD-ROM to be accepted by a major system OEM. Digital Equipment Corporation offers it as a peripheral on its Micro-Vax line. Because Philips is a major producer of consumer electronics equipment, the firm is expected to be a major competitor in the CD-ROM market. Philips, together with Sony, has been instrumental in establishing standards for CD and CD-ROM drives. In 1985, Philips also entered into a joint venture with DuPont to produce optical media of various types in large quantities.

VAN DER HEEM ELECTRONICS
Subsidiary of N. V. Philips
Regulusweg 15
2500 AB The Hague
The Netherlands

1985 total net sales: $16,215,793,000 Net income: $335,443,000

This firm is a division of Hollande Signaalapparaten BV, a subsidiary of N.V. Philips. Products include a ruggedized 12" write-once drive used by certain military organizations in Europe and for other applications where a high resistance to stress is needed. The initial MegaDoc optical storage systems provided by Philips also made use of this firm's products. Production volume is small.