1987 DISK/TREND® REPORT

OPTICAL DISK DRIVES

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FOREWORD

It has been a turbulent twelve months since the publication of last year's report. While optical disk drive revenues are still small, the number of participants has grown significantly, with IBM's entry as a drive reseller adding an element of credibility. Although the industry is immature, with a poorly developed infrastructure, its technological base is now well enough established to allow attention to be directed to manufacturing and marketing issues.

Some aspects of the industry remain unstable or poorly defined. Manufacturers must finally settle upon standards for drives and media. Some supporting software is available, but more is required. Erasable media must be incorporated in product designs and standards. And competitors must make the investment in high efficiency production facilities if they are to withstand competition and promote market growth. It's not an industry for the fainthearted or underfinanced.

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 second year of publication for a separate DISK/TREND report on optical disk drives. 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 again been omitted for this year's report on optical disk drives because the 1986 market was too small 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. However, where erasable drives are becoming a significant forecast segment, they are specifically forecast.

* All Disk/Trend product groups have been renumbered as a result of the consolidation of several groups with small, declining shipments. For optical disk drives, only the group numbers are modified.

* Application tables have been added for each group this year, replacing the distribution channel summary and projections, which readers have told us are less useful to them.

SUMMARY: OPTICAL DISK DRIVES

Industry size

The optical disk drive industry continued to expand in 1986. As in 1985, the growth rate of the industry is high, but total unit shipments are still low. In 1986, 31,700 optical disk drives were shipped for revenues of $203 million. 87.4% of unit shipments were made by non-U.S. manufacturers. In 1990, annual shipments are expected to increase to about 1,248,000 units which will provide revenues of $1,407.2 million. About 48% of the 1990 unit shipments, but only about 16.3% of revenues, will be from CD-ROM read-only drives. About 21% of the 1990 revenues, but only 2.2% of shipments, will be derived from high end read/write drives, because of higher average unit prices.

Non-U.S. manufacturers captured over 92% of 1986 total worldwide revenues for optical disk drives, but the share for U.S. manufacturers is expected to grow, and they will hold about 23% of worldwide revenues in 1990. IBM's sales of optical disk drives are expected to amount to $81.5 million in 1990, about 24.9% of the U.S. total, but only 5.7% of the world total revenue for optical disk drives.

For the next three years, 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. Captive systems produced by non-U.S. manufacturers are forecasted to account for a relatively large fraction, about 80%, of revenue from captive drives in the 1990 worldwide revenue totals.

TABLE 1

CONSOLIDATED WORLDWIDE REVENUES

ALL EXISTING OPTICAL DISK DRIVE GROUPS

REVENUE SUMMARY

	DISK DRIVE REVENUES, BY SHIPMENT DESTINATION ($M)									
	1986 Revenues		Forecast							
			1987		1988		1989		1990	
	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW
U.S. Manufacturers										
IBM Captive	--	--	16.2	17.6	43.7	54.8	49.0	61.7	66.2	81.5
Other U.S. Captive	--	--	--	--	--	.3	6.4	16.1	40.3	47.4
TOTAL U.S. CAPTIVE	--	--	16.2	17.6	43.7	55.1	55.4	77.8	106.5	128.9
PCM	--	--	--	--	--	--	--	--	--	--
OEM	11.6	15.6	31.1	39.4	60.9	85.2	92.9	125.6	144.0	198.0
TOTAL U.S. NON-CAPTIVE	11.6	15.6	31.1	39.4	60.9	85.2	92.9	125.6	144.0	198.0
TOTAL U.S. REVENUES	11.6	15.6	47.3	57.0	104.6	140.3	148.3	203.4	250.5	326.9
Non-U.S. Manufacturers										
Captive	52.0	135.2	73.3	155.2	102.3	202.6	119.7	390.8	142.2	517.6
PCM	--	--	--	--	--	--	--	--	--	--
OEM	31.1	52.2	87.4	137.0	163.6	256.6	257.5	390.9	389.5	562.7
TOTAL NON-U.S. REVENUES	83.1	187.4	160.7	292.2	265.9	459.2	377.2	781.7	531.7	1,080.3
Worldwide Recap										
TOTAL WORLDWIDE REVENUES	94.7	203.0	208.0	349.2	370.5	599.5	525.5	985.1	782.2	1,407.2

Marketing channels

U.S. companies made no captive shipments in 1986, but non-U.S. companies shipments accounted for two thirds of 1986 revenues, about the same as in 1985. The percentage of captive shipments is expected to gradually decay, and in 1990 will be only about 46% of worldwide revenue. 19.9% of 1990 captive revenues will be generated by U.S. manufacturers.

While IBM's introduction of the 3363 write-once drive creates a potential for PCM sales, the lackluster performance and probable short product life of this drive makes development of any PCM market unlikely.

OEM shipments are expected to generate 54.1% of 1990 industry revenues, up from 33.4% in 1986. U.S. manufacturers will improve their 1990 share of OEM revenues to 26%, up slightly from 23% in 1986, 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.

Revenues are given in this report based on the price of each drive 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. The OEM value of the drive is typically 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	1986 Revenues $M	1986 Revenues %	Forecast 1987 $M	1987 %	1988 $M	1988 %	1989 $M	1989 %	1990 $M	1990 %
U.S. Manufacturers										
IBM Captive	--	--	17.6	5.0%	54.8	9.1%	61.7	6.2%	81.5	5.7%
	--		--		+211.4%		+12.6%		+32.1%	
Other U.S. Captive	--	--	--	--	.3	--	16.1	1.6%	47.4	3.3%
	--		--		--		--		+194.4%	
OEM	15.6	7.6%	39.4	11.2%	85.2	14.2%	125.6	12.7%	198.0	14.0%
	+59.1%		+152.6%		+116.2%		+47.4%		+57.6%	
Total U.S. Manufacturers	15.6	7.6%	57.0	16.2%	140.3	23.3%	203.4	20.5%	326.9	23.0%
	+59.1%		+265.4%		+146.1%		+45.0%		+60.7%	
Non-U.S. Manufacturers										
Captive	135.2	66.6%	155.2	44.4%	202.6	33.7%	390.8	39.6%	517.6	36.7%
	+164.1%		+14.8%		+30.5%		+92.9%		+32.4%	
OEM	52.2	25.8%	137.0	39.4%	256.6	43.0%	390.9	39.9%	562.7	40.3%
	+180.6%		+162.5%		+87.3%		+52.3%		+43.9%	
Total Non-U.S. Manufacturers	187.4	92.4%	292.2	83.8%	459.2	76.7%	781.7	79.5%	1,080.3	77.0%
	+168.4%		+55.9%		+57.2%		+70.2%		+38.2%	
Worldwide Recap										
Captive	135.2	66.6%	172.8	49.5%	257.7	43.0%	468.6	47.6%	646.5	45.9%
	+200.1%		+27.8%		+49.1%		+81.8%		+38.0%	
OEM	67.8	33.4%	176.4	50.5%	341.8	57.0%	516.5	52.4%	760.7	54.1%
	+138.7%		+160.2%		+93.8%		+51.1%		+47.3%	
Total All Manufacturers	203.0	100.0%	349.2	100.0%	599.5	100.0%	985.1	100.0%	1,407.2	100.0%
	+155.0%		+72.0%		+71.7%		+64.3%		+42.8%	

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

Product mix

During the forecast period, read/write drives under one gigabyte should experience the highest growth in revenue due to increases in shipments of erasable drives. The highest revenue growth rates will also be achieved by small read/write drives, followed by read-only drives.

As shown in figure 1, high capacity drives will eventually lose their current status as the leading contributor to revenues, due to a declining percentage of the total units shipped. High capacity drive unit worldwide shipments will drop from 26.4% in 1986 to 2.6% in 1990.

Read-only optical drives shipments will decline from 60% in 1986 to 47.8% in 1990 as a result of the high growth in small erasable drive shipments. The biggest growth in unit shipments will come from read/write drives under one gigabyte, which are expected to increase from 13.6% of unit shipments in 1986 to 49.6% of unit shipments in 1990. Revenue growth for the smaller read/write drives is lower than the growth rate for unit shipments due to declining average prices.

As of mid-1987, there were nine manufacturers with 4.72" read-only drives in the market (up from six last year) and eleven manufacturers of write-once 5.25" drives (also up from six last year). A few of these drives are announced but not yet in production. Nine manufacturers (a decline of one) are offering 12" drives (Eight are write-once and one is read-only), and one manufacturer has made a preliminary announcement of a 3.5" erasable drive. Other, as yet unannounced 3.5" erasable drives are under development. Two manufacturers have made preliminary announcements of 5.25" erasable drives and several others are developing such products. One 14" drive has been announced.

As shown in Table 7, all but one of the 4.72" drive manufacturers and half of the 12" drive manufacturers are Japanese firms, and most of the 5.25" drives are now of non-U.S. origin. Even with new participants in the market, the association of certain drive sizes with specific geographical manufacturing areas has continued. The U.S. firms still concentrate on 5.25" and 3.5" drives, but Japanese and European suppliers are emphasizing 4.72" and 12" drives, as well as 5.25" drives.

Most optical disk drives shipped will use smaller disks -- 3.5", 4.72", and 5.25". The initial volume shipments of read/write drives have been write-once configurations, but after 1988, erasable drives are expected to capture a growing share of unit shipments. For the 8", 12" and 14" diameters, erasability will arrive at a later date, because design difficulties with larger diameter erasable media are yet to be overcome. 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 dominated, but in 1987, the trend to half high models is well under way for read-only optical drives. Read/write optical drives in half-high configurations probably won't be in volume production before 1990. 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" optical drives will use the 41 millimeter package height normally found in most of today's small diameter Winchester drives.

Figure 1
CHANGING PRODUCT MIX
CONSOLIDATED WORLDWIDE REVENUES
OPTICAL DISK DRIVES

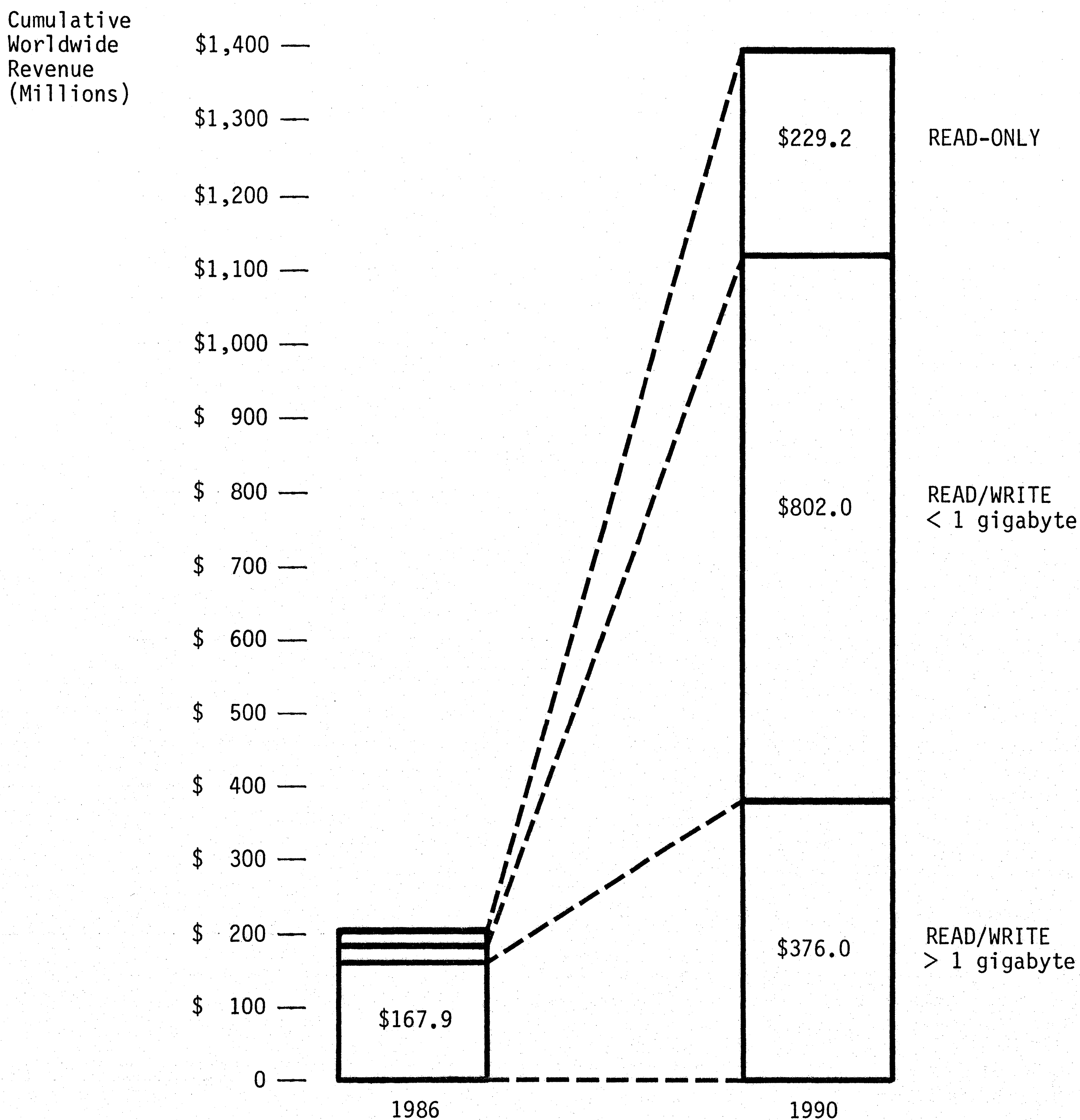

TABLE 3

CONSOLIDATED WORLDWIDE REVENUES
OPTICAL DISK DRIVES
PRODUCT CATEGORY REVIEW

REVENUE SUMMARY

WORLDWIDE REVENUES ALL MANUFACTURERS	1986 Revenues $M	1986 Revenues %	Forecast 1987 $M	1987 %	1988 $M	1988 %	1989 $M	1989 %	1990 $M	1990 %
READ-ONLY	13.9 +148.2%	6.8%	26.5 +90.6%	7.6%	64.4 +143.0%	10.7%	142.2 +120.8%	14.4%	229.2 +61.2%	16.3%
READ/WRITE less than 1 Gigabyte	21.2 +265.5%	10.4%	99.3 +368.4%	28.4%	243.5 +145.2%	40.6%	493.8 +102.8%	50.2%	802.0 +62.4%	57.1%
READ/WRITE more than 1 Gigabyte	167.9 +146.2%	82.8%	223.4 +33.1%	64.0%	291.6 +30.5%	48.6%	349.1 +19.7%	35.4%	376.0 +7.7%	26.6%
Total Worldwide Revenue	203.0 +155.0%	100.0%	349.2 +72.0%	100.0%	599.5 +71.7%	100.0%	985.1 +64.3%	100.0%	1,407.2 +42.8%	100.0%
% U.S. Mfg.	7.6%		16.3%		23.4%		20.6%		23.2%	

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

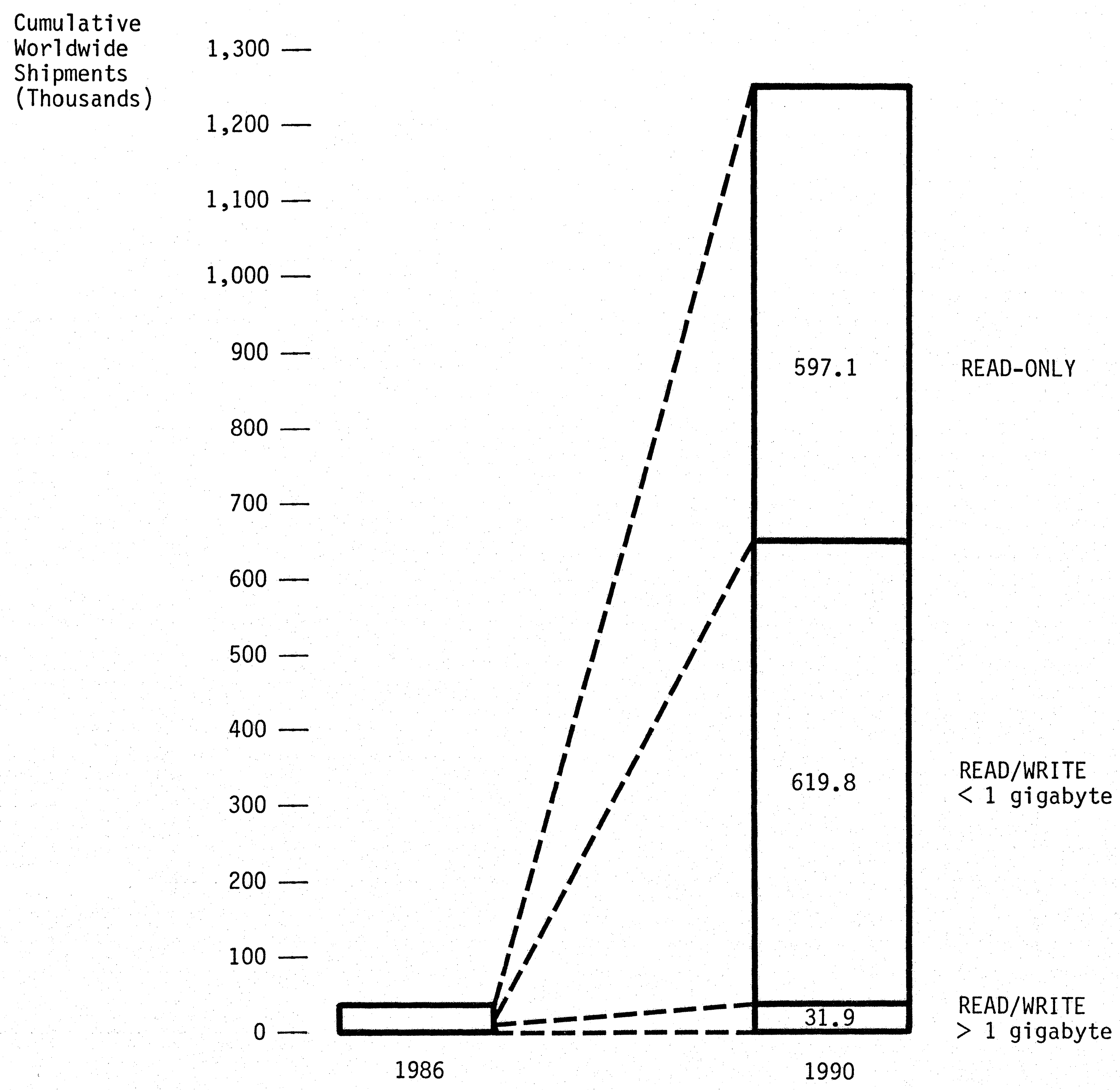

TABLE 4

CONSOLIDATED WORLDWIDE SHIPMENTS
OPTICAL DISK DRIVES
PRODUCT CATEGORY REVIEW

UNIT SHIPMENT SUMMARY

UNIT SHIPMENTS IN THOUSANDS	1986 Shipments Units	1986 Shipments %	Forecast 1987 Units	1987 %	1988 Units	1988 %	1989 Units	1989 %	1990 Units	1990 %
READ-ONLY	19.0	60.0%	49.6	49.8%	137.2	50.7%	334.1	53.8%	597.1	47.8%
	+128.9%		+161.1%		+176.6%		+143.5%		+78.7%	
READ/WRITE less than 1 Gigabyte	4.3	13.6%	36.0	36.1%	112.9	41.7%	259.9	41.8%	619.8	49.6%
	+207.1%		+737.2%		+213.6%		+130.2%		+138.5%	
READ/WRITE more than 1 Gigabyte	8.4	26.4%	14.0	14.1%	20.7	7.6%	27.2	4.4%	31.9	2.6%
	+71.4%		+66.7%		+47.9%		+31.4%		+17.3%	
Total Worldwide Shipments	31.7	100.0%	99.6	100.0%	270.8	100.0%	621.2	100.0%	1,248.8	100.0%
	+117.1%		+214.2%		+171.9%		+129.4%		+101.0%	
% U.S. Mfg.	12.6%		20.5%		23.3%		20.7%		25.6%	

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

OEM market

The pattern of activity in the OEM market follows the same pattern as the general market, with non-U.S. manufacturers capturing the bulk of the shipments. While the U.S. share of OEM worldwide unit shipments is static in the 23% to 26% range, the U.S. share of revenues nearly doubles from 12.6% to 25.6% of worldwide OEM revenues.

Non-U.S. manufacturers dominate the captive market, and it now appears that non-US firms will also capture and retain most of the OEM market for low capacity read/write drives, despite the entry of more U.S. companies to the low capacity segment. The high capacity segment will follow the same pattern; there are more non-U.S. firms in this segment already and they benefit from manufacturing efficiencies gained by 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 engineering experience with optical read-only optical drives.

The OEM market will be volatile, with rapidly evolving products and short product life cycles. Most of the new OEM activity will involve 5.25" and 3.5" disk drives. There will be a significant niche market for write-once drives, but no significant competition for magnetic disk drives until erasable optical drives go into production in 1988. Even then, displacement of magnetic disk drives will be nominal until optical disk drive performance catches up with magnetic disk drives. System OEMs will have great interest in using erasable optical disk drives to replace tape drives, reducing system complexity and improving performance.

TABLE 5

OEM WORLDWIDE REVENUES
OPTICAL DISK DRIVES
PRODUCT CATEGORY REVIEW

REVENUE SUMMARY

WORLDWIDE REVENUES ALL MANUFACTURERS	1986 Revenues $M	1986 Revenues %	Forecast 1987 $M	1987 %	1988 $M	1988 %	1989 $M	1989 %	1990 $M	1990 %
READ-ONLY	13.6	20.1%	26.1	14.8%	63.0	18.4%	128.3	24.8%	204.0	26.8%
	+142.9%		+91.9%		+141.4%		+103.7%		+59.0%	
READ/WRITE less than 1 Gigabyte	11.6	17.1%	65.8	37.4%	159.2	46.7%	240.1	46.6%	393.4	51.8%
	+241.2%		+467.2%		+141.9%		+50.8%		+63.8%	
READ/WRITE more than 1 Gigabyte	42.6	62.8%	84.5	47.8%	119.6	34.9%	148.1	28.6%	163.3	21.4%
	+119.6%		+98.4%		+41.5%		+23.8%		+10.3%	
Total Worldwide Revenues	67.8	100.0%	176.4	100.0%	341.8	100.0%	516.5	100.0%	760.7	100.0%
	+138.7%		+160.2%		+93.8%		+51.1%		+47.3%	
% U.S. Mfg.	23.0%		22.3%		24.9%		24.3%		26.0%	

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 IN THOUSANDS	1986 Shipments Units	1986 Shipments %	Forecast 1987 Units	1987 %	1988 Units	1988 %	1989 Units	1989 %	1990 Units	1990 %
READ-ONLY	18.7	67.6%	49.1	55.8%	135.2	56.2%	311.0	57.6%	551.3	50.1%
	+125.3%		+162.6%		+175.4%		+130.0%		+77.3%	
READ/WRITE less than 1 Gigabyte	3.9	14.1%	28.4	32.2%	89.6	37.1%	207.5	38.4%	526.4	47.7%
	+200.0%		+628.2%		+215.5%		+131.6%		+153.7%	
READ/WRITE more than 1 Gigabyte	5.1	18.3%	10.7	12.0%	16.4	6.7%	21.9	4.0%	25.8	2.2%
	+131.8%		+109.8%		+53.3%		+33.5%		+17.8%	
Total Worldwide Shipments	27.7	100.0%	88.2	100.0%	241.2	100.0%	540.4	100.0%	1,103.5	100.0%
	+134.7%		+218.4%		+173.5%		+124.0%		+104.2%	
% U.S. Mfg.	14.4%		15.8%		17.7%		18.3%		24.3%	

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 (9)	Type	Read-Only Optical Drives	Read/Write Optical Drives <1 GB	Read/Write Optical Drives >1 GB
Cherokee Data Systems	O		5.25	
Eastman Kodak	C,O			14
IBM	C		5.25	
Information Storage, Inc.	O		5.25	
Maximum Storage	O		5.25	
Optimem	O			12
Optotech	C		5.25	
Reference Technology, Inc.	O	12		
Verbatim	O		3.5 E	
Japanese Manufacturers (16)				
Fujitsu, Ltd.	C,O			12
Hitachi, Ltd.	C,O	4.72		12
JVC	O	4.72		
Kawatetsu Instruments	O		5.25	
Matsushita Commun. Ind.	O		5.25	
Matsushita Electric	C,O	4.72		
Matsushita Graphics Commun.	C,O		8	
Mitsubishi Electric	C,O		5.25	
NEC	C	4.72		12
Nippon Columbia	O	4.72		
Pioneer Electronic Corp.	O		8	
Ricoh Co., Ltd.	O		5.25	
Sanyo	O	4.72		
Sharp	O		5.25 E	
Sony Corporation	C,O	4.72	8,5.25 E	12
Toshiba Corporation	C,O	4.72	5.25	12
European Manufacturers (3)				
Art Tech Gigadisc	O			12
Laserdrive, Ltd.	O		5.25	
Laser Magnetic Storage	O	4.72		12

Numbers in table are diameters in inches.

TECHNICAL REVIEW

Optical data storage offers new capabilities that can be applied to a variety of storage problems. 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

Most of the currently important technical issues are shared in common among these three technologies, including:

* The need for lower cost, higher power, higher frequency lasers.
* Undemonstrated media performance and stability.
* Excessive media fabrication costs.
* Lack of physical and recording standards for data interchange.
* Requirements for low mass head design for improved performance and cost.
* The need to develop system and application software.
* Limited availability and performance of automated library sub-systems.
* Inadequate standards for packaging and system interfaces.
* Slow or inefficient error detection and correction.

All of these problem areas will see improvements over the next few years. As a result, the capabilities of optical disk drives will improve rapidly. The most significant product trend is the impending availability of erasable drives and media.

Most of the major technology innovations now in use in the magnetic 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, RCA and 3M have been the early leaders in optical technology, although these firms were, with the exception of 3M, slow to commercialize the technology. Philips has led the way in Europe.

Several firms 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 the 5.25" form factor. The probable availability of large quantities of erasable media in 1988 increases the possibility that universal drives may be available in 1988.

Optical disk drive enhancements

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. The use of holographic optical elements to replace many of the heavier glass lenses and supporting structures is being explored by several firms. Pencom International is now in limited production of holographic optical elements.

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. More powerful lasers also permit the use of beam splitting techniques useful in improving tracking and direct read during write operations.

  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 the 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 and at reasonable cost. 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, write-once optical media was generally in short supply. The manufacturing capacity problem has largely been resolved as new facilities have gone into production. Most of the optical disks made to date use complex multi-layer designs and sputtering techniques to deposit the various layers. Manufacturing facilities operated on a pilot scale until 1986, and the manufacturing techniques used have evolved to the point that several manufacturers can make disk media that can withstand the range of temperatures and humidities likely to be experienced without undue media degradation. At present, there is over-capacity among media suppliers in the aggregate. However, because optical disks from different manufacturers are not widely interchangable among drives, media availability is still a concern.

  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 based disks offered for use with the Pioneer and Ricoh 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. While glass substrates are expected to be much more expensive than plastic, a factor discouraging use, their potential for use in new generations of rigid disk drives suggests that economies of scale could develop sufficiently to make them attractive for use in optical media. The limitations of plastic for larger diameter disks may encourage the use of glass. Media produced for the LMS 12" drives, for instance, uses glass substrates. In mid 1987, Sharp announced erasable optical disk drives using glass as a substrate material. The Sharp announcement may encourage other firms to adopt glass substrates.

* 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 those favored by Art Tech Gigadisc and Laser Magnetic Storage, use an embedded servo technique for fine tracking. There is considerable controversy as to which approach should be considered the standard approach. The outcome of this conflict is significant, as the two formats are not interchangable in present drive designs.

  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.

  Because of IBM's PS/2 personal computer introduction, there is likely to be increasing emphasis on the 3.5" form factor. This is most likely to impact erasable drives, which might substitute for tape drives in the 3.5" form factor. There is also potential impact on the CD-ROM product area. CD equipment in a 3.5" form factor has been discussed by Sony and other Japanese producers, and while there are no known products in development, IBM's actions may spur more activity.

  Many larger diameter drives are table-top or rack mounted. 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 interest in the 8" form factor seems to be concentrated among producers of standalone document storage systems or industrial systems rather than with small system 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 1988.

* 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 preparation and retrieval is becoming less difficult to locate. 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 Bluefish, recently acquired by Lotus Development Corp., have begun to make such programs available.

* Standards: Physical standards for CD and for CD-ROM were set by Sony and Philips. The High Sierra group effectively established a proposed recording format standard for the industry, and hardware that supports this format will be increasingly common.

  In early 1986, Sony and Philips 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 1988. The announcement of the CD-I specification confused the market, especially the publishing segment, and delayed the release of published materials in the CD-ROM format. CD-I is more likely to appeal to the consumer marketplace than achieve success as a computer peripheral device.

Physical standards for other types of optical drives are not as advanced, and lack of standardization will delay acceptance of optical drives by 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 late 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 1987 of differences regarding the method used for track following. Proponents of the continuous servo format have been unable to reach agreement with supporters of the sampled servo format, and it appears that the impasse will be resolved by issuing two versions of the new standard, therefore perpetuating confusion among the OEMs. IBM's announcement of the 3363 has provided a stimulus for the committee to move more rapidly to a standard lest the committee be pre-empted by user acceptance of the 3363 as an industry de-facto standard. The lackluster performance and relatively low capacity of the IBM drive suggest that while IBM may have set a de facto standard for 200 megabyte drives, there will be no real effect on the content of the ANSI group proposal.

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 Art Tech 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.

Standards for erasable drives and media have been proposed and are now being discussed. These include both 3.5" and 5.25" formats, but are unlikely to be available before 1989.

Recorded media standards permitting media interchange across drives of a given physical format will 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 "jukeboxes", 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. The original libraries were too expensive to be attractive for use with lower capacity optical drives. However, small optical drives are beginning to receive library support and to be offered for use in departmental systems. It is likely that less expensive, lower performance libraries will become available in the future. It is also 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 have been 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 (an Eastman Kodak subsidiary) 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.

  Error correction is a complex process and requires an amount of time that introduces significant delays in data transmission from the drive to the host computer. Overall performance can be greatly improved by efficient on-the-fly error correction implementations. Laserdrive has already developed such a product, and other firms are expected to offer this feature in order to gain competitive advantage.

Optical disk technology and applications

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 and upon the recording format standard proposed by the High Sierra group. 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. Other formats for optical read-only memory (OROM) have also been proposed, notably a 5.25" format, but have aroused little interest.

  While it is possible to use properly designed read-only media with write-once drives, and 3M and other companies have proposed such media in a 5.25" format, 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. Conversely, read-only products other than CD-ROM are unlikely to be of great interest except for a limited number of applications dependent upon drive performance.

  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-1987, there were still relatively few titles available on CD-ROM, and of these, only Microsoft's "Bookshelf" appears to have any prospects for broad acceptance.

  Another significant factor is the need to have a common standard for recording format that allows disks to be interchanged between systems. An ad hoc group of companies has prepared such a standard and submitted it to the appropriate standards committees, where it is now in the final approval process.

* Non-reversible optical disks: The first optical disk recording systems to enter the market are "non-reversible" or "write-once" systems. In 1986, after many years of costly development programs undertaken by several European and Japanese manufacturers, such devices began to move into production status. By early 1987, other major U.S. and Japanese firms such as Eastman Kodak and Mitsubishi had announced 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 drives can provide several gigabytes on a single removable disk. Smaller drives 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 or dye-polymer designs have no metallic films and are expected to be more corrosion resistant than the original generation of metallic films. Other optical media using platinum or tin alloys as the recording layer may also become popular because of their corrosion resistance.

  In broad terms, two kinds of systems will be offered: a) document/image storage, and b) 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 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. 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. As an example, at the 1987 AIIM conference, Eastman Kodak displayed several optical systems designed to supplement or replace microfilm systems used for record management. Similarly, NEC has achieved some success with image storage systems for the law enforcement market in the U.S.

Data storage systems have been late 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 Laser Magnetic Storage, Optotech, Optimem, ISI, Art Tech 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.

To date, image storage applications have created the broadest demand for optical disk drives, perhaps because their slow performance is less critical than would be the case in a classic data storage application. While Storage Technology Corporation was unsuccessful in bringing its high performance 7640 product to market, it did succeed in setting expectations for the functionality of a high-end drive. The STC project has been cancelled and is now up for sale. The next generation of write-once optical drives will offer improved performance, with average access times in the 60-80 millisecond range for 5.25" drives. This improvement should enhance the attractiveness of the optical drive in data storage applications.

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 over six 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. Several major financial institutions have been running trials with optical storage library systems with generally favorable results: Significant installations will be made over the next 12 months.

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. While several approaches offer technical solutions to this problem, all seem to add undesirable complexity and cost or positioning time degradation.

  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. Media stability with time, phase reversal time, and the number of possible write/erase cycles still represent problem areas for erasable phase change technology.

A third technology, potentially the least expensive to manufacture, is erasable dye or 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.

Two other interesting, but low probability technologies have commercial possibilities. One is an erasable recording process based upon the micro-deformation of a thin metal film as the result of laser irradiation. When irradiated at a higher power level, the deformed spot assumes its original shape. The films involved are typically Ni-Ti or Cu-Zn-Al alloys. The approach, which is being developed by Optek Corporation, involves shifting the energy level of electrons in a material which holds them in a stable state for long periods in either the high or low energy state. A visible wavelength laser pulse moves an illuminated area to a high energy state. An infra-red laser pulse causes the electrons to revert to the low energy state, emitting light as they do so. The presence or absence of light in response to a read (infra-red) pulse yields a bit of information. The process is infinitely reversible. Neither approach is close to being in a manufacturable status.

Magneto-optical storage, however, is close to being in a manufacturable status. Most of the technical problems have been overcome by 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 and product announcements of drives in 3.5" and 5.25" formats have been made by Verbatim, 3M, Sony and several other Japanese firms. A few of these firms will manufacture magneto-optical drives and media in volume in 1988. Others, including Maxtor, have revealed the existence of development programs. While media and drive producers have concentrated upon magneto-optical recording, phase change technology could follow in a few years if acceptable stability, write/erase cycling 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. Because the cost of even a low end optical drive will substantially exceed that of a low end magnetic drive for some years to come, mass displacement of low end magnetic disk drives by optical disk drives is improbable.

* 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 10 megabyte 5.25" floppy disk drives announced by Eastman Kodak and Konica will develop markets with specialized systems and in the personal computer add-on market. Future products may double capacities to over 20 megabytes. Iomega has already announced a 5.25", 20 megabyte Bernoulli disk drive. Several smaller firms are working on 3.5" floppy drives with capacities in excess of 20 megabytes. But capacities in this range are only the beginning of the potential expansion of floppy drive capabilities. Two other 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 has announced a development project for a 16 megabyte, 3.5" drive based on barium ferrite as the recording material. In addition to Toshiba, Sony and Matsushita Electric have revealed programs to develop 3.5" drives and media using perpendicular recording. 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 the very high capacity floppy 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.

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.

Another advancement of floppy disk technology that is receiving attention from a number of companies is the development of flexible media drives that combine optical and magnetic technologies. Iomega and several other firms have active development programs for such products. Such drives might offer significant low end competition due to favorable drive and media costs, although they may offer less in the way of performance.

* 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. However, it does not currently appear that 3M is providing major support to this development area.

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 and/or performance, 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 Drexler 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.

A new development in the card area in 1986 was an announcement by Optical Recording Corporation, a Canadian firm, of optical card technology capable of storing 200 megabytes in a credit card size format. The recording layer is a metal/dye combination. Development of drives and controllers suitable for use with the card media is yet to be done on a commercial scale.

* <u>Optical tape</u>: 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.

Storage Technology Corp. has introduced an automated tape cartridge library that uses standard IBM 3480 type tape cartridges and can hold up to 6000 tapes. This product appears to be of great interest to many firms. It will not be seriously challenged by optical drive based systems until IBM introduces an anticipated 5.25" erasable disk based library storage system, possibly at the end of the decade.

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 techniques. 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.

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 Laser Magnetic Storage, a joint venture of N. V. Philips and Control Data, LMS drives sold by Philips are considered captive, and LMS 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. and LMS are considered non-U.S. manufacturers, since their majority ownership is non-U.S.

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. Drives currently produced all have one spindle, but future drive configuration may include more than one spindle.

Revenue: Based on sales of disk drives alone, as normally sold by individual manufacturers. Controllers and library units 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 1987 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.

APPLICATION CLASSIFICATION

Shipments of disk drives are analyzed by attachment to the following classes of equipment:

Mainframe/superminicomputer: Large multi-user, general purpose processor or an associated terminal.

Minicomputers/multiple user microcomputers: Includes business and professional uses, including network file servers, that typically serve multiple users. Examples: IBM System/36, DEC PDP-11/44.

Microcomputers: Business and professional computers normally used by a single user. Examples: IBM PS/2 model 60, Apple Macintosh.

Office systems/workstations: Specialized equipment for dedicated use in specific office applications such as word processing or document storage. Examples: Wang OIS series, Toshiba TOSFILE.

Non-office systems/workstations: Specialized equipment for dedicated non-office applications such as design, order processing/shipping, industrial control, military, medical, law enforcement applications.

Consumer and hobby computers: Systems sold primarily to consumers for non-business applications. Examples: Commodore 64, MSX systems, most Atari models (Apple II is considered to be a professional/business microcomputer).

Other applications: Any application not included above.

READ-ONLY OPTICAL DISK DRIVES

READ-ONLY OPTICAL DISK DRIVES

Coverage

Examples of coverage in this group include:

4.72" disk diameter (CD-ROM)

Hitachi	CDR-1503S, 1553S, CDR-2500
JVC	XR-R1001, XR-R100
Laser Magnetic Storage	CM100, CM110, CM200, CM210
Matsushita Electric	SQ-D1, SQ-D100, SQ-D101
NEC	PC-CD101
Nippon Columbia (Denon)	DRD-250, DRD-251, DRD-550, DRD-551
Sanyo	ROM2500
Sony	CDU-100, CDU-5002
Toshiba	XM-2000A, XM-2100A, XM-3000B

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), but almost all drives in this category are of the 4.72" CD-ROM type. The CD-ROM has become the dominant product type in this group because manufacturers could leverage off the design, manufacturing and standards infrastructure developed for the very successful CD consumer products. Early CD-ROM product packaging was not consistent with computer industry practice; early products were free standing or top loading types. CD-ROM packaging is now moving rapidly to half height configurations, but the new wave of 3.5" disk drives used in personal computers will extend the life of the stand-alone package.

Market status

19,000 read-only drives were shipped worldwide in 1986, and all but a few were CD-ROM types manufactured by non-U.S. companies. Hitachi, LMS and Sony were the major producers, but Nippon Columbia and Toshiba also began production in 1986. Reference Technology, a U.S. firm, is shipping small quantities of a 12" read-only memory that offers more capacity and faster access times than CD-ROMs. This firm also remarkets the Hitachi CD-ROM.

Digital Equipment Corporation was the first major system manufacturer to offer a CD-ROM as a system peripheral. The LMS 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 as the amount of published material in the CD-ROM format grows. Some, such as IBM, have demonstrated CD-ROMs on their systems but have made no product announcement.

The market for read-only disk drives continues to be 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, a limited but growing number of titles is available. Only Microsoft's 'Bookshelf' seems to have the potential to attract a large business-oriented following. Other titles expected to have wide appeal are in preparation by a number of publishers and are expected to be available after mid-1987.

The preparation of materials for CD-ROM publication can be time consuming and expensive, but systems to help prepare and format CD-ROM publications are becoming available, reducing both expense and risk to the publisher. Facilities for mastering and replicating disks 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. However, the cost of preparing (authoring) the material can be substantial. Some specialized equipment (authoring systems) became available in 1986 to improve the mechanics of the process, but a well designed CD-ROM publication can cost hundreds of thousands of dollars and much time to compose. Replicated disk prices at the OEM level are $4-$5 per disk. From a production cost standpoint, the stage is set for rapid growth, but authoring costs and complexity are a brake on growth.

Marketing trends

Forecasted 1987 worldwide unit shipments of about 49,600 units will rise rapidly to over 597,000 units in 1990. While not gigantic, this market is attracting additional competitors. Sanyo, JVC, and NEC all have recently entered the market. The additional competition, coupled with the nominal size of the market, will tend to depress prices, much as the prices of floppy disk drives 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, remain interested in new export opportunities. CD-ROM drive prices will decline rapidly. Early average OEM prices were in the $600 to $700 range, declining to the $500 range in 1987. The average price will decline to the $300 range in 1990.

The growth rate for CD-ROM sales will level in 1990 as the CD-PROM, a write-once drive also capable of reading the CD-ROM disk goes into production. Most customers will prefer the flexibility of the CD-PROM, even if they don't have a strong need for it over the CD-ROM.

Personal computers and single user workstations will provide the dominant attachment opportunities for CD-ROMs in the next few years. Early sales of CD-ROM optical drives will be generated by system manufacturers (such as DEC, and, possibly, IBM) and publishers or aftermarket subsystem manufacturers offering a package consisting of drive, software, published material and interface. Amdek, for instance, is distributing a package consisting of the Hitachi drive, Microsoft system software and the Microsoft 'Bookshelf' applications package.

As many drives will be offered with an IBM PC interface, retail dealers will easily be able to add CD-ROM drives to PC systems once sufficient database and supporting software products become available. Because the majority of the PC market is in the U.S., and the U.S. is already a large market for specialized databases, CD-ROM sales will also be greatest in the U.S.

The CD-ROM market will be little affected by CD-I, CD-V and other variant CD formats aimed at mass consumer markets. Video capabilities of the type provided by the recently demonstrated RCA DVI video compression chips may expand the applicability of CD-ROM in computer assisted training and education. RCA demonstrated its capabilities in early 1987, but it will probably be at least two years before the chips are in volume production.

Applications

The read-only optical disk drive is best understood as a device that makes possible disk-based electronic publishing. The published content can be of broad general interest, such as a dictionary or atlas, or specific to a company, such as a manual or parts list. Databases currently distributed include Department of Commerce statistics, drug side effects, legal research materials, construction materials catalogs, and selected professional publications. 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.

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.

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.

CD-ROM also has the inherent capability to store and recover digitized images and audio, a characteristic which suggests many applications in the field of technical training, language instruction, and other educational uses. When it becomes available, the DVI chip set developed by RCA Laboratories may remove some of the technical barriers.

Still needed is an inexpensive, easy to use mechanism for transferring images or audio material to a CD-ROM document. Currently available equipment is too expensive to encourage small publishing projects, but inexpensive scanning/editing systems are expected within a year or two.

Currently, read-only drives appear primarily on micro-based systems, including individual personal computers and workstations. In the future, they will also be attached to department level network file servers and to large processors through microcomputer based file servers to provide access to CD-ROM data bases for mainframe and mini-computer use.

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 service personnel, taxi drivers, urban planners, and public utilities. Interest also exists in the U.S. defense community.

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.

* Educational materials for languages, technical training, driver education and other curricula.

* 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.

* Financial industry statistics, such as stock price history, for use by brokers and analysts.

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. The areas receiving the most attention are:

* Integration of audio and video content into CD published materials.
* Standards for file formats, so that disks can be used on any small computing system.
* Average access times, which decreased below 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. Unfortunately, there are several styles of cartridge proposed or in use, which is slowing the standardization effort.
* 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 becoming available.
* Cost reduction programs. Plastic molded lenses, for instance, are replacing ground glass lenses.
* 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 major unresolved standards area pertains to the design of the cartridge used to contain the disk. As of mid 1987, there is no clear industry consensus. The cartridge holds the disk in place within the drive, preventing loss of focus due to vibration, shock, or mounting in other than a horizontal position, and permits 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.

As for other standards issues, the early establishment of the Sony/Philips de facto standard for CD-ROM established a basis for CD-ROM physical disk interchangeability and provided 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, subsequently prepared a proposed recording standard and submitted it in 1986 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 has become the national sponsor of the High Sierra Group proposal. Because the High Sierra Group had broad industry participation, most companies consider its proposal a de facto standard and expect relatively quick approval, with only minor changes by standards bodies. 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. In 1986, most of the drives shipped were not compatible with the full height and half high form factors that have been adopted for 5.25" products. However, many drives now in production are either full height or half high models: Matsushita Electric exhibited a half high CD-ROM at the 1986 NCC conference and other major suppliers subsequently did the same. The introduction of the PS/2 family of personal computers created a de facto standard for 3.5" storage peripherals. There is some possibility of 3.5" CD-ROMs appearing in a few years, but the nominal shipment levels compared to floppy or rigid disk drives will probably force both manufacturers and customers to be satisfied with external packaging for CD-ROMs used with personal computers, since replication prices are based on availability of 4.72" audio CD disk production facilities.

Most CD-ROMs will be offered with SCSI interfaces and host adapters for 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 in at least nine companies in 1987. The form factor will evolve to a half high de facto standard by the end of 1987, but there will be no strong pressure for a 3.5" drive before 1990.

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 $300 by late 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 work-stations, 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 1990.

7. CD-ROM growth will be impacted in 1990 by write-once drives in the CD-ROM form factor. However, no other form of read-only optical memory will seriously challenge CD-ROM before 1991.

8. 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.

9. Automated libraries for CD-ROMs will be required to make CD-ROMs practical peripheral devices for mainframe and minicomputer systems. Such libraries will be available by 1990.

1987 DISK/TREND REPORT

TABLE 8

READ-ONLY OPTICAL DISK DRIVES

REVENUE SUMMARY

	DISK DRIVE REVENUES, BY SHIPMENT DESTINATION ($M)									
	1986 Revenues		Forecast 1987		1988		1989		1990	
	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	--	--	--	--	--	--	--	--	--	--
OEM	.9	.9	.9	.9	.9	.9	.9	.9	--	--
TOTAL U.S. NON-CAPTIVE	.9	.9	.9	.9	.9	.9	.9	.9	--	--
TOTAL U.S. REVENUES	.9	.9	.9	.9	.9	.9	.9	.9	--	--
Non-U.S. Manufacturers										
Captive	--	.3	--	.4	--	1.4	--	13.9	--	25.2
OEM	10.0	12.7	19.4	25.2	45.3	62.1	90.0	127.4	146.6	204.0
TOTAL NON-U.S. REVENUES	10.0	13.0	19.4	25.6	45.3	63.5	90.0	141.3	146.6	229.2
Worldwide Recap										
TOTAL WORLDWIDE REVENUES	10.9	13.9	20.3	26.5	46.2	64.4	90.9	142.2	146.6	229.2
OEM Average Price ($000)	.752	.727	.529	.532	.469	.466	.414	.413	.370	.370

TABLE 9

READ-ONLY OPTICAL DISK DRIVES

UNIT SHIPMENT SUMMARY

	DISK DRIVE UNIT SHIPMENTS, BY SHIPMENT DESTINATION (000)									
	1986 Shipments		Forecast							
			1987		1988		1989		1990	
	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	--	--	--	--	--	--	--	--	--	--
OEM	.1	.1	.1	.1	.1	.1	.1	.1	--	--
TOTAL U.S. NON-CAPTIVE	.1	.1	.1	.1	.1	.1	.1	.1	--	--
TOTAL U.S. SHIPMENTS	.1	.1	.1	.1	.1	.1	.1	.1	--	--
Non-U.S. Manufacturers										
Captive	--	.3	--	.5	--	2.0	--	23.1	--	45.8
OEM	14.4	18.6	38.3	49.0	98.5	135.1	219.6	310.9	396.2	551.3
TOTAL NON-U.S. SHIPMENTS	14.4	18.9	38.3	49.5	98.5	137.1	219.6	334.0	396.2	597.1
Worldwide Recap										
TOTAL WORLDWIDE SHIPMENTS	14.5	19.0	38.4	49.6	98.6	137.2	219.7	334.1	396.2	597.1
Cumulative Shipments										
IBM	--	--	--	--	--	--	--	--	--	--
Non-IBM	21.3	27.0	59.7	76.6	158.3	213.8	378.0	547.9	774.2	1,145.0
WORLDWIDE TOTAL	21.3	27.0	59.7	76.6	158.3	213.8	378.0	547.9	774.2	1,145.0

TABLE 10

READ-ONLY OPTICAL DISK DRIVES

WORLDWIDE REVENUES ($M)

BREAKDOWN BY DISK DIAMETER

	1986 Revenues		Forecast 1987		Forecast 1988		Forecast 1989		Forecast 1990	
	12"	4.72"	12"	4.72"	12"	4.72"	12"	4.72"	12"	4.72"
U.S. MANUFACTURERS										
Captive	--	--	--	--	--	--	--	--	--	--
OEM	.9	--	.9	--	.9	--	.9	--	--	--
TOTAL U.S. REVENUES	.9	--	.9	--	.9	--	.9	--	--	--
NON-U.S. MANUFACTURERS										
Captive	--	.3	--	.4	--	1.4	--	13.9	--	25.2
OEM	--	12.7	--	25.2	--	62.1	--	127.4	--	204.0
TOTAL NON-U.S. REVENUES	--	13.0	--	25.6	--	63.5	--	141.3	--	229.2
WORLDWIDE RECAP										
Captive	--	.3	--	.4	--	1.4	--	13.9	--	25.2
	--	--	--	+33.3%	--	+250.0%	--	+892.9%	--	+81.3%
OEM	.9	12.7	.9	25.2	.9	62.1	.9	127.4	--	204.0
	--	+170.2%	--	+98.4%	--	+146.4%	--	+105.2%	--	+60.1%
Total Revenues	.9	13.0	.9	25.6	.9	63.5	.9	141.3	--	229.2
	--	+176.6%	--	+96.9%	--	+148.0%	--	+122.5%	--	+62.2%
ANNUAL SHARE, BY DIAMETER	6.5%	93.5%	3.4%	96.6%	1.4%	98.6%	.6%	99.4%	--	100.0%

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

TABLE 11

READ-ONLY OPTICAL DISK DRIVES

WORLDWIDE SHIPMENTS (000)

BREAKDOWN BY DISK DIAMETER

	1986 Shipments		Forecast 1987		Forecast 1988		Forecast 1989		Forecast 1990	
	12"	4.72"	12"	4.72"	12"	4.72"	12"	4.72"	12"	4.72"
U.S. MANUFACTURERS										
Captive	--	--	--	--	--	--	--	--	--	--
OEM	.1	--	.1	--	.1	--	.1	--	--	--
TOTAL U.S. SHIPMENTS	.1	--	.1	--	.1	--	.1	--	--	--
NON-U.S. MANUFACTURERS										
Captive	--	.3	--	.5	--	2.0	--	23.1	--	45.8
OEM	--	18.6	--	49.0	--	135.1	--	310.9	--	551.3
TOTAL NON-U.S. SHIPMENTS	--	18.9	--	49.5	--	137.1	--	334.0	--	597.1
WORLDWIDE RECAP										
Captive	--	.3	--	.5	--	2.0	--	23.1	--	45.8
	--	--	--	+66.7%	--	+300.0%	--	--	--	+98.3%
OEM	.1	18.6	.1	49.0	.1	135.1	.1	310.9	--	551.3
	--	+126.8%	--	+163.4%	--	+175.7%	--	+130.1%	--	+77.3%
Total Shipments	.1	18.9	.1	49.5	.1	137.1	.1	334.0	--	597.1
	--	+130.5%	--	+161.9%	--	+177.0%	--	+143.6%	--	+78.8%
ANNUAL SHARE, BY DIAMETER	.5%	99.5%	.2%	99.8%	.1%	99.9%	--	100.0%	--	100.0%

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

TABLE 12

READ-ONLY OPTICAL DISK DRIVES

APPLICATIONS SUMMARY
Percentage of Worldwide Shipments

APPLICATION	1986 Estimate Units (000)	1986 Estimate %	1990 Projection Units (000)	1990 Projection %
MAINFRAME/SUPERMINI General purpose	--	--	26.9	4.5
MINICOMPUTERS AND MULTI-USER MICROS Business and professional, including networks	.1	.3	38.8	6.5
MICROCOMPUTERS Business and professional, single user	13.7	72.2	370.1	62.0
OFFICE SYSTEMS AND WORKSTATIONS Dedicated application	1.8	9.6	59.7	10.0
NON-OFFICE SYSTEMS AND WORKSTATIONS Technical, distribution, medical, other specialized	3.4	17.9	89.6	15.0
CONSUMER AND HOBBY COMPUTERS	--	--	6.0	1.0
OTHER APPLICATIONS	--	--	6.0	1.0
Total	18.9	100.0	597.2	100.0

READ/WRITE OPTICAL DISK DRIVES LESS THAN 1 GIGABYTE

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, Tracker
Fujitsu	M2505B
Hitachi	OD 101-1
IBM	3363
Information Storage Inc.	525WC, HD 525
Kawatetsu Instruments	KL200S
Laserdrive	LD800W
Matsushita Communication Ind.	JU-9400
Maximum Storage	APX-3000
Mitsubishi	MW-113-1
Optotech	5984
Ricoh	RO-5040WL
Sharp	tba (Erasable)
Sony	tba (Erasable)
Toshiba	WM-D050

8" disk diameter

Matsushita Graphic Commun.	PF-10
Pioneer	DD-8001
Sony	WDD-2000

Two types of drives fit into this group: Write Once Read Many, (WORM) and Erasable. 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. When available, the CD-PROM will also fit into this category. The small read/write drives discussed in this section are typically used with small computer systems of the mini and micro class and with many intelligent workstations.

Market status

It's still a thin market for optical disk drives, but IBM's announcement of the 3363, a drive made exclusively for IBM by Matsushita Electric, has given the market some much needed credibility.

1986 unit shipments were 4,300 units, and only ISI and Optotech made significant contributions to production figures. Worldwide revenues amounted to $21.2 million. Optotech began production shipments in mid-1986, and IBM, Cherokee Data Systems and Laserdrive are preparing to ship products in 1987.

In 1987, shipments from IBM and Ricoh are expected to lead a stronger market, but while 1987 will see increased shipment levels of write-once drives, system design-in cycles, software development time, lack of standards, and OEM preferences for erasable storage will postpone high volume shipments in this category until after 1987.

System manufacturers and integrators are beginning to take optical drives seriously. Both IBM and DEC have internal design programs and Unisys has adopted the Hitachi 12" drive for mainframe use. While 1987 shipments to integrators will be modest, the system design activity occurring in 1987 is expected to result in a shipment upsurge in 1988 and 1989.

The most successful penetration of the system integrator market to date has been achieved throught the combined efforts of Ricoh and Maxtor, which has exclusive rights to market Ricoh OEM optical drives in the U.S. Maxtor's reach into the OEM arena will put Ricoh in the lead for 1987 shipments to OEMs. In the process, Maxtor is receiving an education in the vagaries of the optical drive market place which will serve it well when it begins producing its own planned erasable drives.

Erasable drives are still in a pre-manufacturing 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, although samples should be available from several manufacturers by late 1987.

Marketing trends

Worldwide shipments of disk drives in this group are forecasted to continue at a modest level, with 36,000 units in 1987. By 1990, shipments are expected to exceed 619,800 units. The preponderance of early sales went to the add-on market, distributed through subsystem manufacturers, which provided a market for the 5.25" drives that so far have made up the majority of products in this category. In 1987, this pattern will start to change: Many of the shipments by IBM will reach users already packaged in personal computers, and most of the Ricoh drives sold through Maxtor will go to system manufacturers to be included in complete systems.

The majority of 5.25" drives will be provided by U.S. firms through 1988, but non-U.S. firms will subsequently take the lead. Because initial demand is modest, major Japanese disk drive firms, while developing and announcing 5.25" optical disk drive products, are expected to make relatively small efforts to develop the U.S. market until demand is stronger. Others, such as Ricoh, will rely upon sales arrangements with strong U.S. storage products producers to develop markets. Some 12 to 15 eventual competitors are anticipated. Some Japanese producers have concentrated on 8" drives in the less than 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. Most OEMs prefer the 5.25" form factor, leaving the 8" drive of interest primarily for specialized industrial and office systems.

Japanese firms will also have to contend with new and existing firms based in the U.S., plus unfavorable exchange rates. LMS has 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, such as Laserdrive, which is backed by Olivetti, have substantial financial resources and can be expected to be very effective competitors. Competitors based in the U.S. will be shifting production offshore to remain competitive. Optotech plans to manufacture in Taiwan; IBM and Laserdrive have their drive mechanisms made in Japan.

In 1988, disk drives using erasable media will begin to ship in significant numbers, diverting growth from write-once disk drives, including both 3.5" and 5.25" configurations.

Projected Growth: Write-Once vs. Erasable Drives

Worldwide captive & OEM unit shipments (In thousands)	1988		1989		1990	
	5.25"	3.5"	5.25"	3.5"	5.25"	3.5"
Write-once	81.1	--	124.4	--	129.3	--
Erasable	6.5	18.9	32.5	79.4	142.1	280.8
Total Read/Write	87.6	18.9	156.9	79.4	271.4	280.8

The large forecasted growth in 3.5" erasable drive shipments will result from an expected displacement of cartridge tape drives used with small systems for backup and save/restore applications. By 1990, 5.25" write-once drive growth will also flatten as a result of competition from both 5.25" and 3.5" erasable drives. 5.25" write-once drive shipments will also be hurt by competition from CD-PROM shipments in 1990.

Before 1990, it is unlikely that IBM will be in internal production of any optical disk drive. However, IBM's announcement of the 3363 places it in the market as a major competitor, even though the drive mechanism is produced for IBM by Matsushita Electric. IBM is expected to introduce a small erasable optical disk drive of its own manufacture 3-5 years in the future. This drive will probably be offered as an adjunct to IBM's personal computers and advanced technical workstations, and also as the key element in a mass storage system. IBM's interim strategy of adopting a purchased mechanism is a low risk opportunity to gain experience in the optical storage marketplace.

The CD-PROM is a proposed 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, it will not offer any significant packaging advantage over 5.25" write-once drives, because the electronics will be sufficiently complex to require a full height package, at least for the initial products. Performance will not match the typical 5.25" drive.

While the anticipated low price of a CD-PROM drive will generate sales, some publishers of data bases, fearing a recurrence of the piracy that has plagued personal computer software publishers, may discourage the development and marketing of a read/write drive in CD-ROM format. Others will welcome it for its capability to update a previously distributed database. Regardless of any perceived disadvantages, the writeable CD-ROM, or CD-PROM as it is sometimes called, will probably be on the market in 1988. Its low price will make it an attractive add-on for small computer users who need to back up or to update large data bases.

Applications

Write-once optical drives under 1 gigabyte have found their first applications as save/restore devices in microcomputer and minicomputer systems where interchange isn't required, but are used primarily as a method for storing images in office, medical, and other specialized systems. The erasable drives will initially find their primary use as disk backup devices, providing that they are price-competitive with tape cartridge drives. As performance improves to the level of current small Winchester disk drives, they may also begin to displace low end rigid disk drives in situations where removability is an advantage.

In data processing applications, small optical drives will also be used for 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.

8" drives have had some use in Japan, largely for stand-alone document storage systems. While they offer more capacity than the 5.25" drives, their larger form factor and higher price limit usefulness in many applications and it is unlikely that they will be as successful as 5.25" drives.

The 4.72" write-once drives expected in 1988 can serve as a vehicle for software and database distribution as well as for backup, providing that the cost of the drive and media is low. The writeability feature permits timely update of a previously installed database. Furthermore, the ability to write gives the database publisher certain security and anti-piracy options not readily available on read only media, in that individual disks or sections of disks can be serialized or encrypted for use on a specific system or group of systems at a nominal penalty in cost and time.

Departmental level systems for document storage or image storage will use the lower capacity higher performance read/write drives. It is likely that departmental 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 drive prices decline below $500 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 erasable optical disk offering 30-60 megabytes of capacity at an end user media price approximating $50 might be very competitive against tape cartridge 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 capability 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 for tape cartridge media.

Small erasable disk drives will find significant use as system disks in low end applications when average access times and data transfer rates of these small drives are competitive with those of rigid magnetic disk drives offering equivalent capacity. 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. However, drive prices will have to be competitive with magnetic disk drives if optical drives are to be successful in this application.

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 as well as 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 updatable 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.

Recording technology: A variety of optical recording technologies and media fabrication processes are in use, creating interchange problems and OEM confusion. At present, pit forming or bubble forming writing methods are in the majority, but writing using the phase change between amorphous and crystalline states to vary reflectivity at a spot may become more common. IBM, Sony, Fujitsu and Matsushita are currently using phase change recording. Write-once dye based media are being used by Eastman Kodak, Pioneer and Ricoh. In general, these are not interchangeable.

Interchangeable media designs will eventually evolve. The creation of interchange standards will promote market acceptance and media producers will be able to produce media usable on a variety of drive designs. The surviving designs will be those with low manufacturing cost solutions.

Because it is easier to make small diameter erasable media with acceptable stability and yield, 3.5" and 5.25" erasable drives will be in production first. Erasable 12" media probably won't be available until after 1990.

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. Because organic recording layers such as dyes seem to have better corrosion resistance than the metal films typicaly used, dye based media is likely to displace the original metal film types over time.

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. But magneto-optical techniques may not be the long range solution. Progress has been made in commercializing erasable phase change and other types of erasable recording even though these technologies are behind magneto-optical in development. 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. Samples of erasable phase change media may become available as early as 1988.

Dye based media may eventually become commercially significant for erasable optical disks. 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 based 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 based erasable media will not be commercially available until 1990 or later. Dye based media's relative immunity to environmental influences enhances its desirability as a low cost solution to the erasability problem.

Substrates: Plastic is the currently preferred material in order to reduce media cost and improve manufacturability. At present, 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.

Glass may be used in some small drives. The material is free of birefringence effects that distort the optical path, is non-permeable to moisture, is flat, and distortion free. While mechanically strong, it has not been shown that small cracks or chips caused during drive assembly or cartridge assembly will not propogate when the disk is rotated at high speed, causing eventual disintegration of the disk. More testing needs to be done to convince drive and media makers of adequate safety. Sharp has announced a 5.25" erasable drive using glass substrate media. If successful, other manufacturers are likely to do the same.

Access times: One of the major limitations of optical drives is average access time, which exceeds 100 milliseconds on all products yet announced except for the yet to be produced Cherokee Pathfinder, the recently announced Mitsubishi and Matsuhita Communication Industrial 5.25" drives and the Verbatim/Eastman Kodak 3.5" drive. The first magneto-optical drives will have an additional latency for writing operations caused by the need to erase each 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. Several techniques have been proposed to eliminate the need for an erase pass, and it is likely that future generations of M-O drives will not require a separate erase pass. For 3.5" erasable drives, the latency may be more tolerable than in 5.25" drives, which are slower.

The long access times of today's optical disk drives make them unattractive as competitors for magnetic disks in most system disk drive applications, but are less important when the optical drive is used in an automated library because the fetch times and drive spin-up times are long in comparison to the drive access time.

Manufacturers of smaller drives are targeting access times of under 100 milliseconds for new 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 50-80 millisecond range in 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 may begin to appear in 1989 on small diameter drives.

Optical disk drives rotate at lower speeds than do typical magnetic disk drives, so optical drive latency worsens the performance of optical drives in comparison with magnetic drives. Improvements in media materials, laser power, and tracking and focusing servos should eventually enable optical disk latency to approach magnetic disk latency. The MCI JU-9400, rotating at 2400 RPM, is the first such improved drive to become available.

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. Where media have a high defect density, the error correction process can add substantial latency to data retrieval times. Drives will begin to incorporate more sophisticated ECC circuitry capable of doing on-the-fly error correction in such a short time that ECC latency will not be observed.

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, limiting use to external mounting with most personal computers. Half height designs are planned and may be available in 1989.

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

Track following: Most optical disk drive units make use of a pregrooved substrate surface to establish track location. The desire for minimal media cost and certain performance benefits has resulted in the development of drives capable of using grooveless media and a sector servo approach, even though the drive will be more expensive. Because the approaches are fundamentally incompatible, universal interchangeability will not be achieved.

Standards: There are not yet any final 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 1988. Drafts of standards for 5.25" and 3.5" erasable media are currently in preparation. There appear to be fewer conflicting approaches for these than was the case for the write-once media, so generation of standards may occur by mid 1989.

It is unlikely that there will be early standardization of the 200 and 300 millimeter media size due to the variety of existing designs already in production. The appearance of IBM in the market will create a de facto standard for the 200 megabyte drive. However, most drive designs are moving beyond this capacity to the 300-500 megabyte range and will feel little impact. A side effect of the IBM introduction will be to galvanize the standards committees into faster action, lest the optical drive standards effort be pre-empted by IBM.

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.

* File management functions in the computer operating system must be modified so that the optical disk appears to the operating system to be identical to a magnetic disk drive.

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 have delayed high volume shipments of optical drives.

Forecasting assumptions

1. IBM will announce an internally manufactured erasable 5.25" drive, with shipments starting in early 1990. IBM write-once drive shipments beginning in late 1987 will increase through 1989, then decline as IBM's erasable drives start to become available.

2. Erasable media will be available in production quantities in 1988. Volume production will begin in mid-1988. Erasable drive shipments will have competition from high capacity floppy disk drives targeted at the tape replacement market.

3. Japanese 5.25" drives will become generally available on an OEM basis in 1987, but U.S. producers of 3.5" and 5.25" drives will lead in 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 and non-U.S. production will equal U.S. production in 1990.

4. Most write-once media interchange specifications will be standardized by mid-1988. Erasable media specifications will be standardized by late 1989.

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

6. 4.72" read/write drives will be in production by late 1988, but the number of producers will be limited at first. Shipments will also be impacted in 1990 and after by erasable optical drive shipments.

7. There will be no flexible substrate optical disk drive in production prior to 1991.

TABLE 13

READ/WRITE OPTICAL DISK DRIVES, LESS THAN 1 GIGABYTE

REVENUE SUMMARY

	DISK DRIVE REVENUES, BY SHIPMENT DESTINATION ($M)									
	1986 Revenues		Forecast 1987		1988		1989		1990	
	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW
U.S. Manufacturers										
IBM Captive	--	--	16.2	17.6	43.7	54.8	49.0	61.7	66.2	81.5
Other U.S. Captive	--	--	--	--	--	.3	2.8	8.9	30.4	34.2
TOTAL U.S. CAPTIVE	--	--	16.2	17.6	43.7	55.1	51.8	70.6	96.6	115.7
OEM	3.9	6.2	18.1	24.0	46.2	60.2	70.0	90.1	118.5	155.5
TOTAL U.S. NON-CAPTIVE	3.9	6.2	18.1	24.0	46.2	60.2	70.0	90.1	118.5	155.5
TOTAL U.S. REVENUES	3.9	6.2	34.3	41.6	89.9	115.3	121.8	160.7	215.1	271.2
Non-U.S. Manufacturers										
Captive	--	9.6	3.6	15.9	6.3	29.2	9.5	183.1	30.2	292.9
OEM	1.4	5.4	21.9	41.8	57.0	99.0	93.3	150.0	165.5	237.9
TOTAL NON-U.S. REVENUES	1.4	15.0	25.5	57.7	63.3	128.2	102.8	333.1	195.7	530.8
Worldwide Recap										
TOTAL WORLDWIDE REVENUES	5.3	21.2	59.8	99.3	153.2	243.5	224.6	493.8	410.8	802.0
OEM Average Price ($000)	2.524	2.974	2.174	2.317	1.678	1.777	1.091	1.157	.726	.747

TABLE 14

READ/WRITE OPTICAL DISK DRIVES, LESS THAN 1 GIGABYTE

UNIT SHIPMENT SUMMARY

	DISK DRIVE UNIT SHIPMENTS, BY SHIPMENT DESTINATION (000)									
	1986		Forecast							
	Shipments		1987		1988		1989		1990	
	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW
U.S. Manufacturers										
IBM Captive	--	--	6.0	6.5	16.2	20.3	20.4	25.7	26.7	33.0
Other U.S. Captive	--	--	--	--	--	.1	1.1	4.0	16.0	18.0
TOTAL U.S. CAPTIVE	--	--	6.0	6.5	16.2	20.4	21.5	29.7	42.7	51.0
OEM	1.8	2.9	8.9	12.4	31.5	39.9	76.1	94.9	204.8	262.8
TOTAL U.S. NON-CAPTIVE	1.8	2.9	8.9	12.4	31.5	39.9	76.1	94.9	204.8	262.8
TOTAL U.S. SHIPMENTS	1.8	2.9	14.9	18.9	47.7	60.3	97.6	124.6	247.5	313.8
Non-U.S. Manufacturers										
Captive	--	.4	.4	1.1	.7	2.9	1.2	22.7	4.3	42.4
OEM	.3	1.0	9.5	16.0	30.0	49.7	73.6	112.6	186.4	263.6
TOTAL NON-U.S. SHIPMENTS	.3	1.4	9.9	17.1	30.7	52.6	74.8	135.3	190.7	306.0
Worldwide Recap										
TOTAL WORLDWIDE SHIPMENTS	2.1	4.3	24.8	36.0	78.4	112.9	172.4	259.9	438.2	619.8
Cumulative Shipments										
IBM	--	--	6.0	6.5	22.2	26.8	42.6	52.5	69.3	85.5
Non-IBM	2.9	5.7	21.7	35.2	83.9	127.8	235.9	362.0	647.4	948.8
WORLDWIDE TOTAL	2.9	5.7	27.7	41.7	106.1	154.6	278.5	414.5	716.7	1,034.3

TABLE 15

READ/WRITE OPTICAL DISK DRIVES, LESS THAN 1 GIGABYTE

WORLDWIDE REVENUES ($M)

BREAKDOWN BY DISK DIAMETER

	1986 Revenues		Forecast 1987		Forecast 1988				Forecast 1989				Forecast 1990			
	8"	5.25"	8"	5.25"	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	--	--	--	17.6	--	54.8	--	--	--	61.7	--	--	--	81.5	--	--
Other U.S. Captive	--	--	--	--	--	--	--	.3	--	2.6	--	6.3	--	19.8	--	14.4
OEM	--	6.2	--	24.0	--	51.8	--	8.4	--	67.1	--	23.0	--	86.8	--	68.7
TOTAL U.S. REVENUES	--	6.2	--	41.6	--	106.6	--	8.7	--	131.4	--	29.3	--	188.1	--	83.1
NON-U.S. MANUFACTURERS																
Captive	9.6	--	9.6	6.3	12.0	13.6	--	3.6	12.0	162.1	--	9.0	12.0	262.9	--	18.0
OEM	2.7	2.7	4.5	37.3	4.7	85.6	5.5	3.2	5.9	113.7	19.8	10.6	5.9	165.5	39.6	26.9
TOTAL NON-U.S. REVENUES	12.3	2.7	14.1	43.6	16.7	99.2	5.5	6.8	17.9	275.8	19.8	19.6	17.9	428.4	39.6	44.9
WORLDWIDE RECAP																
Captive	9.6	--	9.6	23.9	12.0	68.4	--	3.9	12.0	226.4	--	15.3	12.0	364.2	--	32.4
	+300.0%	--	--	--	+25.0%	+186.2%	--	--	--	+231.0%	--	+292.3%	--	+60.9%	--	+111.8%
OEM	2.7	8.9	4.5	61.3	4.7	137.4	5.5	11.6	5.9	180.8	19.8	33.6	5.9	252.3	39.6	95.6
	+125.0%	+584.6%	+66.7%	+588.8%	+4.4%	+124.1%	--	--	+25.5%	+31.6%	+260.0%	+189.7%	--	+39.5%	+100.0%	+184.5%
Total Revenues	12.3	8.9	14.1	85.2	16.7	205.8	5.5	15.5	17.9	407.2	19.8	48.9	17.9	616.5	39.6	128.0
	+241.7%	+584.6%	+14.6%	+857.3%	+18.4%	+141.5%	--	--	+7.2%	+97.9%	+260.0%	+215.5%	--	+51.4%	+100.0%	+161.8%
ANNUAL SHARE, BY DIAMETER	58.1%	41.9%	14.2%	85.8%	6.9%	84.6%	2.3%	6.2%	3.6%	82.6%	4.0%	9.8%	2.2%	77.0%	4.9%	15.9%

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

TABLE 16

READ/WRITE OPTICAL DISK DRIVES, LESS THAN 1 GIGABYTE

WORLDWIDE SHIPMENTS (000)

BREAKDOWN BY DISK DIAMETER

	1986 Shipments		Forecast 1987		Forecast 1988				Forecast 1989				Forecast 1990			
	8"	5.25"	8"	5.25"	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	--	--	--	6.5	--	20.3	--	--	--	25.7	--	--	--	33.0	--	--
Other U.S. Captive	--	--	--	--	--	--	--	.1	--	1.0	--	3.0	--	9.0	--	9.0
OEM	--	2.9	--	12.4	--	25.9	--	14.0	--	43.9	--	51.0	--	71.8	--	191.0
TOTAL U.S. SHIPMENTS	--	2.9	--	18.9	--	46.2	--	14.1	--	70.6	--	54.0	--	113.8	--	200.0
NON-U.S. MANUFACTURERS																
Captive	.4	--	.4	.7	.5	1.5	--	.9	.5	19.3	--	2.9	.5	33.7	--	8.2
OEM	.4	.6	.8	15.2	.9	39.9	5.0	3.9	1.1	67.0	22.0	22.5	1.1	123.9	66.0	72.6
TOTAL NON-U.S. SHIPMENTS	.8	.6	1.2	15.9	1.4	41.4	5.0	4.8	1.6	86.3	22.0	25.4	1.6	157.6	66.0	80.8
WORLDWIDE RECAP																
Captive	.4	--	.4	7.2	.5	21.8	--	1.0	.5	46.0	--	5.9	.5	75.7	--	17.2
	+300.0%	--	--	--	+25.0%	+202.8%	--	--	--	+111.0%	--	+490.0%	--	+64.6%	--	+191.5%
OEM	.4	3.5	.8	27.6	.9	65.8	5.0	17.9	1.1	110.9	22.0	73.5	1.1	195.7	66.0	263.6
	+33.3%	+250.0%	+100.0%	+688.6%	+12.5%	+138.4%	--	--	+22.2%	+68.5%	+340.0%	+310.6%	--	+76.5%	+200.0%	+258.6%
Total Shipments	.8	3.5	1.2	34.8	1.4	87.6	5.0	18.9	1.6	156.9	22.0	79.4	1.6	271.4	66.0	280.8
	+100.0%	+250.0%	+50.0%	+894.3%	+16.7%	+151.7%	--	--	+14.3%	+79.1%	+340.0%	+320.1%	--	+73.0%	+200.0%	+253.7%
ANNUAL SHARE, BY DIAMETER	18.6%	81.4%	3.3%	96.7%	1.2%	77.7%	4.4%	16.7%	.6%	60.5%	8.5%	30.4%	.3%	43.9%	10.6%	45.2%

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

TABLE 17

READ/WRITE OPTICAL DISK DRIVES, LESS THAN 1 GIGABYTE

WORLDWIDE SHIPMENTS (000)

ERASABLE/WRITE-ONCE DRIVE ANALYSIS

	1986 --Shipments--		Forecast -----1987----		-----1988----		-----1989----		-----1990----	
	Units	%	Units	%	Units	%	Units	%	Units	%
U.S. MANUFACTURERS										
Captive Total	--		6.5		20.4		29.7		51.0	
Write-Once	--	--	6.5	100.0	20.3	99.6	25.7	86.6	14.9	29.2
Erasable	--	--	--	--	.1	.4	4.0	13.4	36.1	70.8
OEM Total	2.9		12.4		39.9		94.9		262.8	
Write-Once	2.9	100.0	12.4	100.0	25.9	65.0	39.9	42.0	45.8	17.4
Erasable	--	--	--	--	14.0	35.0	55.0	58.0	217.0	82.6
Total U.S.	2.9		18.9		60.3		124.6		313.8	
Write-Once	2.9	100.0	18.9	100.0	46.2	76.7	65.6	52.7	60.7	19.3
Erasable	--	--	--	--	14.1	23.3	59.0	47.3	253.1	80.7
NON-U.S. MANUFACTURERS										
Captive Total	.4		1.1		2.9		22.7		42.4	
Write-Once	.4	100.0	1.1	100.0	1.5	51.8	13.3	58.7	16.2	38.2
Erasable	--	--	--	--	1.4	48.2	9.4	41.3	26.2	61.8
OEM Total	1.0		16.0		49.7		112.6		263.6	
Write-Once	1.0	100.0	16.0	100.0	39.8	80.2	69.1	61.5	120.0	45.5
Erasable	--	--	--	--	9.9	19.8	43.5	38.5	143.6	54.5
Total Non-U.S.	1.4		17.1		52.6		135.3		306.0	
Write-Once	1.4	100.0	17.1	100.0	41.3	78.6	82.4	61.0	136.2	44.5
Erasable	--	--	--	--	11.3	21.4	52.9	39.0	169.8	55.5
WORLDWIDE RECAP										
Total Worldwide Shipments	4.3		36.0		112.9		259.9		619.8	
	+207.1%		+737.2%		+213.6%		+130.2%		+138.4%	
Write-Once	4.3	100.0	36.0	100.0	87.5	77.6	148.0	57.0	196.9	31.8
	+207.1%		+737.2%		+143.0%		+69.1%		+33.0%	
Erasable	--	--	--	--	25.4	22.4	111.9	43.0	422.9	68.2
	--		--		--		+340.5%		+277.9%	

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

TABLE 18

READ/WRITE OPTICAL DISK DRIVES, LESS THAN 1 GIGABYTE

APPLICATIONS SUMMARY
Percentage of Worldwide Shipments

APPLICATION	1986 Estimate Units (000)	1986 Estimate %	1990 Projection Units (000)	1990 Projection %
MAINFRAME/SUPERMINI General purpose	--	--	18.6	3.0
MINICOMPUTERS AND MULTI-USER MICROS Business and professional, including networks	.2	5.2	93.0	15.0
MICROCOMPUTERS Business and professional, single user	.6	14.6	167.2	27.0
OFFICE SYSTEMS AND WORKSTATIONS Dedicated application	1.5	35.5	155.0	25.0
NON-OFFICE SYSTEMS AND WORKSTATIONS Technical, distribution, medical, other specialized	1.9	43.5	136.4	22.0
CONSUMER AND HOBBY COMPUTERS	--	--	18.6	3.0
OTHER APPLICATIONS	.1	1.2	31.0	5.0
Total	4.2	100.0	619.9	100.0

READ/WRITE OPTICAL DISK DRIVES MORE THAN 1 GIGABYTE

READ/WRITE OPTICAL DISK DRIVES, MORE THAN 1 GIGABYTE

Coverage

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

14" disk diameter

Eastman Kodak	6800

12" disk diameter

Art Tech Gigadisc	GD1001
Eastman Kodak	6800
Fujitsu	F6441B1
Hitachi	OD 301-1
NEC	N7911/N6329-21, N6513
Laser Magnetic Storage	Laserdrive 1200
Optimem	1000
Sony	WDD 3000
Toshiba	DF-0450

High capacity optical disk drives are read/write drives, either write-once or erasable. At present, only write-once drives are available in this capacity range. The drives are likely to be used with large mini-computers and mainframes 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 but one of the available drives in this group use 12" media, and all use a single side of a single disk.

8" or 5.25" media may eventually appear in a high capacity drive, but such drives will probably use multiple disks per drive or be capable of accessing both sides of the disk simultaneously.

Market status

Shipments in 1985 were predominantly used in captive systems, but in 1986 OEM drives led with 61% of the 8,400 units shipped worldwide. 1986 revenues were $167.9 million, of which 25% were derived from OEM sales. While still small, this represents healthy growth over the 4,900 units shipped in 1985. As in 1985, most of the units shipped were produced by non-U.S. firms. The shipment leaders in 1986 were Laser Magnetic Storage, Hitachi, and Optimem.

Drives produced by U.S. and European firms were used mostly for specialized image processing applications. Japanese production was used primarily in document storage applications. In 1987, Japanese producers are expected to continue to manufacture the majority of drives in this product group because of suitability for use in systems capable of storing documents produced in Asian character sets. But the market share held by non-Japanese producers is increasing, as optical storage units begin to work their way into on-line retrieval applications in large organizations.

An increasing interest in larger optical drives has been evidenced by government and financial organizations over the last year, and some OEMs are beginning to quote on orders of significant magnitude as prospective customers leave the technology evaluation stage and begin making hard decisions about configurations and suppliers. The endorsement of optical technology by Eastman Kodak and other firms supplying microfilm equipment for records management will also help to expand the available market.

Marketing trends

High capacity optical disk drives will be used primarily on larger systems and in more specialized applications, so shipment growth rates for drives with more than 1 gigabyte capacity will be smaller than for other optical disk drive groups. Worldwide unit shipments are forecasted to increase from 8,400 units in 1986 to 31,900 units in 1990. Revenues are expected to grow to $376 million, 26.6% of the worldwide optical disk drive market. Nearly two thirds of the market is in the U.S. Growth within the forecast period is being slowed by competition from smaller optical disks and the long lead time on software development for use of optical drives in large systems.

Applications will continue to be concentrated in image processing and archiving, where the higher price and lower performance of current products is acceptable. The demand from the record management market is expected to build slowly, with the highest shipments into this segment anticipated after 1990, for reasons discussed in the following section.

Eastman Kodak will be in limited production of a 14" write-once disk drive in 1987. This unit is available to OEMs and will probably be used by Eastman Kodak in its own line of image processing systems on a captive basis in the future. The firm is offering a variety of systems to the records management market using its own and other optical drives. Its product offerings at the AIIM conference in 1987 received a favorable reaction, but the greatest short term interest was concentrated in the smaller systems.

While IBM has an optical disk drive development program underway, no production is anticipated prior to 1990. It is unlikely that IBM will find write-once technology attractive, given the relatively short time until erasable drives are available. The most probable IBM optical drive is a small diameter multi-disk configuration using magneto-optical erasable media, using a library mechanism with capacity per disk less than 1 gigabyte. But IBM usually has multiple development programs, and an 8" or 12" erasable drive is not out of the question despite the technical difficulties involved. An IBM introduction of a large capacity drive, if it occurs within the forecast span of this report, would probably boost shipments of large capacity drives above the projections.

Applications

Image storage, rather than data storage, characterizes most of the applications for larger capacity optical disk drives. The over 1 gigabyte group will be used mostly for records management, medical, geophysical, military or industrial imaging, plus more limited archival storage with mainframes, and to accumulate transaction documents that must be stored for future reference but are not needed for current operations.

Several financial institutions have been experimenting with optical drives for transaction storage applications. These programs are now being expanded. 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. Such applications can be found in industrial, earth resources and defense applications.

Typical 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.

Records management

* Personnel records.
* Tax records and tax rolls.

* X-ray and scanner images.

* Law enforcement records

* 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.

* Insurance claim and policy records

Data acquisition

* Capture of data from scanners, seismic detectors or other imaging devices.

* Capture of data having military or intelligence significance.

The early users of high capacity drives have concentrated on the storage of images, including document filing systems used 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.

In 1986, the largest application area for high capacity optical drives was in dedicated office systems. By 1990, small drives will have displaced the larger drives in most office dedicated uses, but the larger drives will hold their own with technical workstations and multi-user processors in the mini and mainframe class.

The records management market will eventually be a major consumer of high capacity optical disk drives, but this market is likely to experience slow growth due to the conservative nature of the market. Records managers will be reluctant to abandon large investments in existing systems without ample experimentation to convince them that there are no hidden perils in the new technology. In some user organizations, infighting between MIS managers and records managers will further delay purchase decisions.

Finally, prospective buyers must contend with difficulties in obtaining adequate equipment to convert existing film records into a form suitable for optical disk storage, and delays in development of application software. There will also be competition from smaller capacity drives in many system applications; for many companies, it will seem wiser to experiment with a small scale system before making major committments.

Mainframes and minicomputers will become hosts for large optical drives, as they have the capability needed to process or distribute the large amounts of data stored. Tape and microfilm systems currently used in mainframe environments will be partially displaced 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 office automation systems and for most medical systems. Microcomputers with large capacity optical disk drives will also be used for systems that store and manipulate engineering drawings, technical specifications and reference materials. These smaller systems will need to be equipped with smaller library units to meet departmental needs, but most library producers have concentrated on larger capacity subsystems. If the smaller units, with disk storage capacity of 5-10 units are not produced, this segment of the market will eventually be captured by smaller diameter drives used with library units of 10-20 disk capacity.

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. This is of less consequence when the drive is used in a library subsystem, because of the long time required to locate, mount, and spin up the disk to operating speed, compared with the drive average access time. Considerable work is being done by manufacturers to reduce drive 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. While average access time may be less important in automatic library based systems, access times must be dramatically improved if large optical drives are ever to acquire a more general role in data processing systems.

Most of the drives in the more than 1 gigabyte group are in the 12" media diameter class, but 14" diameter media is also represented. The

Eastman Kodak program was mentioned earlier; if Eastman Kodak is successful, other firms will be encouraged to offer similar products.

Standards for very high capacity media will take several years to materialize, because the initial product designs are already established, even though incompatible. The ANSI X3B11 committee, which has the U.S. charter to develop such a standard, has begun deliberations, but does not expect to have 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 of a large capacity drive is unlikely, nor is it clear that any such product would be a large diameter design.

Large drives frequently will 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 with from 10 to over 200 disks available to a single drive in a library. Average retrieval and spinup times will be approximately 1/10 to 1/3 minute. Some libraries will be equipped with multiple drives and automated pickers that can operate independently of each other, minimizing access time.

Other technical issues affecting larger capacity drives are discussed below:

* System design: Most large capacity optical disk storage systems will incorporate an automated library. Several firms, including Cygnet, Filenet, Laser Magnetic Storage, Hitachi and others have designed libraries, discovering in the process that it is a major project, requiring substantial time and investment. To be a generally applicable product, the library may have to accommodate several brands of disk drive, an awkward consideration given the lack of product standardization in the industry. The library unit also has to be interfaced to the computer system with which it is to be used, requiring significant development time.

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

* Packaging: The larger capacity optical disk drives will typically have a rack mount configuration. Because these drives will often be used with library devices, there will be interest in defining a standardized mechanical interface that will 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 are becoming available as 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. Art Tech 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 in the preparation of a standard for 12" optical media. Laser Magnetic Storage also favors a sector servo approach for its future products.

* 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 and power 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.

* Lasers: The larger form factors of the high capacity optical drive favors the use of larger head assemblies carrying multiple lasers. The use of multiple lasers can improve drive performance by permitting direct read during write, higher bit densities, use of unusual active layer material, and possibly other benefits. If head designs that separate the laser from the head optics are adopted to reduce head mass, it may also be possible to use non-semiconductor lasers and still achieve reasonable performance. Because non-semiconductor lasers can operate at higher frequencies and powers, very high performance may be possible by using them in optical storage systems. RCA, for instance, has produced a few specialized systems for the U.S. government using non-semiconductor lasers. However, cost and reliability will have to be traded for performance in such designs.

* 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 expectations of achieving 2800 to 3600 RPM in the future through the use of 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 1990. There are also significant technical problems to be overcome in the fabrication of large diameter erasable media.

  Substrates: Both plastic and glass are in use for 12" media substrates, and Eastman Kodak is using an aluminum substrate for its 14" drive. Because of the difficulty in molding large diameter plastic substrates with adequately low birefringence, it seems likely that glass will play an increasingly prominent role in attempts to fabricate readily producible erasable media for large diameter drives. Producers of glass substrates have demonstrated that glass hardened by ion bombardment has adequate mechanical strength to withstand routine use under projected conditions for future drive designs. However, there is still uncertainty as to the effects of small imperfections such as nicks, scratches or chips caused during handling of the disk.

More work must be done by drive, media, and substrate producers to determine whether such imperfections represent a longer term hazard.

The aluminum substrates being used by Eastman Kodak may be usable for erasable media if erasable dye based media is successfully developed, but the pace of development has been slow and it is unlikely that any practical erasable dye based media will be available within the forecast period of this report.

Forecasting assumptions

1. No IBM-produced units in this category will be shipped until after 1990.
2. Technical difficulties will delay availability of larger diameter erasable media for this product group until after 1989.
3. There will be an adequate supply of write-once media for most products in this group.
4. Generally recognized media interchange standards for this product group will not exist until after 1988.
5. Products in this class will be used primarily with mainframes, large minicomputers, and image 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.
7. There will be no shipments of 5.25" or 8" drives in this product group within the forecast period.

TABLE 19

READ/WRITE OPTICAL DISK DRIVES, MORE THAN 1 GIGABYTE

REVENUE SUMMARY

	DISK DRIVE REVENUES, BY SHIPMENT DESTINATION ($M)									
	1986 Revenues		Forecast 1987		1988		1989		1990	
	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW
U.S. Manufacturers										
IBM Captive	--	--	--	--	--	--	--	--	--	--
Other U.S. Captive	--	--	--	--	--	--	3.6	7.2	9.9	13.2
TOTAL U.S. CAPTIVE	--	--	--	--	--	--	3.6	7.2	9.9	13.2
OEM	6.8	8.5	12.1	14.5	13.8	24.1	22.0	34.6	25.5	42.5
TOTAL U.S. NON-CAPTIVE	6.8	8.5	12.1	14.5	13.8	24.1	22.0	34.6	25.5	42.5
TOTAL U.S. REVENUES	6.8	8.5	12.1	14.5	13.8	24.1	25.6	41.8	35.4	55.7
Non-U.S. Manufacturers										
Captive	52.0	125.3	69.7	138.9	96.0	172.0	110.2	193.8	112.0	199.5
OEM	19.7	34.1	46.1	70.0	61.3	95.5	74.2	113.5	77.4	120.8
TOTAL NON-U.S. REVENUES	71.7	159.4	115.8	208.9	157.3	267.5	184.4	307.3	189.4	320.3
Worldwide Recap										
TOTAL WORLDWIDE REVENUES	78.5	167.9	127.9	223.4	171.1	291.6	210.0	349.1	224.8	376.0
OEM Average Price ($000)	8.2	8.3	8.1	7.8	7.2	7.2	6.7	6.7	6.3	6.3

TABLE 20

READ/WRITE OPTICAL DISK DRIVES, MORE THAN 1 GIGABYTE

UNIT SHIPMENT SUMMARY

	DISK DRIVE UNIT SHIPMENTS, BY SHIPMENT DESTINATION (000)									
	1986 Shipments		Forecast							
			1987		1988		1989		1990	
	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	.3	.4
TOTAL U.S. CAPTIVE	--	--	--	--	--	--	.1	.2	.3	.4
OEM	.8	1.0	1.2	1.5	1.6	2.7	2.7	4.3	3.3	5.5
TOTAL U.S. NON-CAPTIVE	.8	1.0	1.2	1.5	1.6	2.7	2.7	4.3	3.3	5.5
TOTAL U.S. SHIPMENTS	.8	1.0	1.2	1.5	1.6	2.7	2.8	4.5	3.6	5.9
Non-U.S. Manufacturers										
Captive	1.3	3.3	1.7	3.3	2.4	4.3	2.9	5.1	3.2	5.7
OEM	2.4	4.1	5.9	9.2	8.8	13.7	11.5	17.6	13.0	20.3
TOTAL NON-U.S. SHIPMENTS	3.7	7.4	7.6	12.5	11.2	18.0	14.4	22.7	16.2	26.0
Worldwide Recap										
TOTAL WORLDWIDE SHIPMENTS	4.5	8.4	8.8	14.0	12.8	20.7	17.2	27.2	19.8	31.9
Cumulative Shipments										
IBM	--	--	--	--	--	--	--	--	--	--
Non-IBM	6.3	16.1	15.1	30.1	27.9	50.8	45.1	78.0	64.9	109.9
WORLDWIDE TOTAL	6.3	16.1	15.1	30.1	27.9	50.8	45.1	78.0	64.9	109.9

TABLE 21

READ/WRITE OPTICAL DISK DRIVES, MORE THAN 1 GIGABYTE

WORLDWIDE REVENUES ($M)

BREAKDOWN BY DISK DIAMETER

	1986 Revenues		Forecast 1987		1988		1989		1990	
	14"	12"	14"	12"	14"	12"	14"	12"	14"	12"
U.S. MANUFACTURERS										
Captive	--	--	--	--	--	--	7.2	--	13.2	--
OEM	--	8.5	3.3	11.2	6.6	17.5	9.0	25.6	13.5	29.0
TOTAL U.S. REVENUES	--	8.5	3.3	11.2	6.6	17.5	16.2	25.6	26.7	29.0
NON-U.S. MANUFACTURERS										
Captive	--	125.3	--	138.9	--	172.0	--	193.8	--	199.5
OEM	--	34.1	--	70.0	--	95.5	--	113.5	--	120.8
TOTAL NON-U.S. REVENUES	--	159.4	--	208.9	--	267.5	--	307.3	--	320.3
WORLDWIDE RECAP										
Captive	--	125.3	--	138.9	--	172.0	7.2	193.8	13.2	199.5
	--	+146.2%	--	+10.9%	--	+23.8%	--	+12.7%	+83.3%	+2.9%
OEM	--	42.6	3.3	81.2	6.6	113.0	9.0	139.1	13.5	149.8
	--	+120.7%	--	+90.6%	+100.0%	+39.2%	+36.4%	+23.1%	+50.0%	+7.7%
Total Revenues	--	167.9	3.3	220.1	6.6	285.0	16.2	332.9	26.7	349.3
	--	+139.2%	--	+31.1%	+100.0%	+29.5%	+145.5%	+16.8%	+64.8%	+4.9%
ANNUAL SHARE, BY DIAMETER	--	100.0%	1.5%	98.5%	2.3%	97.7%	4.6%	95.4%	7.1%	92.9%

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

TABLE 22

READ/WRITE OPTICAL DISK DRIVES, MORE THAN 1 GIGABYTE

WORLDWIDE SHIPMENTS (000)

BREAKDOWN BY DISK DIAMETER

	1986 Shipments		Forecast 1987		1988		1989		1990	
	14"	12"	14"	12"	14"	12"	14"	12"	14"	12"
U.S. MANUFACTURERS										
Captive	--	--	--	--	--	--	.2	--	.4	--
OEM	--	1.0	.1	1.4	.2	2.5	.3	4.0	.5	5.0
TOTAL U.S. SHIPMENTS	--	1.0	.1	1.4	.2	2.5	.5	4.0	.9	5.0
NON-U.S. MANUFACTURERS										
Captive	--	3.3	--	3.3	--	4.3	--	5.1	--	5.7
OEM	--	4.1	--	9.2	--	13.7	--	17.6	--	20.3
TOTAL NON-U.S. SHIPMENTS	--	7.4	--	12.5	--	18.0	--	22.7	--	26.0
WORLDWIDE RECAP										
Captive	--	3.3	--	3.3	--	4.3	.2	5.1	.4	5.7
	--	+17.9%	--	--	--	+30.3%	--	+18.6%	+100.0%	+11.8%
OEM	--	5.1	.1	10.6	.2	16.2	.3	21.6	.5	25.3
	--	+131.8%	--	+107.8%	+100.0%	+52.8%	+50.0%	+33.3%	+66.7%	+17.1%
Total Shipments	--	8.4	.1	13.9	.2	20.5	.5	26.7	.9	31.0
	--	+68.0%	--	+65.5%	+100.0%	+47.5%	+150.0%	+30.2%	+80.0%	+16.1%
ANNUAL SHARE, BY DIAMETER	--	100.0%	.7%	99.3%	1.0%	99.0%	1.8%	98.2%	2.8%	97.2%

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

TABLE 23

READ/WRITE OPTICAL DISK DRIVES, MORE THAN 1 GIGABYTE

APPLICATIONS SUMMARY
Percentage of Worldwide Shipments

APPLICATION	1986 Estimate Units (000)	1986 Estimate %	1990 Projection Units (000)	1990 Projection %
MAINFRAME/SUPERMINI General purpose	.9	10.5	5.7	18.0
MINICOMPUTERS AND MULTI-USER MICROS Business and professional, including networks	2.2	25.8	8.9	28.0
MICROCOMPUTERS Business and professional, single user	.2	2.3	4.5	14.0
OFFICE SYSTEMS AND WORKSTATIONS Dedicated application	2.8	33.7	3.2	10.0
NON-OFFICE SYSTEMS AND WORKSTATIONS Technical, distribution, medical, other specialized	2.3	27.7	8.0	25.0
CONSUMER AND HOBBY COMPUTERS	--	--	--	--
OTHER APPLICATIONS	--	--	1.6	5.0
Total	8.4	100.0	31.9	100.0

OPTICAL DISK DRIVE SPECIFICATIONS

1987 DISK/TREND REPORT

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. 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 shown. Product specifications and prices given are those in effect at the time of report publication and may be changed 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, and for products announced to date, recorded media is generally not interchangeable between systems.

Interface

Specific interfaces are listed for most of the drives. The abbreviation "PC" means "IBM PC/XT" interface.

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. For CD-ROM drives, the capacity given is the mode 1 capacity as this is the way almost all drives are used.

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 products listed, report users may need to make verbal inquiries of the manufacturers for updates.

1987 DISK/TREND optical disk product groups

For the 1987 report, products are classified in three groups.

Group 9: Read-only optical disk drives.

Group 10: Read/write disk drives, less than 1 gigabyte.

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

MANUFACTURER	ART TECH GIGADISC	CHEROKEE DATA SYSTEMS	CHEROKEE DATA SYSTEMS	EASTMAN KODAK	FUJITSU, LTD.
DRIVE	GD1001	PATHFINDER	TRACKER	6800	M2505B
DISK/TREND GROUP	11	10	10	11	10
MARKET	OEM	OEM	OEM	Captive, OEM	OEM
MEDIA: Nominal disk diameter	12"	130 mm	130 mm	14"	130 mm
Recording medium	Au-Pt-Polymer	TeOx	TeOx	Dye Polymer	Te Alloy
Track format	Spiral	Spiral,concent.	Spiral,concent.	Spiral	Spiral
Recording method	Bubble	Pit	Pit	Pit	Phase Change
DRIVE: Operating mode	Write Once	Write Once	Write Once	Write Once	Write Once
Interface	SCSI/Prop.	ESDI	ESDI	SCSI, IPI-3	ESDI,SCSI
Speed control	CAV	CAV	CAV	CLV	CAV
CAPACITY/RECORDING DENSITY					
Total capacity (MBytes)	F: 1,000	F: 315	F: 260	F: 3,400	F: 300
Capacity per track (Bytes)	F: 25,600	F: 20,754	F: 20,754	N/A	F: 16,325
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	40,000	15,178	14,178	61,600	18,320
Track density (TPI)	14,432	15,000	15,000	14,111	15,875
Maximum linear density (BPI)	14,500	15,000	15,000	21,000	24,924
Rotational speed (RPM)	1121.5	2941	2941	600-1800	1800
PERFORMANCE					
Positioner type	Crs: Voice Coil Fine: Solenoid	Crs: Voice Coil Fine: Solenoid	Crs: Voice Coil Fine: Solenoid	Crs: Linear Fine: Lens Actuator	Crs: Stepping Motor Fine: Lens Actuator
Average positioning time (msec)	200	43	108.4	500 (100*)	100
Average rotational delay (msec)	27	10.3	18.6	27	16.67
Average access time (msec)	227	53.3	127	527	116.67
Data transfer rate (KBytes/sec)	625	1250	1250	1000	693.6
FIRST CUSTOMER SHIPMENT	3Q84	1987	6/87	1987	9/87
U.S. OEM PRICE FOR 100 UNITS	$6,933	--	--	$32,625	--
COMMENTS	Also works with 3M media.	Ruggedized drive.	Ruggedized drive. Early version of Pathfinder.	*within band. $44,100 with controller	

MANUFACTURER	FUJITSU, LTD.	HITACHI, LTD.	HITACHI, LTD.	HITACHI, LTD.	IBM
DRIVE	F6441B1	CDR 1503S CDR 1553S CDR 2500	OD 101-1	OD 301A-1	3363-A01 3363-A11 3363-B01 3363-8700
DISK/TREND GROUP	11	9	10	11	10
MARKET	Captive	Captive/OEM	Captive/OEM	Captive/OEM	Captive
MEDIA: Nominal disk diameter	12"	120 mm	130 mm	300 mm	130 mm
Recording medium	Te Alloy	Aluminum	Te-Se-Pb	Te-Se-Pb	Doped TeOx
Track format	Concentric	Spiral	Spiral	Spiral	Spiral
Recording method	Phase change	Mastering	Pit	Pit	Phase Change
DRIVE: Operating mode	Write Once	Read Only	Write Once	Write Once	Write Once
Interface	Modified 3350	PC/SCSI	SCSI	SCSI/GPIB/SMD	IBM
Speed control	CAV	CLV	CAV	CAV	CAV
CAPACITY/RECORDING DENSITY					
Total capacity (MBytes)	F: 1,376	F: 552	F: 300	F: 1,310	F: 201.36
Capacity per track (Bytes)	F: 30,720	F: N/A	F: 16,400	F: 31,700	F: 11,776
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	44,800	40,640	18,624	41,300	17,100
Track density (TPI)	15,875	15,875	16,000	16,000	15,875
Maximum linear density (BPI)	24,144	27,600	24,000	19,500	21,166
Rotational speed (RPM)	900	535-200	1,800	600	875
PERFORMANCE					
Positioner type	Crs: Voice Coil Fine: Lens Actuator	Crs: Stepping Motor Fine: Galvonom.	Crs: Voice Coil Fine: Galvonom.	Crs: Voice Coil Fine: Galvonom.	Crs: Voice Coil Fine: Galvonom.
Average positioning time (msec)	216.7	190	93	200	230
Average rotational delay (msec)	33.3	110	17	50	34.3
Average access time (msec)	250	300	110	250	274.3
Data transfer rate (KBytes/sec)	783	153.6	690	440	171
FIRST CUSTOMER SHIPMENT	3Q85	2Q85	2Q87	3Q85	2Q87
U.S. OEM PRICE FOR 100 UNITS	N/A	--	$3,000	$5,800	--
COMMENTS	Available only in Japan. F6441A1 has SCSI interface. F6442B2 is 32 disk library.	CDR 1553 has SCSI interface. S models are stand alone.	Price includes controller.	Price includes controller.	Mechanism by Matsushita Electric.

MANUFACTURER	INFORMATION STORAGE INC.	INFORMATION STORAGE INC.	KAWATETSU INSTRUMENTS	LASER MAGNETIC STORAGE	LASER MAGNETIC STORAGE
DRIVE	525 WC	HD 525	KL200S	CM100 CM110	CM201 CM210
DISK/TREND GROUP	10	10	10	9	9
MARKET	OEM	OEM	OEM	OEM	OEM
MEDIA: Nominal disk diameter	130 mm	130 mm	130 mm	120 mm	120 mm
Recording medium	Te Alloy	Te Alloy	Te Alloy	Aluminum	Aluminum
Track format	Concentric	Concentric	Concentric	Spiral	Spiral
Recording method	Pit	Pit	Pit	Mastering	Mastering
DRIVE: Operating mode	Write Once	Write Once	Write Once	Read Only	Read Only
Interface	ESDI/SCSI/PC	ESDI/SCSI/PC	ESDI/SCSI/PC	Prop.	SCSI/PC-XT
Speed control	CAV	CAV	CAV	CLV	CLV
CAPACITY/RECORDING DENSITY					
Total capacity (MBytes)	F: 122	F: 500	F: 122	F: 600	F: 600
Capacity per track (Bytes)	F: 8,192	F: 18,750	F: 8,192	F: N/A	F: N/A
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	14,901	25,000	14,901	41,250	41,250
Track density (TPI)	15,875	26,000	15,875	15,875	15,875
Maximum linear density (BPI)	11,500	22,000	11,500	27,600	27,600
Rotational speed (RPM)	1800	1800	1800	500-200	500-230
PERFORMANCE					
Positioner type	Crs: Stepping Motor Fine: Galvonom.	Crs: Stepping Motor Fine: Galvonom.	Crs: Stepping Motor Fine: Galvonom.	Rotary Galvonometer	Rotary Galvonometer
Average positioning time (msec)	150	150	150	890	415
Average rotational delay (msec)	16.7	16.7	16.7	110	85
Average access time (msec)	166.7	166.7	166.7	1000	500
Data transfer rate (KBytes/sec)	312.5	750	300	153.6	153.6
FIRST CUSTOMER SHIPMENT	3Q85	4Q87	1Q87	1Q85	2Q87
U.S. OEM PRICE FOR 100 UNITS	$800	$1200	--	$540	--
COMMENTS	Grooveless tracking system I.S.I. will certify media.	Preliminary specification. Grooveless tracking system	Grooveless tracking system Licensee of ISI	CM110 has SCSI interface. $650 with controller.	41 mm high CM210 has SCSI interface. Uses cartridge.

MANUFACTURER	LASER MAGNETIC STORAGE	LASERDRIVE LTD.	MATSUSHITA COMMUNICATION INDUSTRIAL CO.	MATSUSHITA ELECTRIC CO.	MATSUSHITA ELECTRIC CO.
DRIVE	LASERDRIVE 1200	LD800W	JU-9400	SQ-D1	SQ-D100
DISK/TREND GROUP	11	10	10	9	9
MARKET	OEM	OEM	OEM	Captive/OEM	Captive/OEM
MEDIA: Nominal disk diameter	12"	130 mm	130 mm	120 mm	120 mm
Recording medium	Te Alloy	Te-C/Te Alloy	Te Alloy	Aluminum	Aluminum
Track format	Spiral	Spiral	Spiral	Spiral	Spiral
Recording method	Pit	Pit	Pit	Mastering	Mastering
DRIVE: Operating mode	Write Once	Write Once	Write Once	Read Only	Read Only
Interface	SCSI/ISI	Prop./SCSI	SCSI	SCSI/PC	SCSI/PC
Speed control	CAV	CLV	CAV	CLV	CLV
CAPACITY/RECORDING DENSITY					
Total capacity (MBytes)	F: 1,000	F: 405	F: 300	F: 540	F: 600
Capacity per track (Bytes)	F: 32,800	F: 21,000 avg.	F: 16,000	F: N/A	F: N/A
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	32,000	18,750	18,598	40,600	41,250
Track density (TPI)	15,875	15,875	15,875	15,875	15,875
Maximum linear density (BPI)	14,111	20,159	24,937	27,600	27,600
Rotational speed (RPM)	480	1114-557	2400	530-200	500-250
PERFORMANCE					
Positioner type	Linear, Voice Coil	Crs: Stepping Motor Fine: Galvonom.	Linear, Voice Coil	Crs: Voice Coil Fine: Voice Coil	Crs: Stepping Motor Fine: Voice Coil
Average positioning time (msec)	150	135	62.5	540	295
Average rotational delay (msec)	62.5	40	12.5	110	105
Average access time (msec)	213	175	75	650	400
Data transfer rate (KBytes/sec)	313	347	925	153.6	153.6
FIRST CUSTOMER SHIPMENT	3Q83	4Q87	2Q87	3Q86	2Q86
U.S. OEM PRICE FOR 100 UNITS	$8,400	$1500	--	--	--
COMMENTS	Has direct read during write.	Real time ECC. $3000 with controller.		41 mm high.	Standalone and slot mount versions available.

MANUFACTURER	MATSUSHITA ELECTRIC CO.	MATSUSHITA GRAPHIC COMMUNICATION	MAXIMUM STORAGE INC.	MITSUBISHI ELECTRIC	NEC
DRIVE	SQ-D101	PF-10 PF-100	APX-3000	MW113-1	PC-CD101
DISK/TREND GROUP	9	10	10	10	9
MARKET	Captive/OEM	Captive/OEM	OEM	OEM	OEM
MEDIA: Nominal disk diameter	120 mm	200 mm	130 mm	130 mm	120 mm
Recording medium	Aluminum	Te-Ox	Te Alloy	Te-Se	Aluminum
Track format	Spiral	Spiral	Concentric	Spiral	Spiral
Recording method	Mastering	Phase Change	Pit	Pit	Mastering
DRIVE: Operating mode	Read Only	Write Once	Write Once	Write Once	Read Only
Interface	SCSI/PC	Proprietary	ESDI/PC	ESDI/SCSI*	Prop/SCSI
Speed control	CLV	CLV	CAV	CAV	CLV
CAPACITY/RECORDING DENSITY					
Total capacity (MBytes)	F: 540	F: 700	F: 122	F: 300	F: 540
Capacity per track (Bytes)	F: N/A	F: 32,000	F: 8,192	F: 15,872	N/A
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	40,600	23,330	14,901	18,750	40,640
Track density (TPI)	15,875	23,333	15,875	15,875	15,875
Maximum linear density (BPI)	27,600	15,394	11,500	24,700	27,600
Rotational speed (RPM)	530-200	900	1800	1800	530-200
PERFORMANCE					
Positioner type	Crs: Voice Coil Fine: Voice Coil	Linear, Voice Coil	Crs: Stepping Motor Fine: Galvonom.	Crs: Linear, Voice Coil Fine: Lens Actuator	Crs: Stepping Motor Fine: Lens Actuator
Average positioning time (msec)	540	200	150	63	500
Average rotational delay (msec)	110	180	16.7	17	85
Average access time (msec)	650	380	166.7	80	585
Data transfer rate (KBytes/sec)	153.6	675	312.5	625	153.6
FIRST CUSTOMER SHIPMENT	3Q86	2Q86	2Q87	3Q87	1Q87
U.S. OEM PRICE FOR 100 UNITS	--	--	--	--	--
COMMENTS	Free standing.	Available in Japan only.	Licensed by ISI	SCSI needs external controller.	Mechanism from Ohme Electric.

MANUFACTURER	NEC	NEC	NIPPON COLUMBIA	NIPPON COLUMBIA	NIPPON COLUMBIA
DRIVE	N6329-21 N7911	N6513	DRD-251 DRD-253	DRD-250 DRD-252	DRD-550 DRD-552 DRD-554
DISK/TREND GROUP	11	11	9	9	9
MARKET	Captive	Captive	OEM	OEM	OEM
MEDIA: Nominal disk diameter	12"	12 "	120 mm	120 mm	120 mm
Recording medium	3M	3M	Aluminum	Aluminum	Aluminum
Track format	Spiral	Spiral	Spiral	Spiral	Spiral
Recording method	Pit	Pit	Mastering	Mastering	Mastering
DRIVE: Operating mode	Write Once	Write Once	Read Only	Read Only	Read Only
Interface	Modified SASI	Modified SASI	SCSI	Proprietary	SASI/SCSI
Speed control	CAV	Zone CLV	CLV	CLV	CLV
CAPACITY/RECORDING DENSITY					
Total capacity (MBytes)	F: 1,016	F: 1,800	F: 553	F: 553	F: 553
Capacity per track (Bytes)	F: 32,768	29,500-56,500	F: N/A	F: N/A	F: N/A
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	31,000	41,000	40,640	40,640	40,640
Track density (TPI)	15,900	15,875	15,475	15,475	15,475
Maximum linear density (BPI)	20,000	20,000	26,008	26,008	26,008
Rotational speed (RPM)	900	600-330	535-194	535-194	535-194
PERFORMANCE					
Positioner type	Linear, Voice Coil	Crs: Voice Coil Fine: Lens Actuator	Linear, Voice Coil	Linear, Voice Coil	Linear, Voice Coil
Average positioning time (msec)	270	650	300	300	190
Average rotational delay (msec)	33.3	50-90	110	110	110
Average access time (msec)	303.3	700-740	410	410	300
Data transfer rate (KBytes/sec)	785	452	153.6	153.6	153.6
FIRST CUSTOMER SHIPMENT	4Q83	1Q87	3Q86	3Q86	4Q85
U.S. OEM PRICE FOR 100 UNITS	$14,350	--	--	--	--
COMMENTS	N7921 is drive library unit. 48 disk capac.		41 mm high. DRD-253 mounts externally.	41 mm high. DRD-252 mounts externally.	DRD 550 mounts in full height slot. DRD-554 has audio output.

MANUFACTURER	NIPPON COLUMBIA	OPTIMEM	OPTOTECH	PIONEER	REFERENCE TECHNOLOGY
DRIVE	DRD-551 DRD-553 DRD-555	1000 1000/S	5984 5984AT	DD-8001	2000
DISK/TREND GROUP	9	11	10	10	9
MARKET	OEM	OEM	OEM	OEM	OEM
MEDIA: Nominal disk diameter	120 mm	12"	130 mm	203 mm	12"
Recording medium	Aluminum	Au-Pt-Polymer	Te-Se	Cyanine Dye	Aluminum
Track format	Spiral	Spiral	Spiral/Concent.	Spiral	Spiral
Recording method	Mastering	Bubble	Pit	Pit	Mastering
DRIVE: Operating mode	Read Only	Write Once	Write Once	Write Once	Read Only
Interface	Proprietary	SCSI/SASI/Prop.	SCSI/PC	SCSI	SCSI
Speed control	CLV	CAV	CAV	CAV	CAV
CAPACITY/RECORDING DENSITY					
Total capacity (MBytes)	F: 553	F: 1,000	F: 202	F: 750	F: 1,000
Capacity per track (Bytes)	F: N/A	F: 25,000	F: 10,752	F: 32,432	F: 19,600
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	40,640	40,000	18,826	23,125	51,000
Track density (TPI)	15,475	14,432	15,625	15,875	14,896
Maximum linear density (BPI)	26,008	15,300	14,620	15,875	24,000
Rotational speed (RPM)	535-194	1121.5	1200	450	1800
PERFORMANCE					
Positioner type	Linear, Voice Coil	Crs: Voice Coil Fine: Galvonom.	Crs: Stepping Motor Fine: Voice Coil	Crs: Voice Coil Fine: Galvonom.	Crs: Voice coil Fine: Galvonom.
Average positioning time (msec)	190	150	170	184	125
Average rotational delay (msec)	110	27.5	25	66	16.7
Average access time (msec)	300	177.5	195	250	151
Data transfer rate (KBytes/sec)	153.6	625	275	308	1000
FIRST CUSTOMER SHIPMENT	4Q85	2Q84	3Q85	4Q85	4Q84
U.S. OEM PRICE FOR 100 UNITS	--	$6,900	$2,300	--	$8,900
COMMENTS	External mount except for DRD-551 DRD-555 has audio output.	Also uses 3M media in pit forming mode. 1000/S includes host adaptor for PC.	AT version mounts in IBM PC/AT.	Sold in Japan only.	

MANUFACTURER	RICOH	SANYO	SANYO	SHARP	SONY
DRIVE	RO-5040WL	ROM2500	SOF8501	Erasable	CDU-100 CDU-5002
DISK/TREND GROUP	10	9	11	10	9
MARKET	Captive/OEM	Captive,OEM	Captive	OEM	OEM
MEDIA: Nominal disk diameter	130 mm	120 mm	300 mm	130 mm	120 mm
Recording medium	Cyanine Dye	Aluminum	Te Alloy	Te-Fe-Co	Aluminum
Track format	Spiral	Spiral	Concentric	Spiral	Spiral
Recording method	Pit	Mastering	Pit	Magneto-Optic	Mastering
DRIVE: Operating mode	Write Once	Read Only	Write Once	Erasable	Read Only
Interface	SCSI	SCSI,IBM	Proprietary	SCSI	Prop./PC
Speed control	CLV	CLV	CAV	CAV	CLV
CAPACITY/RECORDING DENSITY					
Total capacity (MBytes)	F: 400	F: 540	F: 1,000	F: 211	F: 540
Capacity per track (Bytes)	F: N/A	F: N/A	F: N/A	F: N/A	F: N/A
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	37,500	40,640	--	N/A	40,640
Track density (TPI)	15,900	15,875	14,100	15,875	15,875
Maximum linear density (BPI)	32,200	27,600	--	N/A	27,600
Rotational speed (RPM)	668-334	500-200	--	900	500-200
PERFORMANCE					
Positioner type	Crs: Voice Coil Fine: Voice Coil	Crs: Linear Fine: Lens Actuator	Crs: Linear Fine: Galvonom.	Crs: Voice Coil Fine: Lens Actuator	Linear, Voice Coil
Average positioning time (msec)	108	300	--	150	665
Average rotational delay (msec)	60	150	--	33.4	86
Average access time (msec)	168	450	300	183.4	750
Data transfer rate (KBytes/sec)	312.5	153.6	125	150	153.6
FIRST CUSTOMER SHIPMENT	4Q86	7/87	1985	1988	3Q85
U.S. OEM PRICE FOR 100 UNITS	--			--	$575
COMMENTS	SCSI controller included in price. Library unit available.	41 mm high. Internal and external mount.	Available only in Japan.	Preliminary Specification	CDU-5002 fits full-height PC slot, CDU-100 free-standing: SCSI version available.

MANUFACTURER	SONY	SONY	SONY	TOSHIBA CORPORATION	TOSHIBA CORPORATION
DRIVE	Erasable	WDD 2000	WDD 3000	XM-2000A XM-2100A	XM-2100B
DISK/TREND GROUP	10	10	11	9	9
MARKET	OEM	OEM/Captive	OEM/Captive	OEM	OEM
MEDIA: Nominal disk diameter	130 mm	200 mm	12"	120 mm	120 mm
Recording medium	Te-Fe-Co	Se-Sb/Bi-Te	Se-Sb/Bi-Te	Aluminum	Aluminum
Track format	Spiral	Spiral	Spiral	Spiral	Spiral
Recording method	Magneto-Optic	Phase change	Phase change	Mastering	Mastering
DRIVE: Operating mode	Erasable	Write Once	Write Once	Read Only	Read Only
Interface	SCSI	SCSI/Prop.	SCSI/Prop.	SCSI	SCSI
Speed control	CAV	CLV	CAV/CLV	CLV	CLV
CAPACITY/RECORDING DENSITY					
Total capacity (MBytes)	F: 325	F: 500	F:1,100/1,600	F: 540	F: 540
Capacity per track (Bytes)	F: 17,400	F: N/A	F: 25,600	F: N/A	F: N/A
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	18,751	18,750	43,750	40,640	40,640
Track density (TPI)	15,875	12,700	15,875	15,875	15,875
Maximum linear density (BPI)	25,000	25,391	24,937	27,600	27,600
Rotational speed (RPM)	1800	900-535	720/720-360	530-200	530-200
PERFORMANCE					
Positioner type	Crs: Voice Coil Fine: Lens Actuator	Linear, Voice Coil	Linear, Voice Coil	Crs: Voice Coil Fine: Lens Actuator	Crs: Voice Coil Fine: Lens Actuator
Average positioning time (msec)	100	250	250/620	300	300
Average rotational delay (msec)	16.7	44.7	42/62.5	100	100
Average access time (msec)	116.7	295	292/682.5	400	400
Data transfer rate (KBytes/sec)	510	300	300	153.6	153.6
FIRST CUSTOMER SHIPMENT	4Q87	4Q84	2Q85	3Q87	4Q86
U.S. OEM PRICE FOR 100 UNITS	--	$5,300	$7,200	$530	$550
COMMENTS	Preliminary Specification	Controller is $4000.	Controller is $4000. 50 disk library unit available.	Embedded SCSI Controller. External mount.	Internal full size mount.

MANUFACTURER		TOSHIBA CORPORATION	TOSHIBA CORPORATION	TOSHIBA CORPORATION	VERBATIM	VICTOR COMPANY OF JAPAN, LTD.
DRIVE		XM-3000B XM-3100B	WM-D050	DF-0450 DF-0460	MOD 1	XR-R1001 XR-R100
DISK/TREND GROUP		9	10	11	10	9
MARKET		OEM	Captive/OEM	OEM/Captive	OEM	OEM
MEDIA:	Nominal disk diameter	120 mm	130 mm	12"	95 mm	120 mm
	Recording medium	Aluminum	Te-C	Te-C	Tb-Fe-Co	Aluminum
	Track format	Spiral	Spiral	Spiral	Concentric	Spiral
	Recording method	Mastering	Pit	Pit	Magneto-optic	Mastering
DRIVE:	Operating mode	Read Only	Write Once	Write Once	Erasable	Read Only
	Interface	SCSI	SCSI	GPIB/SCSI	SCSI	SCSI
	Speed control	CLV	CAV/CLV	CLV	CAV	CLV
CAPACITY/RECORDING DENSITY						
	Total capacity (MBytes)	F: 540	F: 250/400	F: 1,800	F: 50	F: 540
	Capacity per track (Bytes)	F: N/A	F: 14,336/NA	F: N/A	F: 10,000	F: N/A
	Data surfaces per spindle	1	1	1	1	1
	Tracks per surface	40,640	20,000	45,000	4,000	40,640
	Track density (TPI)	15,875	15,875	15,875	6,350	15,875
	Maximum linear density (BPI)	27,600	21,900	19,450	15,825	27,600
	Rotational speed (RPM)	530-200	925	427-215	600	530-200
PERFORMANCE						
	Positioner type	Crs: Voice Coil Fine: Lens Actuator	Linear, Voice Coil	Linear, Voice Coil	Linear	Crs: Voice Coil Fine: Lens Actuator
	Average positioning time (msec)	300	180	900	20	300
	Average rotational delay (msec)	100	32	105	50.5	110
	Average access time (msec)	400	212	1000	70*	410
	Data transfer rate (KBytes/sec)	153.6	120	313	125	153.6
FIRST CUSTOMER SHIPMENT		2Q86	4Q86	4Q84	1988	3Q87
U.S. OEM PRICE FOR 100 UNITS		$600	$4500	$11,000/12,000	--	--
COMMENTS		41 mm high. Sold only in Japan.		DF-0460 has SCSI interface.	Preliminary specification. * Includes over write latency.	41 mm high. XR-R100 is free standing.

MANUFACTURER PROFILES

1987 DISK/TREND REPORT

MANUFACTURER PROFILES

All manufacturers now producing optical disk drives, or those which are expected to later 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 1986, this figure is not reported explicitly in this year's report. "1986 total net sales" covers the fiscal year ending in 1986 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, 1986, unless otherwise noted.

Manufacturers located in the United States that have majority owners headquartered in another country are grouped in the geographical area covering the owner's home office.

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 1986 is used, as cited by the Federal Reserve Bulletin and rounded to 3 significant figures.

Country	Currency	Currency units/U.S. dollar
France	Franc	6.93
Japan	Yen	168.35
Netherlands	Guilder	2.45
Italy	Lira	1491.16

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 has designed a 300 megabyte ruggedized 5.25" write-once drive that it expects to supply to customers in the defense and mineral resources industries. Volume shipments are expected to begin in the third 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

1986 total net sales: $7,590,000,000 (FY ending 6/30/86) Net income: $617,000,000

DEC is not actively producing an optical drive, but has drives under development. The firm was the first major system supplier to offer the CD-ROM as a system peripheral. The CD-ROM 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

1986 total net sales: $11,550,000,000 Net income: $374,000,000

Eastman Kodak has at least two optical disk drives, one a very high capacity 14" 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, and is not yet in production. The 14" drive began its production run in 1987. It uses a 14" diameter format and employs proprietary dye/polymer media. The drive is used in

Eastman Kodak's KIMS series image storage product lines and is also offered on an OEM basis as a computer peripheral. Media will be made by Verbatim at its North Carolina facility. The company also purchases 12" optical drives from Hitachi and 5.25" optical drives from ISI for use in the KIMS product line. Eastman Kodak produces an automated library unit for use with its own drive and purchases library units for systems using drives from other manufacturers.

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

1986 total net sales: $7,102,000,000 (FY ending 10/31/86) Net income: $516,000,000

Hewlett-Packard does not currently produce optical disk drives, but has an active technology evaluation program at its Boise, Idaho facilities. Boise is also the firm's development facility for its advanced head and disk technology. Some related work on optical drive technology is being done at HP Laboratories.

HONEYWELL, INC.
Sperry Space Systems Division
19019 North 59th Avenue
Glendale, AZ 85308

Honeywell purchased Sperry's Optical Products Group and Aerospace Group at the time that Sperry and Burroughs merged to form Unisys, and combined them to form the Sperry Space Division. At the same time, Honeywell obtained Sperry's 9% share of ownership in ISI. The Sperry group is continuing development of a militarized drive based on ISI technology and is working jointly with ISI on the project. A 300 megabyte 5.25" write-once drive may begin shipping in 1988.

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 (20%) and Tallgrass (20%). Sperry, now incorporated into Unisys, also became a significant investor, and acquired rights to ISI technology for use in military systems. This product area, along with Sperry's investment, was subsequently sold to Honeywell. ISI is supplying drives to Honeywell, but Honeywell will eventually 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, in some cases by licensing its design. 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 500 megabyte, 5.25" write-once drive for delivery in late 1987. In 1986, ISI licensed two other firms, Maximum Storage Inc. and Kawatetsu Instruments, to manufacture its designs.

INTERNATIONAL BUSINESS MACHINES CORPORATION
Route 22
Armonk, NY 10504

1986 total net sales: $51,250,000,000 Net income: $4,789,000,000

While IBM is known to have an active program underway in Tucson, Arizona, 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 IBM's new PS/2 personal computer family may appear in the future, but it is expected that these requirements will be filled with outside purchases of OEM CD-ROM drives. In April, 1987, IBM announced the model 3363 write-once drive for use with its personal computers. The mechanism for this drive is obtained from Matsushita Electric; IBM supplies the electronics, software, and final assembly at its Tucson facility. While IBM has not revealed its future product plans, it is widely believed in the industry that IBM is working on 5.25" erasable optical technology for use with workstations, desktop computers, and mass storage subsystems.

IOMEGA CORPORATION
1821 West 4000 South
Roy, UT 84067

1986 total net sales: $126,000,000 Net income: $5,080,000

Iomega is best known for its successful line of Bernoulli Box flexible disk drives. As part of its development efforts for future products, the firm has established a development group in Boulder, Colorado, that is working on a Bernoulli principle drive using optical rather than magnetic recording. Any product is several years away from formal announcement.

MAXIMUM STORAGE, INC.
5025 Centennial Boulevard
Colorado Springs, CO 80919

Privately held, MSI was founded in September, 1986, by Paul Schroeder, one of the founders of INMOS. Startup has been rapid, as MSI licensed technology from ISI and began producing a 5.25" write-once drive having specifications similar to the ISI drive in early 1987. The firm is also working on a higher capacity write-once drive of its own design for release in late 1987. MSI has designed its drives for use with IBM PC and PC-compatible computers.

MAXTOR CORPORATION
150 River Oaks Parkway
San Jose, CA 95134

1986 total net sales: $175,299,000 (FY ending 3/29/87) Net income: $26,337,000

Maxtor, with manufacturing facilities in California and Singapore, is a highly successful supplier of high performance, high capacity 5.25" rigid disk drives. In 1986, Maxtor entered into an agreement with Ricoh in which Maxtor acquired exclusive U.S. marketing rights for the Ricoh 5.25" write-once optical disk drive. Because of Maxtor's strong market penetration in the OEM community, this has been a successful effort for both parties. Maxtor is making a long term commitment to the optical disk drive industry, and is developing a magneto-optic erasable disk drive of its own design. Because Maxtor has a strategy of positioning itself at the high end of the product spectrum, this forthcoming product may be expected to offer higher capacity and faster access time than most competing products. Maxtor may also be able to leverage its optical program through its 1987 acquisition of U.S. Design, a subsystem integrator that serves the DEC market. U.S. Design offers optical disk drive subsystems with DEC interfaces in addition to other storage subsystems using magnetic disk drives.

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

1986 total net sales: $163,000,000 Net income: $7,200,000

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 Art Tech 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 drive 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. 3M Company subsequently acquired a small ownership position. Optimem has been hurt in recent months by the departure of most of its senior management, and it may take the firm some time to recover from the disruption.

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

Founded in 1984, Optotech is one of the early suppliers of 5.25", 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 in Taiwan. 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 in ISI) and several other small firms. Optotech also has an investment in Mountain Technologies, a firm specializing in drive conversions for harsh environments.

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 system integration; its product line now includes hardware and software to interface optical disk drives to small systems.

SEAGATE TECHNOLOGY
920 Disc Drive
Scotts Valley, CA 95066

1986 total net sales: $460,000,000 (FY ending 6/30/86) Net income: $34,500,000

Seagate is one of the world's largest suppliers of small rigid disk drives and is highly vertically integrated. The company has begun development of optical drives including a high performance CD-ROM and a

CD format read/write drive. The project is still in the experimental stage; products will not be available for some time.

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

1986 total net sales: $696,000,000 Net income: $17,000,000

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. In July, 1987, STC emerged from Chapter 11 status.

VERBATIM CORPORATION
Subsidiary of Eastman Kodak
1200 W. T. Harris Boulevard
Charlotte, N. C. 28213

Verbatim, known primarily as a maker of floppy disk media, began developing an erasable optical disk drive in 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, New York, to strengthen the program. A non-operating prototype was demonstrated at the 1986 NCC and several later shows. The drive will be produced by Eastman Kodak; media for the drive will be produced by Verbatim at its Charlotte facilities. Kasei Verbatim, a Japanese joint venture between Verbatim and Mitsubishi Chemical, announced in 1987 that it would also make 3.5" magneto-optical media.

Japanese Manufacturers (All fiscal years end in March, 1986, unless otherwise noted.)

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

1986 total net sales: $8,491,221,000 Net income: $175,551,000

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. In October, 1986, Fujitsu announced a 5.25" write-once drive with 300 megabyte capacity for delivery in mid-1987. 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

1986 total net sales: $17,840,154,000 Net income: $522,946,000

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 products 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" write-once drive with a capacity of 300 megabytes was announced at COMDEX in 1986. The CD-ROM product line was expanded in 1986 and 1987 to include 5.25" form factor drives and some new features. Hitachi 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.

JVC (VICTOR COMPANY OF JAPAN, LTD.)
1-4 Nihonbashi-Honcho
Chuo-ku, 103 Tokyo

1986 total net sales: $3,493,514,000 Net profit: $54,137,000

JVC, as it is commonly known, is a major producer of consumer audio equipment, including CD players. Video tape recorders accounted for 65% of JVC sales in 1986, but JVC has been expanding into computer peripherals and has been shipping floppy and rigid disk drives since 1984 and 1985, respectively. The firm is currently introducing CD-ROM drives and will be in production in the last half of 1987.

KAWATETSU INSTRUMENT LTD.
Subsidiary of Kawasaki Steel Corporation
14-4 Nihonbashi Kodemma-cho
Chuo-ku, Tokyo 103

1986 total net sales: $6,878,378,000 Net income: $96,929,000

Kawatetsu Instrument is a smaller company specializing in electronic instrumentation. The firm began producing 5.25" write-once optical disk drives at its Nishinomiya plant in December of 1986 under license from I.S.I.. Kawatetsu Instrument will market the drives to OEM customers in Asian markets through Kanto Denshi, a trading company, and may act as a second source of supply to I.S.I. if demand warrants.

MATSUSHITA COMMUNICATION INDUSTRIAL CO., LTD.
4-3-1, Tsunashima-Higashi
Kohoku-ku, Yokohama 223

1985 total net sales: $1,787,686,000 Net income: $64,259,000
(FY ending 11/30/85)

The primary products of MCI include key telephones, car audio equipment and floppy disk drives. Disk drives are made at a highly automated plant in Hanamaki. In 1987, MCI announced a 5.25" 300 megabyte write-once optical disk drive offering 75 millisecond average access time and 925 kilobyte per second data transfer rate. These specifications, as of mid 1987, were the highest performance specifications yet announced for a small optical drive.

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

1985 total net sales: $20,339,382,000 (FY ending 11/30/85) Net income: $666,433,000

MEI's Panasonic, National, Technics, and Quasar brands are among the most widely known in the world for appliances, consumer electronics, and communications equipment. The MEI High Fidelity/Audio division is offering CD-ROM products, with half-high models to be available in late 1987. The parent firm has also developed an 8" write-once drive that is now manufactured by Matsushita Graphics Communication Systems and used in captive document storage systems. In April, 1987, IBM announced a 200 megabyte write-once disk drive whose mechanism is made for IBM by Matsushita Electric's Disk Division. 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.

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

1985 total net sales: $20,339,382,000 (FY ending 11/30/85) Net income: $663,433,000

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. MGCS now manufactures the drive itself for use in the Panafile series of document storage systems. As of mid 1987, these systems were marketed only in Japan, but MGCS is considering marketing them in the U.S.

MITSUBISHI ELECTRIC CORP.
2-2-3, Marunouchi
Chiyoda-ku, Tokyo 100

1986 total net sales: $10,816,727,000 Net income: $145,601,000

This company is most noted for heavy machinery production, but is also quite active in defense electronics and consumer electronics. Data and communication systems represent 28% of sales. In 1987, Mitsubishi introduced a 5.25" 300 megabyte write-once optical drive with 80 millisecond average access time, making it one of the fastest optical disk drives announced as of mid-1987. The drive will be sold as part of an optical storage library system that can contain as many as two drives and 152 disks.

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

1986 total net sales: $11,704,776,000 Net income: $314,915,000

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

1986 total net sales: $464,021,000 Net income: $1,960,000

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, providing packaging flexibility to manufacturers of small systems. CD-ROM hardware production in limited quantities began in the fourth quarter of 1985. Half high models are now available. 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

1986 total net sales: $1,589,866,000 Net income: $20,832,000
(FY ending 9/30/86)

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 these drives is an unusual dye based 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 based media to be brought to market.

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

1986 total net sales: $6,155,010,000 Net income: $184,075,000

Copiers, photographic equipment, and sensitized papers provide most 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, and the firm showed a prototype OEM 8" write-once drive at the 1986 NCC show. However, Ricoh has concentrated upon developing optical disk drives in the 5.25" form factor, rather than expending further effort on an 8" product. In early 1987, Ricoh and Maxtor entered an agreement whereby Maxtor will be the exclusive marketing agent for Ricoh OEM optical disk drives in the United States. This arrangement appears to be working effectively for both parties. Ricoh is marketing subsystems containing optical drives in the U.S., an activity permitted under the terms of the Ricoh-Maxtor agreement.

SANYO ELECTRIC CO., LTD.
2-18 Keihan-Hondori
Moriguchi, Osaka 570

1985 total net sales: $6,222,946,000 Net income: $168,191,000
(FY ending 11/30/85)

Sanyo is a major supplier of consumer electronics, appliances and components such as solar cells, and is one of Japan's more active offshore manufacturers. About 19% of sales are computing and business equipment. Sanyo is actively involved in CD equipment and media production and introduced a CD-ROM drive in 1987. The firm also makes 12" write-once optical drives for use in its own line of office equipment.

SHARP CORPORATION
22-22 Nagaike-cho
Abeno-ku, Osaka 545

1986 total net sales: $5,674,208,000 Net income: $206,326,000

Sharp is a supplier of electrical and electronic equipment. About 32% of sales are derived from computer or computer related products, including desktop and transportable personal computers. Appliances (22%), electronic parts (35%) and audio products (11%) comprise the remainder of corporate sales. Sharp has been actively developing magneto-optic disk drives and media for several years and has made several technology announcements. In mid-1987, the firm announced a 5.25" 211 megabyte erasable optical drive and indicated that the drive would be available in late 1987.

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

1986 total net sales: $6,155,010,000 (FY ending 10/31/86) Net income: $184,075,000

Sony is well recognized as a leader in consumer electronics and has also earned a position as the major supplier of 3.5" 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. In 1987, Sony announced an erasable 5.25" optical drive using magneto-optical technology. The drive will be available by late 1987 in small quantities and will be in full production in 1988.

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

1986 total net sales: $14,966,184,000 Net income: $321,129,000

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 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 also began in 1986, with half high drives scheduled for the latter half of 1987. The majority 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. Toshiba is actively developing an erasable optical drive, but has not indicated availability yet.

European Manufacturers

ART TECH GIGADISC
1270 Avenue General Eisenhower
31047 Toulouse
France

Beginning as the optical disk operation of Thomson-CSF, ATG was formed as a joint venture in 1984 when CIT-Alcatel, a maker of image processing systems, joined with Thomson-CSF, Rhone-Poulenc, Bull, and several other French companies to form Alcatel-Thomson-Gigadisc. 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 hampered its growth. A new facility alleviated this problem, but disappointing sales caused Alcatel to decide to withdraw from the venture, and for a short time ATG was dormant while new investors were found. Now operating as Art Tech Gigadisc, the firm's new name reflects the change in ownership. 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 or LMS media if properly adjusted. New product efforts include higher capacity write-once drives; a 5.25" drive is also under consideration. Most of the ATG drives have been used in image processing applications. ATG has also developed a library storage unit for 12" media, but it is in limited production status at present.

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 acquired about 25% of ownership at that time. The firm's first product, a 5.25" write-once drive with 400 megabyte capacity, will be formally introduced in 1987. Laserdrive has invested substantially in software that permits the optical drive to appear to the using system as a standard rigid drive and has developed special hardware for on-the-fly ECC. Production of the drive mechanism will be done in Japan under contract, but the electronics and final assembly will be produced in the U.S., where the research and engineering functions are located. Laserdrive is receiving considerable financial and management support from Olivetti, which purchased 80% of Acorn Computer in mid-1985 and now, as a result, has a majority position in Laserdrive.

LASER MAGNETIC STORAGE INTERNATIONAL
Joint venture of N. V. Philips and Control Data
4425 ArrowsWest Drive
Colorado Springs, CO 80907

LMS was formed in 1986 through the combination of Optical Storage International, Computer Peripherals International, and Philips' CD-ROM operations. Philips owns 51% of the company. CPI was a CDC and NCR joint venture that produced tape drives. OSI, formed in 1984, was a joint venture of Philips and Control Data. While Philips now holds the majority interest, the organization originally was managed by Control Data. OSI combined 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 LMS. LMS products currently include a 12" write once drive, with a 5.25" unit in development. Also in the product line are CD-ROM drives, including a half high unit. LMS continues to produce tape drives, which are the firm's most profitable products. Image processing has been the most significant application to date for the company's write-once products. Media is obtained from an LMS manufacturing operation sharing Philips media manufacturing facilities at Blackburn in the UK.

ING. C. OLIVETTI & C., S.P.A.
Via G. Jervis 77
10015 Ivrea
Italy

1986 total net sales: $4,908,000,000 Net income: $379,000,000

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 biggest impact on Olivetti's lifestyle during the past few years was the 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. Olivetti has a major investment in Laserdrive, Ltd., a producer of 5.25" write once drives. The company bought 80% of Acorn Computer in 1985. Because Acorn also had a major ownership position in Laserdrive, Ltd., Olivetti now owns about 65% 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

1986 total net sales: $26,782,000,000   Net income: $476,900,000

The Philips organization, established in 1891 as a manufacturer of electrical equipment, 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. Philips' initial digital optical developments were a 12" write-once drive and the CD-ROM. Philips, together with Sony, has been instrumental in establishing standards for CD and CD-ROM drives. The Philips CD-ROM has the distinction of being the first CD-ROM to be accepted by a major system OEM: Digital Equipment Corporation offered it as a peripheral on its Micro-Vax line. In 1985, Philips also entered into a joint venture with DuPont to produce optical media of various types in large quantities. In 1986, OSI, a joint venture between Philips and Control Data, was reorganized as Laser Magnetic Storage and charged with the responsibility of manufacturing and marketing the Philips CD-ROM, write once products designed by OSI using Philips-developed technology, and magnetic tape drives previously produced by another CDC joint venture. Philips owns 51% of LMS; Control Data has the other 49%. Philips is also involved in a joint venture with Sun Microsystems to develop CD-ROM and CD-I authoring systems using Sun workstations. Philips is also a producer of CD media through its Polygram operation and several joint ventures with Japanese companies.

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

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 ended in 1985.