Holographic data storage

— a new archival solution for the professional market

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Holography has long held promise as a data storage technology with the potential for vast capacity and high data rates. Recent advances in materials, multiplexing architectures and components are finally making this vision a reality. These technical developments are occurring just as we see an explosion in the growth of "fixed-content" archival information. This articles describes how holographic media could provide a long-awaited solution for broadcast archives.

A study conducted by the University of California at Berkeley, entitled *"How Much Information"* states that the world produced nearly 12 billion gigabytes of information in 2003 of which more than half does not change. Analysts predict that this so-called "fixed-content" information will grow faster than that of traditional transaction-based and file-oriented storage.

Fixed-content information is retained for active reference and takes many forms such as critically important business, legal and reference documents, not to mention broadcast archives. Unlike databases or files which change or are constantly updated, the requirements of fixed-content data are: (i) assured data permanence, (ii) expanded data access and (iii) longetivity of the stored information.

Traditionally, professional archive products have served a niche market in digital image archive applications where protection of information is paramount and the archive requirements are very long. Examples include the archiving of patient records in the medical industry, the storage of financial records, insurance records, telephone switch logs and call-centre voice recordings.

However, data archive applications are now going mainstream, becoming one of the most important applications for customers across a broad spectrum of markets. The drivers for the increased growth of archive data are compliance regulations and the fast growing data archive requirements in rich media, broadcast content, scientific applications and many others.

Archive customers require not only stable and long-lived media *with a minimum 50-year archive life*, but also require extremely high levels of equipment reliability and the same multi-generation backward read compatibility offered by tape. Random-access performance that allows rapid access to their data is another critical need.

The challenge for vendors providing professional archive products is to deliver solutions that meet customers' needs for data longevity, security and accessibility, but are also competitive in terms of capacity, performance and price. A recent trend in the archive market is some limited adoption of hard disk drive (HDD) technologies for archive applications and *Content Addressable Storage* is one approach for deploying HDDs in archive applications. Although hard drives can meet some customer requirements for archives – in particular capacity and performance – they are not competitive in terms of price or data longevity for many applications. As will be described below, *holographic data storage* provides a superior solution to HDDs in archive applications.

Information Lifecycle Management

The growth of fixed-content data has also spurred the adoption of *Information Lifecycle Management* (ILM) applications. Traditionally, most electronic data in organizations has resided online, on hard disk drives. Periodic backups to tape provide an extra off-line copy of the data for disaster recovery, in case the primary instance of the data is not available. However, this practice – of a one-size-fits-all storage strategy – is no longer economically viable for increasing numbers of customers.

Prefix	Multiplier
Kilo (k)	10^3
Mega (M)	10^6
Giga (G)	10^9
Tera (T)	10^{12}
Peta (P)	10^{15}
Exa (E)	10^{18}

Many customers are already storing multiple terabytes of data online, rapidly growing this towards petabytes and exabytes of capacity *(see the accompanying table)*. But in many cases, they simply cannot afford to grow their online storage to keep pace with the growth of their data.

ILM offers a cost-effective solution to managing this explosion of data. ILM allows customers to deploy a range of different types of storage devices, each with a variety of different performance, cost and other characteristics. Different types of data can then be stored on different types of storage devices, reducing the overall costs. What results is sometimes referred to as *tiered storage*. ILM enables customers to specify that different types of data should reside on the most appropriate storage tier – based on availability, performance, capacity, longevity expectations, retention criteria and cost. ILM is a dynamic process since, over time, the appropriate location for the data may change. Good ILM implementations must enable the manual or automated migration of data from one storage medium to another.

Archive tier

Within ILM applications, *data archival* becomes a critical tier within the storage mix. It is a long-term repository for information that is important for the organization to maintain but does not justify the investment required for online HDD storage. Archival data not only must remain accessible for extended periods of time (50 years and beyond), but must also be protected from accidental or deliberate alteration.

Near-line storage

Another level within the ILM tiered-storage structure, known as *near-line storage*, is maturing but is currently underserved by vendor products. As the name implies, near-line storage has attributes between on-line HDD storage and archive (or off-line) tape-based storage. An example of near-line storage would be in a file retrieval application which manages a very large number of files. Keeping all files online on HDDs enables file-access times measured in milliseconds, but at very high costs. Likewise, maintaining all files on tape would be much less expensive but the retrieval time would soar from milliseconds to minutes or even longer. A near-line storage tier would provide file access in seconds but at a price significantly lower than if using HDDs.

Today, there are few viable products that serve this near-line tier. Tape libraries are sometimes deployed in this capacity but access time is often slow and recovery from tape is sometimes unreliable.

Holographic storage

Holographic storage not only provides a solution for the archive tier of ILM but also for the near-line storage tier. With an archive life of at least 50 years, true Write Once / Read Many (WORM) capability and the availability of low-cost storage media, holographic storage is an ideal archive solution.

Holographic technology also addresses the near-line tier by providing fast and reliable access to data, but at a price point that is significantly lower than that of HDDs. Data stored anywhere on holographic media is accessible in milliseconds compared to the 10s of seconds or even minutes if stored on tape.

The professional video market

The needs of professional video users are unique when compared to other commercial customers. While IT systems can produce the reliability requirements that match these users' needs, the real-time aspect of audiovisual material and its impact on the video supply chain is frequently misunderstood by IT professionals.

Professional video workflow is a continuum that starts with content acquisition, moves to post-production, mastering, distribution and then on to the archives. This is a long and complicated process that historically has not been served well by digital technologies because of insufficient performance, capacity and bandwidth. Only within the last several years has the move to digitization been aggressively adopted.

Firstly, the drive to improve bottom-line performance pushed the move to digitization in order to reduce the cycle time from acquisition through to distribution. Secondly, the mandate to broadcast high-definition content accelerated the migration because it required a new HD infrastructure.

The next major trend is the migration of technology from analogue to digital formats. The legal requirements for migrating to high-definition video formats has caused the broadcast and film industries to rethink their entire infrastructure. They are leveraging their capital investments to install true digital file-based formats.

Archives are particularly important in this market. Content is valuable and needs to be stored for long periods of time, often indefinitely, and must be done securely and cost-effectively. The shift to HD formats significantly increases the amount of data that must be stored, forcing customers to investigate and deploy new archive strategies. It is no longer practical to deploy racks of off-line tapes as an organization's primary archive.

The limits of HDD storage

For several years, hard disk drives were able to increase capacity at a rapid and steady pace. HDD density doubled at the rate of approximately every 18 to 24 months as shown in *Fig. 1*.

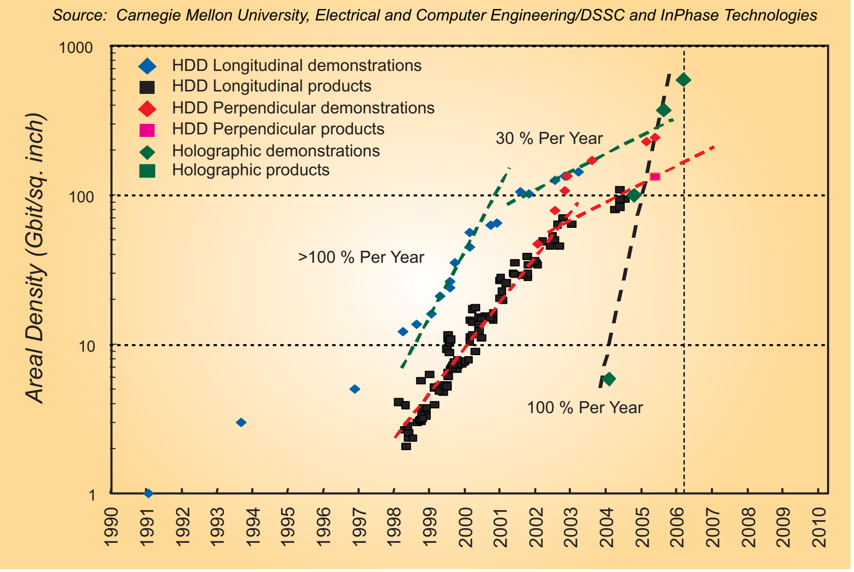


Figure 1
Historical density trends: hard disk drive vs. holographic data storage

As densities increased, prices decreased, and it was hoped that HDDs would eventually become inexpensive enough to provide universal storage for all applications.

However, as HDD densities have grown continually higher, the *rate of growth* has decreased significantly. This has occurred even as the HDD industry has shifted from longitudinal recording to perpendicular recording. Clearly, the approach of storing data on the surface of a medium by packing bits ever more closely together is beginning to reach its practical limits.

In contrast, InPhase Technologies has recently demonstrated increases in storage densities, which match or exceed the maximum historical increases seen with HDDs. Holographic storage is clearly the path to the future.

What is holographic storage?

Holography breaks through the density limits of conventional storage by going beyond recording only on the surface to recording through *the full depth of the medium*. Unlike other technologies that record one data bit at a time, holography allows a million bits of data to be written and read in parallel with a single flash of light. This enables transfer rates significantly higher than current optical-storage devices.

Combining high storage densities and fast transfer rates, with durable reliable low-cost media, holography is poised to become a compelling choice for next-generation storage and content distribution needs.

In addition, the flexibility of the technology allows for the development of a wide variety of holographic storage products that range from handheld devices for consumers to storage products for the enterprise. Imagine 2 GB of data on a postage stamp, 20 GB on a credit card or 300 GB on a disk the size of a DVD.

How is data recorded?

Light from a single blue-laser beam is split into two beams, the signal beam (which carries the data) and the reference beam. The hologram is formed where these two beams intersect in the recording medium *(see Fig. 2)*.

The process for encoding data onto the signal beam is accomplished by a device called a *spatial light modulator* (SLM). The SLM translates the electronic data of 0s and 1s into an optical "checkerboard" pattern of light and dark pixels. The data is arranged in an array (or page) of approximately one million bits. The exact number of bits is determined by the pixel count of the SLM.

InPhase Technologies

InPhase Technologies was founded in December 2000 as a Lucent Technologies venture, spun out of Bell Labs research, with the objective of becoming the first company to bring holographic data storage technology to market. Through revolutionary techniques developed by a team of Bell Labs scientists, InPhase has solved several fundamental problems associated with holographic storage, including the creation of a viable storage medium and the systems expertise required to record holograms. The result of more than ten years of groundbreaking research in holographic storage has culminated in the InPhase Tapestry™ media and drive.

The InPhase founders include the principal systems and material scientists from Bell Labs who invented the core technology. In addition, the engineering and business teams have many years of experience successfully developing and bringing to market a wide range of storage products with companies such as Maxtor, Quantum, Seagate, StorageTek/Sun and Hewlett-Packard.

InPhase is probably the world’s leader in holographic data storage with the largest number of holographers in one location. It is the provider of holographic media and testing equipment to greater than 95% of companies working on holography worldwide. Six of the 10 existing holographic multiplexing methods have either been invented or co-invented by InPhase and the company holds 55 patents and 95 patent applications/disclosures.

At the point of intersection of the reference beam and the data-carrying signal beam, the hologram is recorded in a light-sensitive storage medium. A chemical reaction occurs in the medium when the bright elements of the signal beam intersect the reference beam, causing the hologram to be stored. By varying the reference-beam angle, wavelength or media position, many different holograms can be recorded in the same volume of material.

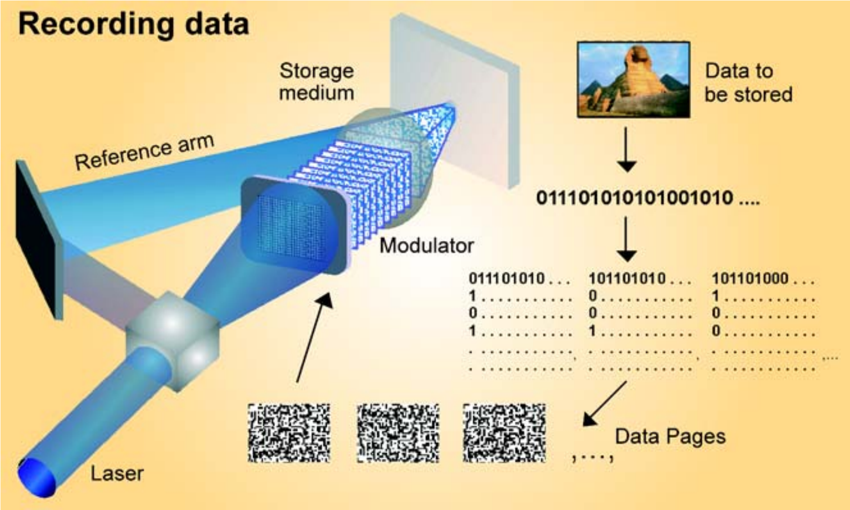


Figure 2
Recording holographic data

Each data page is located at a unique address within the material, and several hundred pages of data, each with their own unique address, are recorded in the same location of the medium. A collection of data pages is referred to as a *book*. InPhase's patented polytopic recording technique enables many holograms to be stored in the same volume of material by overlapping not only pages, but also books of data. This dramatically increases the storage density.

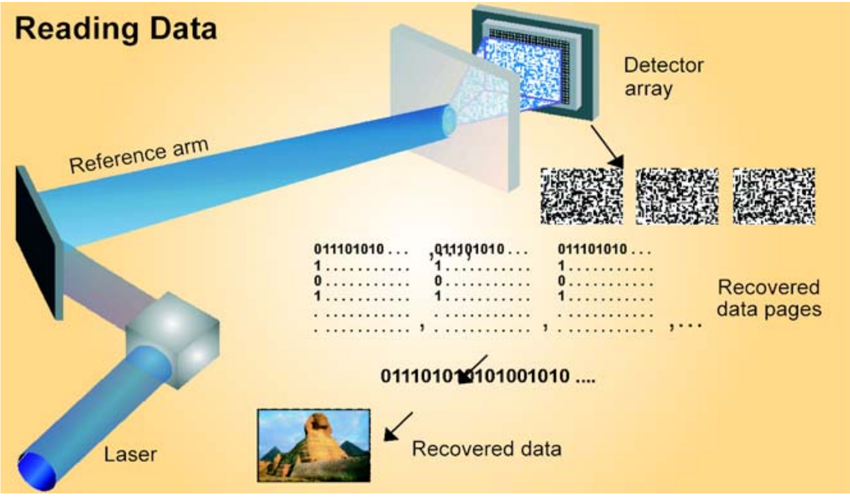


Figure 3
Reading holographic data

How is data read?

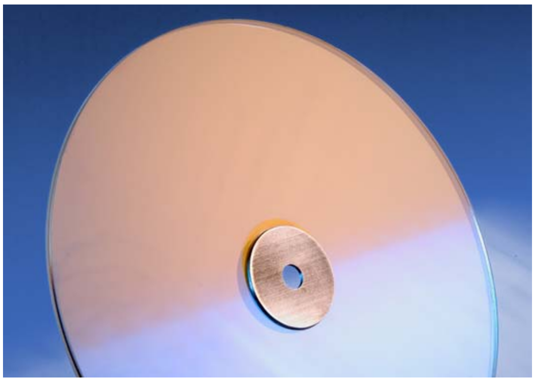
In order to read the data, the reference beam deflects off the hologram, thus reconstructing the stored information as shown in *Fig. 3*. This hologram is then projected onto a detector that reads the data in parallel. This parallel readout of data provides holography with its fast transfer rates.

Holographic storage media

The major challenge to implementing holographic storage has been the development of a suitable storage medium. The *Tapestry*™ storage medium from InPhase Technologies satisfies the many stringent criteria for a viable storage material, including high dynamic range, high photosensitivity, dimensional stability, optical clarity, manufacturability, non-destructive readout, and thickness, environmental and thermal stability.

In addition to developing a new class of materials, InPhase Technologies also developed the *ZeroWave*™ manufacturing process, which enables the cost-effective fabrication of optically-flat media. This makes the media price competitive for mass consumption.

There are very important advantages of *Tapestry*™ holographic storage media over conventional tape. Not only does the media possess a very long 50-year lifetime but it is extremely durable and



does not require any special handling procedures. Tape is subject to the wear of multiple read cycles as the tape comes into physical contact with “read” heads and other mechanical components in the tape path. In contrast, *Tapestry*™ media can be read millions of times since the data is read by light and there is never any mechanical contact.

Furthermore, *Tapestry*™ media requires no special handling and can be stored in standard office environments. Tape must be stored in recommended temperature and humidity conditions, kept evenly wound, stored upright, wound and rewound periodically, protected from magnetic fields and should be allowed to adapt to environmental changes (up to 24 hours) before use.

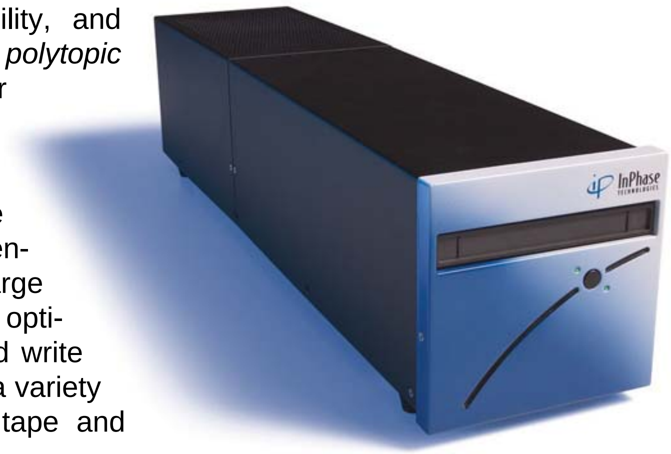
Media lifetime testing

Through careful testing, InPhase Technologies has determined that its *Tapestry*™ holographic media has a lifetime of at least 50 years. This is done through a process known as *accelerated life testing*, where long-term behaviour is simulated by subjecting the media to short-term environmental conditions that are far more severe than would ever be encountered in actual usage.

Specifically, InPhase holographic media is placed in a special environmental chamber where the temperature is raised to 80°C with 95% relative humidity. Periodically the optical quality of the media is measured to determine any degradation in the ability of the media to store data. Typical 50-year archive tests for optical media require the media to maintain optical quality for 1000 hours under these elevated temperature and humidity conditions. InPhase media has shown stable optical properties beyond 3000 hours of testing at 80°C with 95% relative humidity.

Holographic storage products

Only recently has there been a convergence of factors which have allowed InPhase to develop a commercially-viable holographic storage device. Among these is the availability of key components such as blue lasers as well as SLMs and camera chips with sufficiently high resolution. Another key factor is the development of *Tapestry*™ media with appropriate optical qualities, manufacturability, and archive life. Finally, techniques such as *polytopic multiplexing* enable significantly higher storage densities, ensuring competitive storage capacities and prices.



The initial InPhase holographic storage drive will be a WORM drive that is capable of sequential writes and random reads. It contains a large 2 GB buffer to cache the writes, in order to optimize performance through long uninterrupted write sessions. The drive is capable of emulating a variety of existing storage devices such as LTO tape and magneto-optical (MO) drives.

Initially, the drive will have a SCSI interface, although the modular design of the drive enables future interfaces to be of an almost unlimited variety, including Fibre Channel, GigaEthernet, SATA, SAS, USB 2, SAS and others. The result of these standard interfaces and drive emulations means that existing applications can easily interface to the holographic drive as if it were a tape or MO device, with no changes to the application.

Holographic roadmap

The first holographic storage products from InPhase Technologies will target the professional archive and near-line storage markets, with WORM drives and media. These initial products will have a capacity of 300 GB of uncompressed data, with read and write transfer rates of 20 MB/s. Subsequent generations of WORM devices will increase the capacity to 800 GB and the transfer rates to 80 MB/s and then to 1.6 TB and 120 MB/s respectively *(see Fig. 4)*.

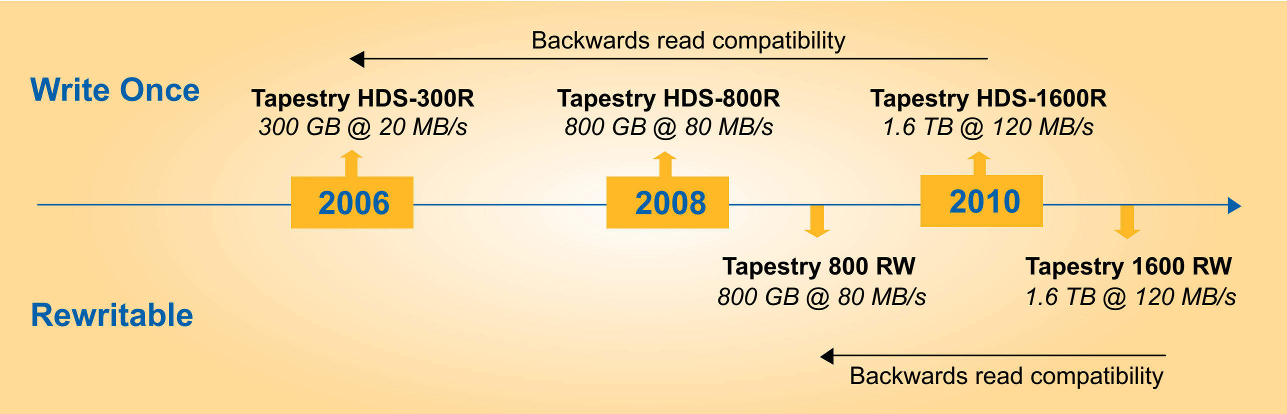


Figure 4
InPhase Technologies – holographic data storage roadmap

InPhase is also developing rewritable holographic media, which will enable media to be erased and reused. The initial rewritable product will have an 800 GB capacity and a transfer rate of 80 MB/s, increasing to 1.6 TB and 120 MB/s respectively.

Finally, holographic storage is also highly adaptable to low-cost read-only applications. Holographic readers can be developed very cheaply, since they do not need to contain expensive optics. Duplication technology is fast and very inexpensive.

Although not shown in *Fig. 4*, InPhase is also developing a portable handheld holographic device for consumer use.

Turner on-air demonstration

In October 2005, Turner Network Television (TNT) became the first television network to air content originating on holographic storage media. Engineers from InPhase Technologies and Turner Broadcasting System (TBS) Inc. ingested a promotional advertisement into an InPhase's *Tapestry*™ holographic disk as a data file. The advert was recorded by InPhase's holographic prototype drive onto the holographic disk which was then electronically migrated to a server and played back to air at the scheduled time. This promotional ad. remains active in Turner's system and is aired whenever called for by the programme schedule of TNT.

The benefits of the InPhase holographic solution, as described by Turner, include large capacity, random access to content, high bandwidth as well as inexpensive, secure and portable media.

Abbreviations

HD	High-Definition	**SAS**	Serial Attached SCSI
HDD	Hard Disk Drive	**SATA**	Serial Advanced Technology Architecture
ILM	Information Lifecycle Management	**SCSI**	Small Computer Systems Interface
LTO	Linear Tape Open	**SLM**	Spatial Light Modulator
MO	Magneto-Optical	**WORM**	Write Once / Read Many

Mike Lanciloti is Director of Product Marketing at InPhase Technologies, helping to commercialize the world's first holographic storage product. Prior to InPhase, he held a range of marketing management positions at Hewlett-Packard's storage and networking businesses and at McDATA Corporation. These positions included market development, technical marketing, product marketing and product management.

Mr Lanciloti began his professional career as a software development engineer. He has a Bachelor of Science degree in Computer Science from the University of Massachusetts at Amherst and a Masters of Business Administration from the University of California at Los Angeles.

Conclusions

The arrival of holographic storage technology is immiment, made possible by recent advances in materials, multiplexing architectures and components. As the rate of increase in hard disk drive capacity levels out, holographic storage will begin to emerge as the clear choice for near-line and archive applications.

InPhase Technologies has already demonstrated capacity and transfer rates of 300 GB and 20 MB/s respectively, both of which will increase markedly in the next few years as the technology matures. Bringing with it lower storage costs and longer media archive life, holographic data storage will help to create a new tapeless era in the video production and broadcast industry.