

Advanced Optical Disk Storage Technology

Fred N. Haritatos

Rome Laboratory
32 Hangar Road
Rome, NY 13441-4114
haritatosf@rl.af.mil
Tel: +1-315-330-4581
Fax: +1-315-330-2728

Abstract

There is a growing need within the Air Force for more and better data storage solutions. Rome Laboratory, the Air Force's Center of Excellence for C3I technology, has sponsored the development of a number of operational prototypes to deal with this growing problem. This paper will briefly summarize the various prototype developments with examples of full mil-spec and best commercial practice. These prototypes have successfully operated under severe space, airborne and tactical field environments. From a technical perspective these prototypes have included rewritable optical media ranging from a 5.25-inch diameter format up to the 14-inch diameter disk format. Implementations include an airborne sensor recorder, a deployable optical jukebox and a parallel array of optical disk drives. They include stand-alone peripheral devices to centralized, hierarchical storage management systems for distributed data processing applications.

Introduction

Command, Control, Communications, Computing, and Intelligence (C4I) is essential to the Air Force and, for that matter, to industry as well. C4I systems must effectively store, retrieve, and manage massive amounts of digital data. Current Air Force systems range from centralized Terabyte and Petabyte storage comprised of large objects (images) to distributed heterogeneous databases that contain many small and large objects (open source databases). Although technologies for storage, processing, and transmission are rapidly advancing to support centralized and distributed database applications, more research is needed to handle massive databases efficiently. Over the years, Rome Laboratory has nurtured a comprehensive program, developing new storage techniques that meet the various demands for data storage and retrieval. This article traces the history of and presents an overview of Rome Laboratory's research in optical disk storage technology.

The Evolution of Optical Disk Technology

In the mid-1970s and early 1980s optical storage reached the consumer market. Industry giants like RCA and Philips developed and marketed playback devices and large format "laser disks" for home movie viewing. While laser disks never generated a large, broad-stream consumer market (VCR is still the dominant technology for home movie viewing), compact disks (CDs) are now the primary means of distributing and listening to high-fidelity music. The introduction of laser diode devices made compact disk systems a viable consumer product. Laser diodes operating within the near-IR. (infrared) spectrum allowed

1 mm embossed pits to be easily detected. The new laser technology, in combination with powerful error detecting and correcting codes, enabled SONY and Philips to introduce the first CD audio product a decade ago.

Better optical media, more powerful laser diodes, and very precise, low-mass optics have propelled optical disk technology to a practical, powerful system. The next-generation device introduced in the mid-1980s provided a flexible write-once, read-many (WORM) capability. This enabled end-users to record and playback computer data from the same drive.

The third generation optical disk, today's rewritable systems, offer record, playback, and erase capability. These magneto-optical (MO) disks are composed of a rare-earth alloy and transition materials, which often include terbium, iron, and cobalt elements. Rome Lab's current development activities are concentrating in using this technology in various disk format sizes.

Optical disk storage is playing a larger role in mass data storage for many military applications; particularly, those applications that require reliable operation under harsh operational environments.

Rome Laboratory's Technology Development Program

Rome Laboratory has sponsored work since the early 1970s to exploit the benefits of optical disk technology. An early prototype used an argon laser to record and playback digital data from a 12.5-inch plastic-based optical disk. Further investment led to the delivery in 1982 of a large-capacity optical jukebox for satellite imagery storage and retrieval applications. The jukebox held 100 write-once, read-many (WORM) disks that provided a [1] one Terabyte storage capacity.

In the late 1980s, we transitioned our rewritable optical storage techniques from our laboratory environment to the "real world." This involved building and testing a family of high-performance prototypes for operation in working Air Force environments. Three advanced development models (ADMs) were built: 1) a 5.25-inch diameter, rewritable optical disk system; 2) a 14-inch rewritable optical disk system and 3) deployable optical jukebox.

5.25-inch Optical Disk System Advanced Development Model

The first Advanced Development Model [2] was designed to operate on board tactical fighter aircraft.



Some of the key environmental performance parameters included: high and low temperature, vibration, mechanical shock, acceleration, altitude, and humidity. The recording head, which moves across the disk surface to read and write, is susceptible to shock and vibration. It usually consists of a laser diode and various optics. By moving the laser diode and the majority of the optical components off the recording head assembly, we were able to reduce this mass. By reducing the recording head mass, we enabled faster access times and exceptional vibration and shock performance, ensuring reliable in-flight operation.

5.25-inch Optical Disk System Advanced Development Model:

Storage capacity:	300 megabytes, single-side
Data transfer rates:	5 megabits per second sustained 10 megabits per second burst
Max access time:	100 milliseconds (inner to outer radius)
Size:	5.0 inches x 6.5 inches x 10.5 inches
Weight:	16 pounds with disk cartridge

To fully evaluate the design robustness under realistic environmental conditions, we conducted an operational flight test on board an F-16 tactical fighter aircraft at Eglin AFB, Florida, from June - July 1989. An important Air Force milestone, it represents the first rewritable optical disk system to successfully fly on a high-performance aircraft using unconstrained flight maneuvers. A second device, provided to NASA-Goddard Space Flight Center and launched on the Space Shuttle Discovery, demonstrated advanced robotic concepts. Information describing the robot's operational environment was stored on the optical disk. The rewritable optical disk contributed greatly to the success of the NASA experiment.

14-inch Optical Disk System Advanced Development Model

The second ADM was [3] designed to provide larger data storage capacity and faster data transfer rates. The equipment operated in tactical environments found in larger aircraft and deployable, data processing facilities.



Digital data was recorded on a 14-inch, rewritable, optical disk. The larger media is a double-sided disk that uses a preformatted spiral pilot track to allow continuous tracking during write, read, and erase operations. As a result of evaluating several candidate approaches, this is the preferred disk construction for operation under severe environmental conditions.



A dual-channel laser diode is used to provide faster data recording and erasure. Each data channel is simultaneously recorded by using individually addressable elements on the laser diode array. The array is imaged through a single optical system and aligned to a common focal plane.

In September 1993, the equipment successfully completed a series of airborne tests on an RC-135 reconnaissance aircraft. This demonstrated its reliability under a wide range of airborne conditions. The equipment operated through tactical descents, mid-air refuelings, 60-degree bank turns and touch-and-go landings. No data were corrupted or lost during the test, and there were no hardware failures.

The 14-inch ADM possessed the following features:

Storage capacity:	6 gigabytes per side (GB)
Data transfer rates:	25 megabits/second sustained 50 megabits/second burst
Max access time:	400 milliseconds
Size:	17.5 inches x 23 inches x 24 inches
Weight:	150 pounds

Deployable Optical Jukebox

Based on past successes with optical disk systems for space and airborne applications, we have developed a follow-on Advanced Development Model [4].



The Advanced Development Model optical jukebox provides mass data storage and retrieval capabilities for ground-based, large data base requirements. This electro-mechanical jukebox stores 10 double-sided rewritable optical disks of 12 gigabytes each. Under computer control, individual optical disks can be located, transported, and inserted into the optical disk drive within 10 seconds. A dual picker robotics mechanism enables fast disk access by reducing the time required to extract and insert a new disk within the drive.

The optical jukebox is designed to be modular for quick setup and tear-down times. Within 30 minutes, the equipment can be disassembled and packed into five deployment cases. Each case is two-man portable. Equipment assembly is completed without special tools, personnel, or training. The equipment was shipped on Jan 1996 to Air Force Special Operations Command for operational evaluation.

With the end of the Cold War and the shrinking DoD budget, there is a growing trend to rely more heavily on commercial-off-the-shelf (COTS) products to satisfy many of the Air Force's mass storage requirements.

Dual-Use Optical Disk Technology

The reliance on dual-use technology has motivated Rome Laboratory's initiative called "High Capacity Optical Jukebox." Many of the media and drive technologies demonstrated under the earlier militarized optical disk program will be transferred to commercial implementation. Under this effort, 50 rewritable optical disks and a rewritable optical drive will be developed and delivered to Rome Laboratory. Each optical disk can be rewritten almost endlessly, thus saving life-cycle media costs. The 14-inch diameter, double-sided optical disk can store 10 GB.

Because the optical disk drive is a modification of a commercial WORM product, we're able to leverage current WORM production lines. The design effort will concentrate on developing a multifunction optical drive that can access both WORM and rewritable media. The disk access times and data transfer rates will be comparable to the current commercial product. One of our objectives is to deliver an optical disk library system that is highly leveraged from an existing write-once product. This offers a path toward commercialization and lower acquisition and maintenance costs.

With today's emphasis on COTS solutions, this approach develops a media and drive design that merges well with commercial product plans. This enables both commercial and military interests to benefit while sharing costs and risks, shortening the development cycle

and saving research and development funds by leveraging an existing commercial product. An important goal is to enable the developer to incorporate the technology into a next-generation commercial product, thus enabling Air Force access to improved mass storage technology.

When the equipment is delivered in 1997, the rewritable library will be mated with a commercial WORM library to provide a 1-Terabyte storage capability. The hybrid (0.5-TB WORM and 0.5-TB erasable) optical disk library will become an integral part of the Hierarchical Storage Management (HSM) environment aimed at satisfying high-performance automated-intelligence data handling and image-exploitation requirements.

Parallel Optical Disk Operations

Another Advanced Development Model is our Optical disk-based Redundant Array of Inexpensive Disks (O-RAID).



The purpose is to determine the feasibility of developing a single, integrated, high-performance device capable of combining the benefits of optical disk technology within a RAID system. The design is partitioned into three basic elements: the optical disk drives, the rewritable media and the electronics controller. The basic O-RAID design consists of multiple optical disk drives operating as a single large optical disk to a host computer requesting the data. Optical disk drives are used because of their high reliability, data retention capabilities and the ability to remove media for storage. The RAID architecture supports increased reliability and accuracy of the data stored. Our initial prototype demonstrated a data transfer speed of 8.8 megabytes per second combined with a base storage capacity of 6.5 gigabytes provided by 5 parallel optical disk drives. The system design is modular and scalable to take advantage of improved optical disk technologies that may be available in the future.

Next-Generation Optical Disk Technology

While today's optical disk systems rely on laser diodes operating at 780 nm to record 1 μ m spots, using shorter wavelength lasers may increase disk storage. Throughout the world, researchers are investigating blue-green laser diodes operating at 460 nm. However, to fully exploit the new laser device advantages, new media and recording techniques must be developed. ARPA selected Rome Laboratory as Executive Agent for the "Short-Wavelength Optical Storage" Technology Reinvestment Project (TRP). The project's primary goal is to develop a 20 GB 5.25-inch optical disk by the year 2000, with access times and transfer rates that are at least equivalent to magnetic disk technology. To do this, we must resolve several key issues relating to substrate materials, servo, format, mastering and substrate processes, recording layers and processes, and read-channel electronics. As the Air Force makes greater use of digital images, video, and multimedia products for their military applications, we must develop cost-effective, high-density data storage. This effort's goal is to develop and demonstrate prototype high-density, rewritable optical disk technology (including media, heads, and drive) and viable manufacturing technology. The project has the potential to radically alter the way information is stored and retrieved in future military data storage systems.

Summary

Optical disk storage technology is playing an increasingly more important role in the Air Force's data storage and management requirements. Rome Laboratory's role has been to advance the state-of-the-art to satisfy the Air Force's unique operational needs through prototype development and operational testing. Our needs cover environments from space to airborne to tactical field conditions. Additionally, optical disk technology provides inherent advantages in distributed computing environments that require Terabyte and Petabyte storage capacities, medium access times and archivability.

However, optical disk, along with most secondary storage devices, suffers from storage capacity limits imposed by its 2-D planar format. Rome Laboratory is addressing these deficiencies by investigating alternative 3-D and 4-D optical memory technologies. These new approaches are being presented in a complementary paper.

References

- [1] Haritatos, Fred N., "Optical Recording," *Defense Electronics*, vol. 25, no. 10, Sept. 1993.
- [2] Haritatos, Fred N., "High Performance Optical Disk Systems for Tactical Applications," *IEEE*, May 1991.
- [3] Haritatos, Fred N., "Air Force Applications for Military Optical Disk Systems," *SPIE/IS&T Image Storage and Retrieval Systems*, Feb. 1992.
- [4] Haritatos, Fred N., "High Performance Optical Disk Systems," *SPIE/OSA Optical Data Storage Conference*, Feb. 1991.