by Lisa Dhar

A New Venture in Holographic Storage

Holography holds great promise as a technology that can overcome two approaching physical barriers to data storage through a powerful combination of high storage densities and fast data-transfer rates. Within a decade, the storage industry expects traditional magnetic storage to reach the superparamagnetic limit, the point at which magnetic orientation energy equals the surrounding thermal energy and small magnetic bits spontaneously flip at ordinary operating temperatures. Areal densities in traditional optical storage confront a similar physical phenomenon, the diffraction limit, in which the wavelength of the recording light limits the size of optical bits. In addition, increasing the data-transfer rate by using traditional magnetic and optical approaches is technically difficult because faster transfer rates require devices that move at incredibly high speeds.

Holography can support storage densities that surpass the superparamagnetic and diffraction limits and provide data-transfer rates of billions of bits per second. It can do so because holographic storage differs from other recording technologies in two fundamental ways. First, holography enables massively parallel recording and reading of data rather than the serial approach of traditional methods. Second, it exploits the entire thickness of a recording medium rather than just the surface. Despite the immense potential of holographic data storage, however, its development has been blocked by the absence of critical recording materials and architec-

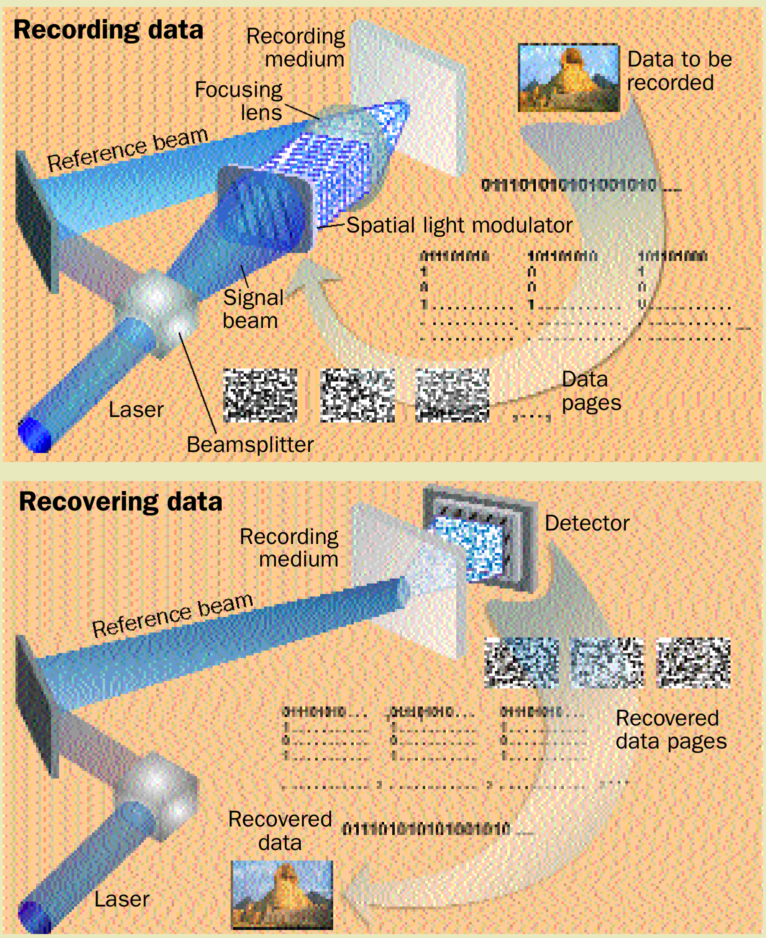
How Holographic Storage Works

In holographic storage, light from a coherent laser source is split into two beams, the signal (data-carrying) and reference beams. These beams enter the photosensitive storage medium from different angles and traverse the same volume. The overlapping beams produce an optical interference pattern, which changes the physical properties of the recording material and its refractive index. This process records information contained in the phase and amplitude of the two beams and yields diffractive volume gratings, which enable the information to be read out.

Data is encoded in the signal beam 1 million bits at a time through the use of a spatial light modulator. The information to be stored is first digitized, but instead of the 1s and 0s being recorded individually as in traditional storage technologies, they are grouped into arrays or pages. These pages are then sent electronically to a spatial light modulator, which rapidly changes its pixel array—and,thus, the signal-light beam as it passes through the modulator—to match the pattern of bits on each data page. The modulator pixels, each about 100 μm^2 in size, either block or transmit light, depending on whether the pixel corresponds to a 0 or a 1. The signal-light beam is, therefore, encoded with the data pages.

Data are read out in a similar manner. By diffracting the reference beam off the recorded optical-interference pattern, the data page is regenerated and captured by an array detector, which allows the data to be reconstructed. This parallel recording and readout of 1 million bits at a time enables the rapid data-transfer rates of holographic storage.

Holography departs from traditional storage technologies in a second way—the data in holography are stored throughout the volume of a recording medium rather than only at the surface. Information stored by the two overlapping light beams possesses a unique volume address provided by the reference beam. Subsequent data pages can be stored in the same volume by altering some aspect of the reference beam, such as its incidence angle. Individual data pages are then read back by simply applying the same reference beam used during recording. This ability to superimpose data throughout the volume yields the enormous density capabilities of holographic storage.



tures and by the lack of components such as suitable laser sources, light detectors, and spatial light modulators, which contain arrays of pixels that block or pass light.

Recent research at Lucent Technologies' Bell Laboratories that focused on these challenges resulted in advances that provide the foundation for a practical, realizable, high-capacity storage system with fast transfer rates and removable recording media. InPhase Technologies, Inc. (Longmont, CO), a newly formed start-up launched from Bell Labs, is developing holographic storage technologies that break through the performance barriers of traditional data-storage approaches.

Holographic recording materials must satisfy stringent criteria, including high dynamic range, high photosensitivity, dimensional stability, optical clarity, nondestructive readout, millimeter thickness, and environmental and thermal stability. Although researchers have evaluated many materials for holographic storage, most suffer from disadvantages that preclude their use in commercial systems. A Bell Labs team has designed new types of polymers that yield high-response, high-sensitivity, dimensionally stable, and environmentally robust storage media in millimeter-thick, optically flat formats.

Traditional holographic recording methods require large optical systems and moving optical parts—architectures that are difficult to implement in commercial systems. The Bell Labs group invented new types of recording configurations that enable simple and compact storage systems compatible with the translating-card and spinning-disk architectures used in much of the storage industry. In addition, the team took advantage of recent developments in compact solid-state lasers, liquid-crystal spatial light modulators, micromirror devices, charge-coupled-device cameras, and complementary-metal-oxide-semiconductor detectors to produce significant advances in component-systems integration.

Lucent Technologies formed InPhase in January to capitalize on the breakthroughs. The company was launched through the Lucent New Ventures Group, a unit dedicated to commercializing Bell Labs technologies that may not fit into Lucent's current businesses. (Since 1996, the Lucent New Ventures Group has spun off more than 30 such companies.) The Bell Labs technical team worked closely with the New Ventures Group through all stages of the launch process, from writing the business plan and raising funding to recruiting a management team and establishing new facilities.

InPhase was spun off with the core technical team from Bell Labs and a management team with deep experience in the storage industry. In addition to receiving support from Lucent, InPhase is financed by Imation Corp. (Oakdale, MN) and venture-capital funding. The new company is developing high-performance holographic data-storage media and systems for business and consumer markets.

For further reading

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Psaltis, D.; Mok, F. *Holographic Memories* **1995**, *273* (5), 70–75.

InPhase Technologies. http://www.inphase-technologies.com.

Lucent New Ventures Group. http://www. lucent.com/newventures/index.html. Ω

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