Holographic Storage Media

Tilghman L. Rittenhouse Literature Seminar April 25, 2002

Memory devices that currently depend upon magnetic or optical storage schemes are rapidly approaching their theoretical limits for capacity.[1] Concurrently, advances in technology needed to implement a holographic storage device continue to improve. However, synthesizing the medium used to actually store the data continues to be problematic, impeding the development of a marketable holographic memory unit.[2]

Crystalline inorganic materials have become a leading candidate in holographic applications such as computer memories. To store data, two laser beams converge upon the storage medium from different angles. One of the laser beams (data beam) is composed of a pattern of spots representing individual bits of data. The other laser beam (reference beam) strikes the crystal from another angle, forming a pattern of constructive and destructive interference within the medium. In a photorefractive crystal, this interference pattern is recorded via electron migration from regions of constructive interference to regions of destructive interference. The resulting charge distribution forms a spatially-dependent refractive index grating within the crystal.[3] Subsequent illumination of the crystal by only the reference laser beam will recreate the data beam, allowing stored data to be accessed.[4]

To meet these demands, a variety of inorganic photorefractive materials are being investigated as holographic storage media. Ferroelectric perovskites such as barium titanate offer advantages such as high sensitivity and fast time response. However, it has proven difficult to grow large crystals of barium titanate with consistent chemical properties. Current work is limited to small crystals that can store only a relatively small number of holograms. Sillenite-type crystals (bismuth silicon oxide, etc.) offer similar sensitivity and response times as barium titanate. However, in addition to the difficulty of growing pure and homogeneous crystals, the sillenite-type crystals suffer from dark decay of the stored data. Currently, storage times in these crystals is far too short to become a viable memory device for applications such as the personal computer.

By far, the front-runner in the field of data storage is lithium niobate. Large lithium niobate crystals can be grown with relatively good homogeneity via Czochralski growth. Annealing via vapor transport equilibration offers further improvements in stoichiometry control. Lithium niobate crystals have set the record in terms of the amount of information stored within a single crystal. A disadvantage of using lithium niobate is its low sensitivity, requiring laser beams with relatively high intensities and long exposure times in order to record a hologram.[1] In addition, lithium niobate also suffers from dark decay of the stored information as well as erasure of the electron grating during readout.[5] Ingenious methods of processing and doping lithium niobate have been developed in order to overcome these shortcomings.

In order to increase sensitivity, lithium niobate crystals are often extrinsically doped with a donor element such as iron. However, the holographic data stored in the crystal will still slowly decay in the dark. The mechanism of dark decay depends upon the dopant characteristics of the crystal.[5,6] At low doping concentrations, cations in the crystal will diffuse and erase the electron charge grating.[7] As a result, for lightly doped lithium niobate crystals, a post-growth anneal in an oxidizing atmosphere is important in order to minimize the concentration of free protons in the crystal available for diffusion. Conversely, in heavily doped lithium niobate crystals, electron tunneling between the dopant atoms becomes the primary means of data erasure. Electron tunneling sets maximum limits on extrinsic doping concentrations.

In order to reduce data volatility during readout of the holograms, "gated" (two color) recording can be utilized.[8-14] Lithium niobate doped with both manganese and iron works well during two color recording.[15] During writing, a high-energy beam is used in conjunction with the lower-energy information and reference beams in order to promote electrons from the deep manganese traps and form the interference pattern in the crystal's iron dopants. Subsequent reading of the holographic data involves only the low-energy reference beam, and although the iron dopants become bleached during readout, the mobile electrons soon become trapped at manganese cations nearby.

The effectiveness of gated holographic writing is evident from the work of Adibi, Buse, and Psaltis.[10] Their work has shown that the post-growth annealing conditions of the doped lithium niobate crystal is critical to its performance. In Figure 1, sample LN1 represents a crystal that has been annealed in too oxidizing of an atmosphere. This results in nearly all of the impurity traps being void of electrons, and therefore there are no free charge carriers available to migrate and form the refractive index pattern. Conversely, sample LN4 has been exposed to a strong reducing atmosphere. Many charge carriers reside in the manganese and iron traps, resulting in the ability to record a strong hologram. However, during reading this material loses the refractive index grating quickly because there are few unoccupied manganese levels to trap the electrons. Samples LN2 and LN3 show acceptable retention of the holographic pattern during reading of the data. These crystals were exposed to annealing atmospheres that left approximately 95% of the manganese traps filled and the iron traps empty before recording.

When holographic memory devices do become marketable, they will offer huge leaps in storage capacity, data access times, and data transfer rates. However, difficulties remain in designing crystals to actually store the refractive index gratings. Continuing research in this field should yield systems that will serve as high-capacity databases by the end of this decade.

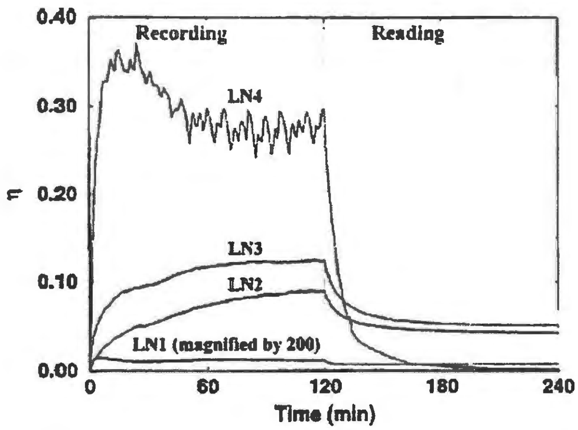

Figure 1. Behavior of lithium niobate crystals doped with manganese and iron.[10]

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