The role of nanotechnology in data storage devices and systems

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The Role of Nano-technology in Data Storage Devices and Systems

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Abstract: As data storage technologies evolve and new applications emerge, the balance among electronic, magnetic, and optical modes of storage shifts in ways that are not always predictable. Commercial success of a given technology, however, is invariably tied to its ability to continually shrink the spatial dimensions of individual bits.

OCIS codes: optical data storage (210.0210), optical devices (230.0230), physical optics (260.0260).

Introduction. The evolution of data storage technologies in recent years has reduced the individual bits' dimensions far below the micron and submicron scales, to the point that we are now entering the era of nano dimensions. In this presentation we provide examples of current magnetic, optical, and electronic data storage devices that operate in the nano regime. We also discuss the potential applications of emerging nano-technologies in future data storage systems.

1. Magnetic Recording. In hard-disk drives, the magnetic layer of the disk (on which digital information resides) is nano-structured. A typical cross-sectional diagram of perpendicular magnetic recording (PMR) media is shown in Fig.1. Also shown in this figure are TEM images of the CoPtCr granular magnetic material. Individual magnetic grains are surrounded by non-magnetic amorphous SiO_2, resulting in reduced magnetic interactions among CoPtCr grains.

A schematic diagram of the read/write head used in PMR is shown in Fig. 2. The giant magneto-resistive (GMR) sensor and the mono-pole inductive write element are other examples of nano-technology adapted for use in commercial hard-disk drives. The inset shows a magnetic force micrograph of a small section of a recorded track on a PMR disk; individual magnetic domains, depicted in black and white, have dimensions of $\sim 20\times 50\,\text{nm}^2$.

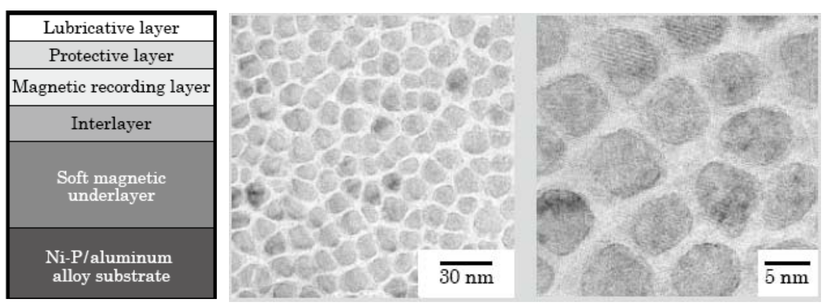
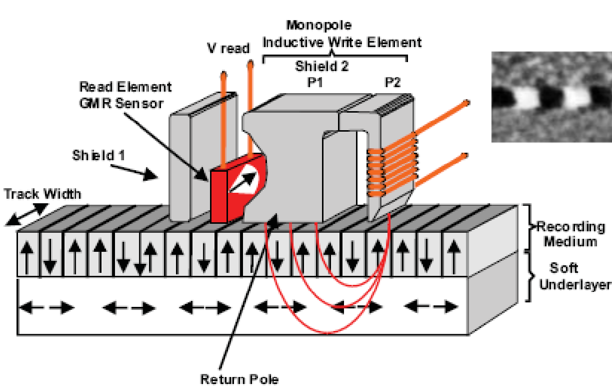


Fig. 1. (Left) Layer structure of PMR disk. The magnetic recording layer's thickness is typically around 10 nm, while the soft under-layer is about 100 nm-thick; other layers are only a few nanometers thick. (Right) TEM images of the magnetic recording layer, showing CoPtCr grains of ~5 nm diameter embedded in a non-magnetic SiO_2 matrix [1].



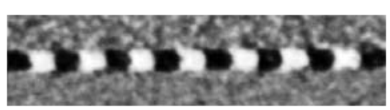


Fig. 2. Diagram of a PMR head flying over a hard disk. The tip of the monopole inductive write element is 50 nm long and 20 nm wide. The magnetic field returns through the soft underlayer of the recording film. Also shown is the GMR read element. (Inset) MFM image of $20\times 50\,\text{nm}^2$ recorded domains [2].

2. Optical Recording. Plasmonic data storage is a new mode of optical recording proposed in recent years [3-5]. Metallic nano-structures have fairly sharp resonances at specific wavelengths. The resonance wavelength is sensitive to the geometrical shape and size of the nano-structure, as well as to its orientation relative to the polarization of the incident light. Fig. 3 shows four identical unit-cells of a plasmonic structure fabricated in a 30 nm-thick gold film using e-beam lithography. Each $500 \times 500\,\mathrm{nm}^2$ cell contains 10 different nano-features. The reflectance and transmittance of these cells under a diffraction-limited focused spot are strong functions of the wavelength, thus providing a spectral means of distinguishing among a large number of different patterns – despite the fact that individual features are much smaller than the diffraction limit.

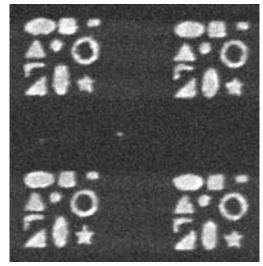


Fig. 3. Four identical $500 \times 500\,\mathrm{nm}^2$ bit-cells, each containing 10 different plasmonic nano-structures etched onto a gold film [4].

An important example of plasmonic data storage is the so-called 5-dimensional optical recording scheme that stores information in a layered disk while encoding data in the wavelength and polarization state of the read/write laser beam. Figure 4 shows two images that have been recorded on a plasmonic material composed of gold nano-rods, taking advantage of the wavelength- as well as polarization-dependence of plasmonic resonances [5]. Also shown in Fig. 4 is a TEM micrograph of the gold nano-rods of differing dimensions and orientations.

Fig. 4. (Left and Center) Images recorded in a thin layer of gold nano-rods using a femto-second pulsed laser. (Right) TEM image of nano-rods having a tunable surface plasmon resonance absorption band (due to their anisotropic shape) with a bandwidth of 40 nm; nano-rod diameters are ~10 nm [5].

3. Electronic Data Storage. Static and dynamic random access memories (SRAM and DRAM), have long been the *primary* storage media of electronic computers. Advances in Flash memory technologies during the past decade have now made these electronic devices a significant contender in the market for *secondary* data storage media as well. While shrinking dimensions brought about by advanced photo-lithography have resulted in a rapid rise in Flash capacities, their relatively slow data-rates and the prospect of diminished data retention time (due to charge leakage) have opened up a niche market for the alternative technologies of magnetic and phase-change random access memories (MRAM and PRAM). All these memories rely on electronic switching of nano-volumes of material at the junctions of a crossed-wire array. In the case of PRAM, for instance, Fig. 5 shows a thin layer of polycrystalline GeSbTe alloy (red) sandwiched between a pair of crossed electrical conductors (gray). Thermo-electric switching between the amorphous and crystalline phases of the GeSbTe material produces a durable, albeit reversible, change in the resistivity of the junction. These materials have the potential to achieve tera bit/cm^2 densities by shrinking the junction area to $\sim 10 \times 10\,\mathrm{nm}^2$. In April 2010 Samsung announced a 512 Mb multi-chip package PRAM, which provides three-times faster "write" per word than NOR chips, thus combining the non-volatile nature of flash memory with the high-speed capability of DRAM.

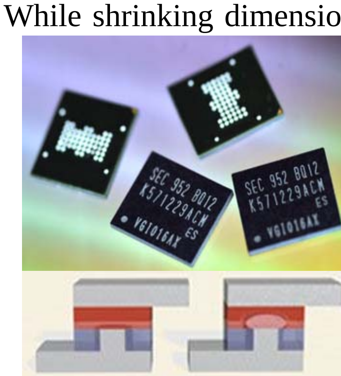


Fig. 5. Samsung's multi-chip package PRAM (shown at the top) uses a cross-wire architecture in which the GeSbTe alloy (red) sandwiched between crossed electrical conductors (grey) undergoes a durable but reversible phase transition between amorphous and crystalline states.

4. Promising Nano Technologies. In addition to plasmonic nano-materials, which are metallic, semiconducting nano-structures such as quantum-dots and quantum-wires have optical and electronic properties that make them attractive for advanced data storage applications.

In a different arena, patterned media are being developed for various modes of data storage. Electron-beam lithography and focused ion-beam techniques have been considered for fabricating the master stamper, followed by a nano-imprint technique for rapid and inexpensive transfer of the mastered patterns to disk substrates. In addition, methods of fiber-optical cable manufacturing have significant potential for mass-producing nano-patterned substrates. Figure 6 shows how micro- and nano-wires could be pulled, using a rod and a cylinder of two materials having differing etch-rates [6,7]. The pulled fibers are subsequently cut, bundled, and pulled again, and the process repeated until two-dimensional periodic array structures of large cross-sectional area are obtained. Slicing these bundles into thin sheets and etching their surface produces patterned substrates such as those shown in Fig.7.

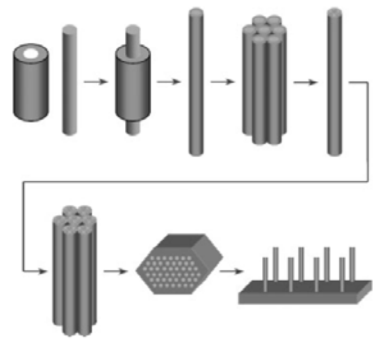


Fig. 6. Scheme of aligned micro-nano-wire array fabrication using fiber drawing manufacturing [6].

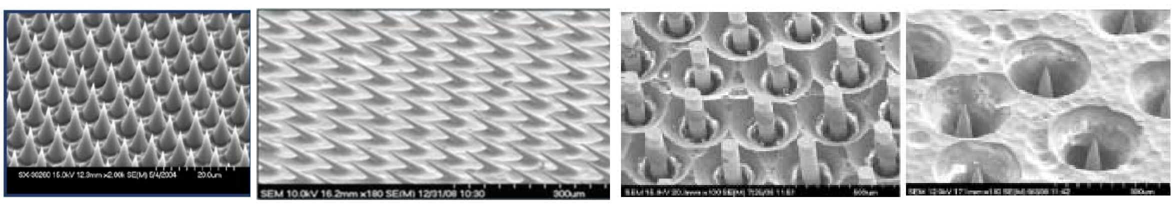


Fig.7. (a) Glass cone array: cones and matrix have different etch-rates; (b) glass cones obtained by slicing the bundle at an angle, then etching; (c, d) exposed tungsten wires after electro-chemical etching of the glass matrix [7].

Another area of nano-technology which is ripe for exploitation is that of pulsed fiber lasers. Photonic crystal (PC) fibers such as those shown in Fig. 8 have strong nonlinear and dispersive properties, which enable their use in spatially-coherent, femto-second laser pulse generation. Inexpensive fiber lasers in conjunction with PC fibers produce extremely short light pulses (exhibiting super continuum spectra) at high repetition rates. These light source are suitable for some of the proposed modes of high-density optical data storage [3-5].

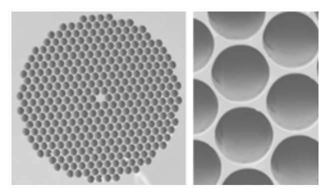


Fig. 8. SEM micrograph of a typical PC fiber. Solid core diameter (at center) = 5 μm, hole diameter = 4 μm.

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