7.10 The Future of Data Storage

- Advances in technology have defied all efforts to define the ultimate upper limit for magnetic disk storage.
  - In the 1970s, the upper limit was thought to be around $2Mb/in^2$.
  - Today's disks commonly support $20Gb/in^2$.
- Improvements have occurred in several different technologies including:
  - Materials science
  - Magneto-optical recording heads.
  - Error correcting codes.
- Future exponential gains in data storage most likely will occur through the use of totally new technologies.
- Research into finding suitable replacements for magnetic disks is taking place on several fronts.
- Some of the more interesting technologies include:
  - Biological materials
  - Holographic systems
  - Micro-electro-mechanical devices
  - Carbon nanotubes
  - Memristors

Biological Materials

- Present day biological data storage systems combine organic compounds such as proteins or oils with inorganic (magentizable) substances.
- Early prototypes have encouraged the expectation that densities of $1Tb/in^2$ are attainable.
- Of course, the ultimate biological data storage medium is DNA.
  - Trillions of messages can be stored in a tiny strand of DNA.
- Practical DNA-based data storage is most likely decades away.

Holographic Data Storage

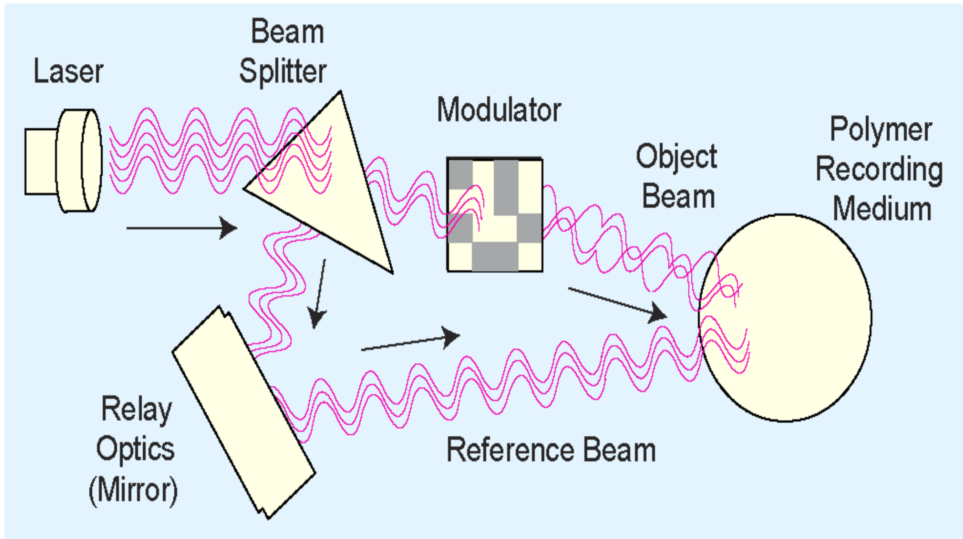

Figure 7.37 a) Holographic Storage (Writing Data)

- Holographic storage uses a pair of laser beams to etch a three-dimensional hologram onto a polymer medium.

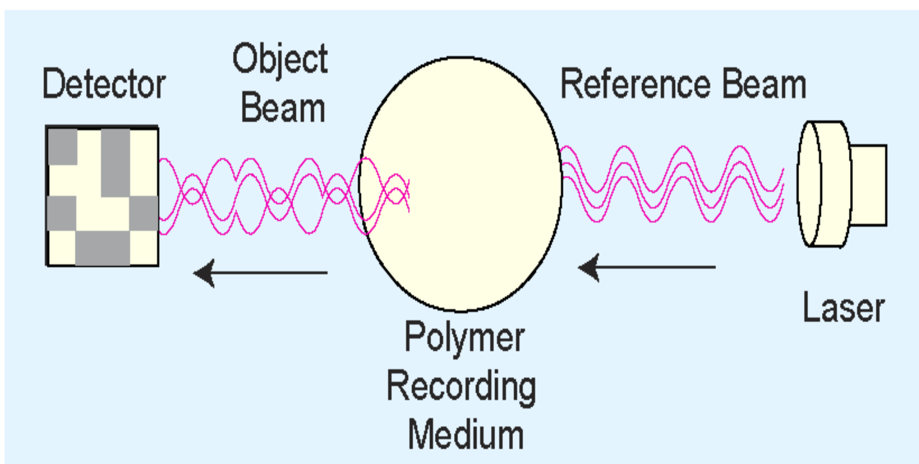

Figure 7.37 b) Holographic Storage (Reading Data)

- Data are retrieved by passing the reference beam through the hologram, thereby reproducing the original coded object beam.
- Because holograms are three-dimensional, tremendous data densities are possible.
- Experimental systems have achieved over 30Gb/in^2, with transfer rates of around 1GBps.
- In addition, holographic storage is content addressable.
    - This means that there is no need for a file directory on the disk. Accordingly, access time is reduced.

- The major challenge is in finding an inexpensive, stable, rewriteable holographic medium.

Micro-electronic-mechanical storage

- Micro-electro-mechanical storage (MEMS) devices offer another promising approach to mass storage.
- IBM's Millipede is one such device.
- Prototypes have achieved densities of 100Gb/in^2 with 1Tb/in^2 expected as the technology is refined.

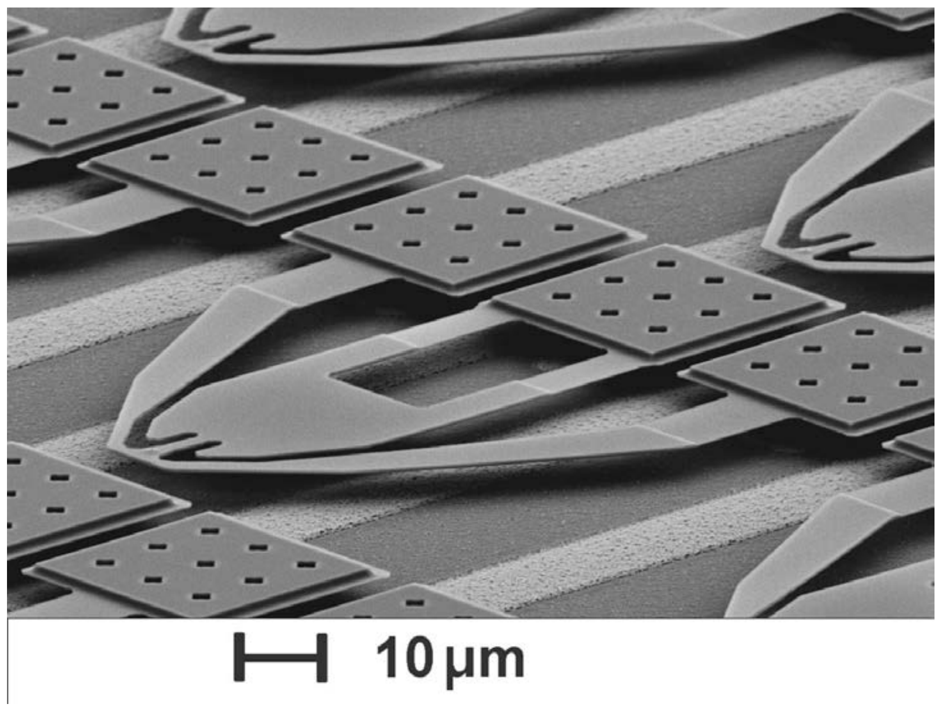

Figure 7.38 A Scanning Electron Microscope Image of the Three-Terminal Integrated Cantilevers of IBM's Millipede Storage Device.

The cantilevers are 70 μm long and 75 μm wide. The outer arms of the cantilevers are just 10 μm wide.

- The tip reads a binary 1 when it dips into the imprint in the polymer
- Millipede consists of thousands of cantilevers that record a binary 1 by pressing a heated tip into a polymer substrate.

Carbon nanotubes (CNT)

- CNTs are a cylindrical form of elemental carbon: The walls of the cylinders are one atom thick.
- CNTs can act like switches, opening and closing to store bits.
- Once “set” the CNT stays in place until a release voltage is applied.

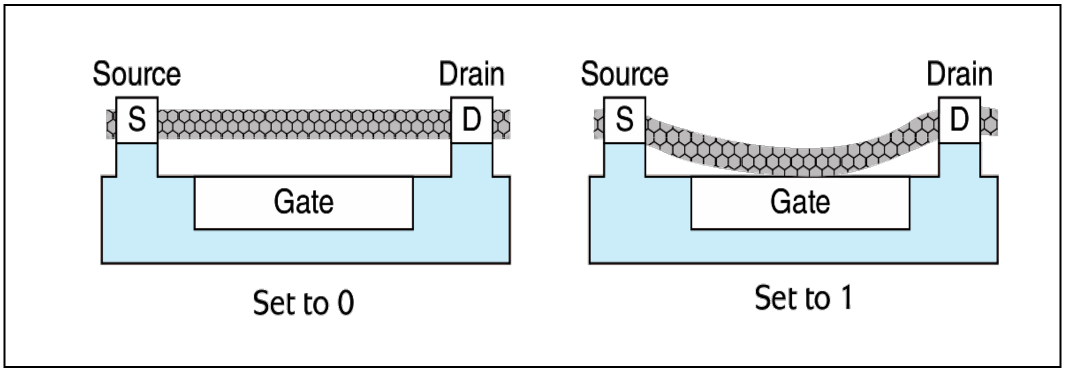

Figure 7.39 Carbon Nanotube Bit Storage
Left – Bit set to 0
Right – Bit set to 1

Memristor memories

- Memristors are electronic components that combine the properties of a resistor with memory.
- Resistance to current flow can be controlled so that states of “high” and “low” store data bits.
- Like CNTs, memristor memories are non-volatile, holding their state until certain threshold voltages are applied.
- These non-volatile memories promise enormous energy savings and increased data access speeds in the very near future.