OPTICAL COMPUTERS: THE FUTURE OF TECHNOLOGY

Abstract:

According to Moore's Law the number of transistors on a computer chip doubles every 18 months. But as we continue to make transistors smaller, we will eventually run out of space on microchips. So in order to keep advancing in computer technology without adding transistors as it is done today, we need to change the composition of the hardware. The next step into the future of computers is in optics. Optics offers many benefits over today's electrical computers including: higher bandwidth, superior processing power, and enlarged storage space.

Optical Computers need not be thought of merely as rapid substitutions for electronic devices. On the contrary, the greatest benefit of optical switches could come from applications that cannot be duplicated by other means. Optical fibers, which can carry prodigious amounts of information, are being used increasingly for communications among computers. Optical switching is a natural candidate to mediate between electronic systems and optical ones. On the other hand, if the computation is done optically to begin with, optical fibers could be employed as direct links between computing systems. There is no doubt that the optical computer is a realistic and exciting prospect.

A computer in which all internal circuits use light instead of electricity. Long predicted, an all-optical computer is not expected for some time as there are enormous hurdles to overcome. However, there are definite advantages to optical circuits over electrical ones. Light beams are neither affected by external radiation, nor by themselves. In fact, light beams can cross each other, allowing for simpler travel paths between inputs and outputs. . Optical computer technology is still in the early stages: functional optical computers have been built in the laboratory, but none have progressed past the prototype stage. Most research projects focus on replacing current computer components with optical equivalents, resulting in an optical digital computer system processing binary data. This approach appears to offer the best short-term prospects for commercial optical computing, since optical components could be integrated into traditional computers to produce an optical/electronic hybrid. Other research projects take a non-traditional approach, attempting to develop entirely new methods of computing that are not physically possible with electronics.

Key words: *Micro chips, optical fibers, optical equivalents.*

Conclusion: Optical computing when compared to electrical computing is advancement. Using optical computing we can have lot of useful applications in computers.

Introduction:

Computers have enhanced human life to a great extent. The speed of conventional computers is achieved by miniaturizing electronic components to a very small micron-size scale so that those electrons need to travel only very short distances within a very short time. The goal of improving on computer speed has resulted in the development of the Very Large Scale Integration (VLSI) technology with smaller device dimensions and greater complexity. Last year, the smallest-to date dimensions of VLSI reached 0.08 mm by researchers at Lucent Technology. Whereas VLSI technology has revolutionized the electronics industry and established the 20th century as the computer age, increasing usage of the Internet demands better accommodation of a 10 to 15 percent per month growth rate. Additionally, our daily lives demand solutions to increasingly sophisticated and complex problems, which requires more speed and better performance of computers. For these reasons, it is unfortunate that VLSI technology is approaching its fundamental limits in the sub-micron miniaturization process. It is now possible to fit up to 300 million transistors on a single silicon chip. Further miniaturization of lithography introduces several problems such as dielectric breakdown, hot carriers, and short channel effects. All of these factors combine to seriously degrade device reliability. Even if developing technology succeeded in temporarily overcoming these physical problems, we will continue to face them as long as increasing demands for higher integration continues. Therefore, a dramatic solution to the problem is needed, and unless we gear our thoughts toward a totally different pathway, we will not be able to further improve our computer performance for the future.

Optical Computers:

An **optical computer** (also called a photonic computer) is a computer that uses light instead of electricity (i.e. photons rather than electrons) to manipulate, store and transmit data. Photons have fundamentally different physical properties than electrons, and researchers have attempted to make use of these properties to produce computers with performance and/or capabilities greater than those of electronic computers. It is a device that uses the photons in visible light or infrared (IR) beams, rather than electric current, to perform digital computations. An electric current flows at only about 10 percent of the speed of light. This limits the rate at which data can be exchanged over long distances, and is one of the factors that led to the evolution of optical fiber. By applying some of the advantages of visible and/or IR networks at the device and component scale, a computer might someday be developed that can perform operations 10 or more times faster than a conventional electronic computer.

Visible-light and IR beams, unlike electric currents, pass through each other without interacting. Several (or many) laser beam scan be shone so their paths intersect, but there is no interference among the beams, even when they are confined essentially to two dimensions. Electric currents must be guided around each other, and this makes three-dimensional wiring necessary. Thus, an optical computer, besides being much faster than an electronic one, might also be smaller. Optical computer technology is still in the early stages: functional optical computers have been built in the laboratory, but none have progressed past the prototype stage.

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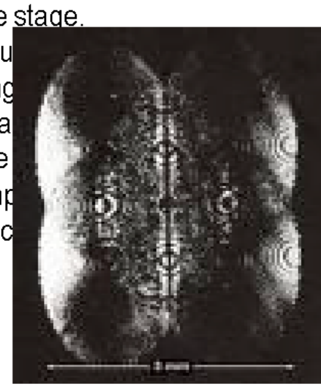


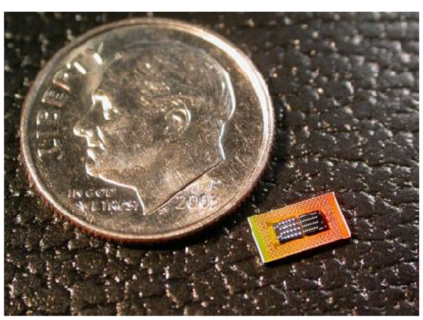
Optical computer prototype optical computer

Optical technology has made its most significant inroads in digital communications, where fiber optic data transmission has become commonplace. The ultimate goal is the so-called photonic network, which uses visible and IR energy exclusively between each source and destination. Optical technology is employed in CD-ROM drives and their relatives, laser printers, and most photocopiers and scanners. However, none of these devices are fully optical; all rely to some extent on conventional electronic circuits and components.

Optical components for binary digital computer:

The fundamental building block of modern electronic computers is the transistor. To replace electronic components with optical ones, an equivalent "optical transistor" is required. This is achieved using materials with a non-linear refractive index. In particular, materials exist where the intensity of incoming light affects the intensity of the light transmitted through the material in a similar manner to the voltage response of an electronic transistor. This "optical transistor" effect is used to create logic gates, which in turn are assembled into the higher level components of the computer's CPU.

The problem with light-based transistors is that they need very large amounts of energy to operate and hence tend to be rather large in size. However recently, a team at Queen's University in Belfast came up with a solution to this particular problem. Their technique provided a possible way to get two individual light beams to interact with each other in a way similar to how electrons interact in an electronic transistor. Now when signal light beam is focused on a metal (in this case a gold film 220nm thick), free electrons are created which are called ‘plasmons’. The plasmon changes depending on the intensity of the light. Using a second 'control light beam' at 45 degrees to the gold film, we can alter the state of the plasmon which in turn will affect the effect of the signal beam. The plasmon will then release energy in the form of light, which acts at the resultant of the two initial light beams. This way we are able to get two separate sources of light to interact and produce a resultant light beam.

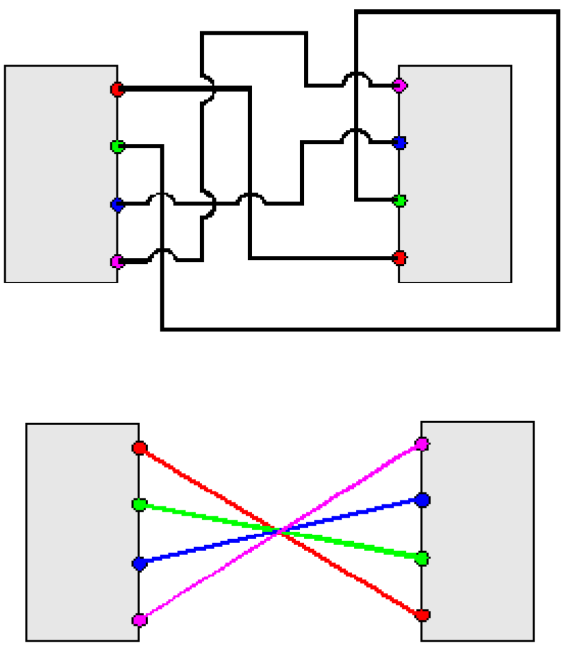


An IBM Optical Chip

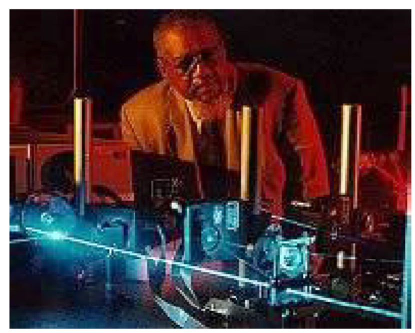
Optics has a higher bandwidth capacity over electronics, which enables more information to be carried and data to be processed arises because electronic communication along wires requires charging of a capacitor that depends on length. In contrast, optical signals in optical fibers, optical integrated circuits, and free space do not have to charge a capacitor and are therefore faster.

Another advantage of optical methods over electronic ones for computing is that optical data processing can be done much easier and less expensive in parallel than can be done in electronics. Parallelism is the capability of the system to execute more than one operation simultaneously. Electronic computer architecture is, in general, sequential, where the instructions are implemented in sequence. This implies that parallelism with electronics is difficult to construct. Parallelism first appeared in Cray super computers in the early 1980's. Two processors were used in conjunction with the computer memory to achieve parallelism and to enhance the speed to more than 10 Gb/ s. It was later realized that more processors were not necessary to increase computational speed, but could be in fact detrimental. This is because as more processors are used, there is more time lost in communication. On the other hand, using a simple optical design, an array of pixels can be transferred simultaneously in parallel from one point to another. Parallelism, therefore, when associated with fast switching speeds, would result in staggering computational speeds.

Another advantage of light results because photons are uncharged and do not interact with one another as readily as electrons. Consequently, light beams may pass through one another in full duplex operation, for example without distorting the information carried. In the case of electronics, loops usually generate noise voltage spikes whenever the electromagnetic fields through the loop changes. Further, high frequency or fast switching pulses will cause interference in neighboring wires. Signals in adjacent fibers or in optical integrated channels do not affect one another nor do they pick up noise due to loops. Finally, optical materials possess superior storage density and accessibility over magnetic materials.



Electrical crossovers (top) require three dimensions, but optical crossovers (bottom) require only two dimensions because light beams do not interact



Dr. Donald Frazier monitors a blue laser light used with electro-optical

Optical cable

Misconceptions, challenges and prospects:

Another claimed advantage of optics is that it can reduce power consumption, but an optical communication system will typically use more power over short distances than an electronic one. This is because the shot noise of an optical communication channel is greater than the thermal noise of an electrical channel which, from information theory, means that we require more signal power to achieve the same data capacity. However, over longer distances and at greater data rates the loss in electrical lines is sufficiently large that optical communications will comparatively use a lower amount of power. As communication data rates rise, this distance becomes shorter and so the prospect of using optics in computing systems becomes more practical.

A significant challenge to optical computing is that computation is a nonlinear process in which multiple signals must interact to compute the answer. Light, which is an electromagnetic wave, can only interact with another electromagnetic wave in the presence of electrons in a material and the strength of this interaction is much weaker for electromagnetic wave light than for the electronic signals in a conventional computer. This results in the processing elements for an optical computer requiring high powers and larger dimensions than for a conventional electronic computer using transistors.

Future optical computer optical computer mouse

Optical Computing:

1.Optical Components and Storage Systems:

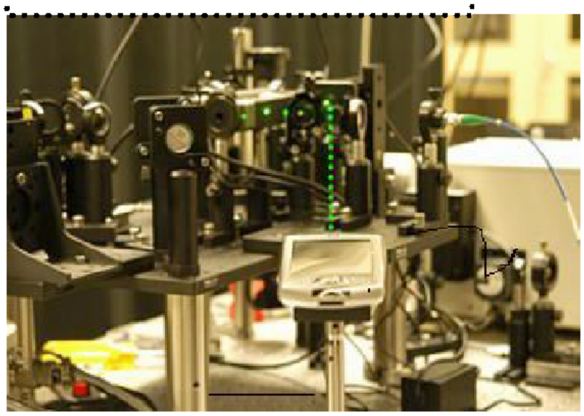
Optics has been used in computing for a number of years but the main emphasis has been and continues to be to link portions of computers, for communications, or more intrinsically in devices that have some optical application or component (optical pattern recognition, etc). Optical digital computers are still some years away, however a number of devices that can ultimately lead to real optical computers have already been manufactured, including optical logic gates, optical switches, optical interconnections, and optical memory. The most likely near-term optical computer will really be a hybrid composed of traditional architectural design along with some portions that can perform some functional operations in optical mode.

2. Research Trends:

Researchers are using new conducting polymers to make transistor-like switches that a smaller and thousand times faster than the silicon transistors. Electricity-conducting organic molecules that are much thinner than semiconductor wires, are being teased into self-assembling. These advances promise super-tiny all-optical chips. In fact, progress in optical storage devices can now shrink an entire Library's book collection down to sugar-cube size. Optical computers could be leaving silicon number crunchers choking in the dust by decade's end.

Optical or photonic computers

Future Optical Computers



3. Photonic logic

Photonic logic is the use of photons (light) in logic gates (AND, NAND, OR, NOR, XOR, XNOR). Photonic logic refers to the usage of light (photons) to form logic gates. Switching is obtained using nonlinear optical effects when two or more signals are combined.
Resonators are especially useful in photonic logic, since they allow a build-up of energy from constructive interference, thus enhancing optical nonlinear effects.

Optical Development Boom:

Photonics development is booming worldwide in optics and optical components for computing and other applications. Estimates of global photonic technology sales in 1999 were as high as $100 billion and rising with the ever-increasing demands of data traffic. KMI Corp. reports data traffic growing at 100%

per year worldwide, while London's Phillips Group estimates that U.S. data traffic will increase by 300% annually.
Left: Blue and red lasers reflecting off mirrors – a glimpse of things to come in computing technology.

Most components now in demand are electro-optical (EO) hybrids, which are limited by the speed of their electronic parts. All-optical components will have the advantage of speed over EO devices, but there is a lack of efficient nonlinear optical (NLO) materials that can respond at low power levels. Almost all current all-optical components require a high level of laser power to function as required.

Researchers from the University of Southern California working with a team from the University of California at Los Angeles have jointly developed an organic polymer with a switching frequency of 60 GHz -- three times faster than the current industry-standard lithium niobate crystal-based devices. Commercial development of such a device could revolutionize the "information superhighway" and speed data processing for optical computing.

Another group at Brown University and IBM Corporation's Almaden Research Center in San Jose, CA, have used ultrafast laser pulses to build ultrafast data-storage devices, achieving switching down to 100ps -- results that are almost ten times faster than currently available "speed limits".

Advantages:

- An interesting property of optical computers, optical pathways- is they can carry many different frequencies of light over each pathway and the light detector(s) can be filtered to respond to each of those frequencies, depending on the flexibly programmed topology used. Very Large arrays (VLA's) (4 Mpixels and above) can be fabricated like large optical arrays, each passing, switching or filtering each of the various frequency laser beams. One more major advantages of optical computing is the increase in the speed of computation. Light travels at 186,000 miles per second, 982,080,000 feet per second. In one nanosecond, photons of light travel just a bit less than a foot. Just right for doing things very quickly in microminiaturized computer chips.
- Optical Computing has the main advantages of small size/high density, high speed, low heating of junctions and substrate, dynamically re-configurable, scalable into larger/smaller topologies/networks, well matched for Imaging, massively parallel computing capability and Artificial Intelligence applications i.e.- neural networks of great complexity.
- Apart from the speed the optical interconnections have several other advantages over their magnetic counterparts. They are immune to electromagnetic interference, and free from electrical short circuits. They have low-loss transmission and provide large bandwidth, capable of communicating several channels in parallel without interference. They are capable of propagating signals within the same or adjacent fibers with essentially no interference or cross-talk. They are compact, lightweight, and inexpensive to manufacture, and more facile with stored information than magnetic materials.
- Another advantage of optical methods over electronic ones for computing is that optical data processing can be done much easier and less expensive in parallel than can be done in electronics. Parallelism is the capability of the system to execute more than one operation simultaneously. Electronic computer architecture is, in general, sequential, where the instructions are implemented in sequence. This implies that parallelism with electronics is difficult to construct. On the other hand a photon-based processor using different wavelengths of light that represent color to human eyes could quickly generate many parallel processes, drastically increasing computing speed and complexity.

- Another advantage of light results because photons are uncharged and do not interact with one another as readily as electrons. Consequently, light beams may pass through one another in full-duplex operation, for example without distorting the information carried. In the case of electronics, loops usually generate noise voltage spikes whenever the electromagnetic fields through the loop changes. Further, high frequency or fast switching pulses will cause interference in neighboring wires. Signals in adjacent fibers or in optical integrated channels do not affect one another nor do they pick up noise due to loops. Finally, optical materials possess superior storage density and accessibility over magnetic materials.
- The future of computing is leaning towards large parallel arrays using photonics, rather than electronics, but will probably be for all practical purposes, be opto-electronic in nature, due to the current realm of electronic computing prevalence of using representative voltages "0" or "1" voltage. Optical computing uses a direct analogy of presence or absence of the recognized signal medium, many laser frequencies on a single optical pathway. Multiplexing many frequencies of laser light onto and De-multiplexing off of an optical pathway are common place in DWDM fiber optics for long haul data transfers between cities at 10 to 40 Gbit/s. Thin films on surfaces can make excellent filters of light or polarization.