

ABSTRACT :

With the growth of computing technology the need of high performance computers (HPC) has significantly increased. 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 computing was a hot research area in 1980's. But the work tapered off due to materials limitations that prevented optochips from getting small enough and cheap enough beyond laboratory curiosities. Now, optical computers are back with advances in self-assembled conducting organic polymers that promise super-tiny of all optical chips.

Optical computing technology is, in general, developing in two directions. One approach is to build computers that have the same architecture as presentday computers but using optics that is Electro-Optical hybrids. Another approaches to generate a completely new kind of computer, which can perform all functional operations in optical mode. In recent years, a number of devices that can ultimately lead us to real optical computers have already been manufactured. These include optical logic gates, optical switches, optical interconnections and optical memory.

Current trends in optical computing emphasize communications, for example the use of free space optical interconnects as a potential solution to remove 'Bottlenecks' experienced in electronic architectures. Optical technologies one of the most promising, and may eventually lead to new computing applications as a consequence of faster processing speed, as well as better connectivity and higher bandwidth.

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1. NEED FOR OPTICAL COMPUTING

The pressing need for optical technology stems from the fact that today's computers are limited by the time response of electronic circuits. A solid transmission medium limits both the speed and volume of signals, as well as building up heat that damages components.

One of the theoretical limits on how fast a computer can function is given by Einstein's principle that signal cannot propagate faster than speed of light. So to make computers faster, their components must be smaller and thereby decrease the distance between them. This has resulted in the development of very large scale integration (VLSI) technology, with smaller device dimensions and greater complexity. The smallest dimensions of VLSI nowadays are about 0.08mm. Despite the incredible progress in the development and refinement of the basic technologies over the past decade, there is growing concern that these technologies may not be capable of solving the computing problems of even the current millennium. The speed of computers was achieved by miniaturizing electronic components to a very small micron-size scale, but they are limited not only by the speed of electrons in matter but also by the increasing density of interconnections necessary to link the electronic gates on microchips.

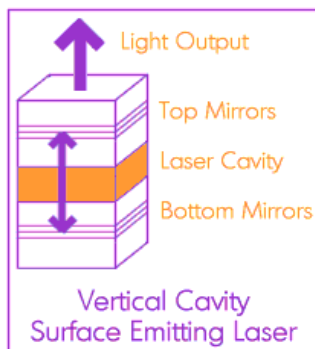
The optical computer comes as a solution of miniaturization problem. Optical data processing can perform several operations in parallel much faster and easier than electrons. This parallelism helps in staggering computational power. For example a calculation that takes a conventional electronic computer more than 11 years to complete could be performed by an optical computer in a single hour. Any way we can realize that in an optical computer, electrons are replaced by photons, the subatomic bits of electromagnetic radiation that make up light.

SOME KEY OPTICAL COMPONENTS FOR COMPUTING

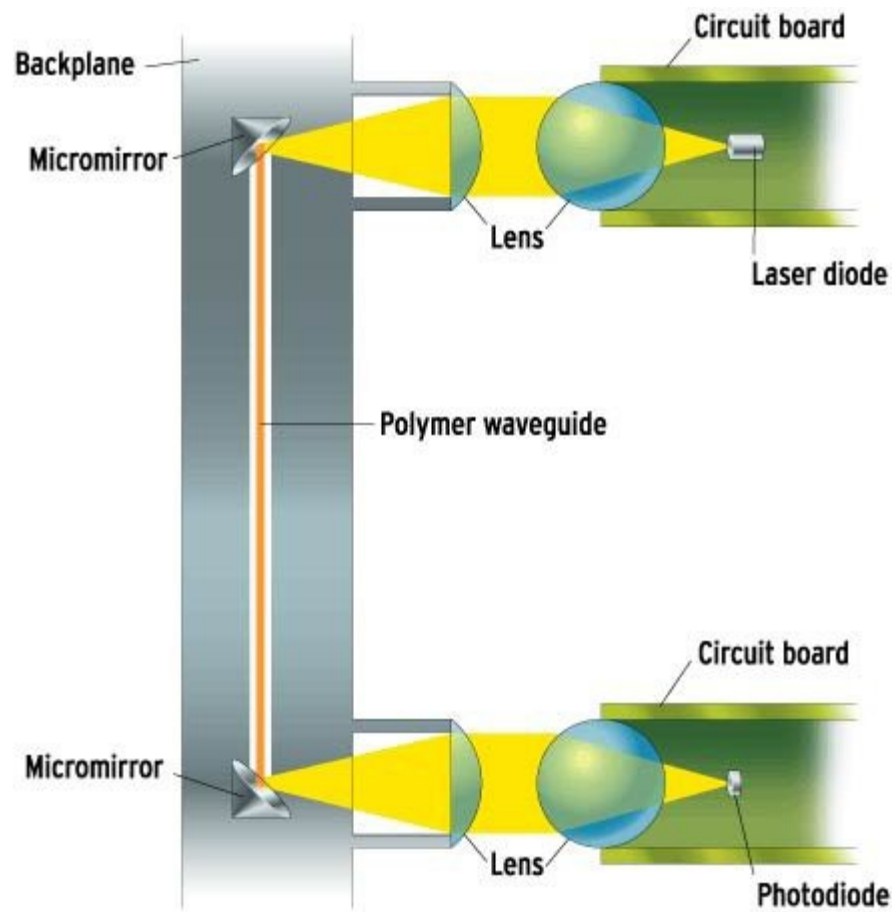
The major breakthroughs on optical computing have been centered on the development of micro-optic devices for data input.

2. VCSEL (VERTICAL CAVITY SURFACE EMITTING LASER):

VCSEL (pronounced 'vixel') is a semiconductor vertical cavity surface emitting laser diode that emits light in a cylindrical beam vertically from the surface of a fabricated wafer, and offers significant advantages when compared to the edge-emitting lasers currently used in the majority of fiber optic communications devices. The principle involved in the operation of a VCSEL is very similar to those of regular lasers.



There are two special semiconductor materials sandwiching an active layer where all the action takes place. But rather than reflective ends, in a VCSEL there are several layers of partially reflective mirrors above and below the active layer. Layers of semiconductors with differing compositions create these mirrors, and each mirror reflects a narrow range of wavelengths back in to the cavity in order to cause light emission at just one wavelength.



OPTICAL INTERCONNECTION OF CIRCUIT BOARDS USING VCSEL AND PHOTODIODE

VCSEL convert the electrical signal to optical signal when the light beams are passed through a pair of lenses and micromirrors. Micromirrors are used to direct the light beams and this light rays is passed through a polymer waveguide which serves as the path for transmitting data instead of copper wires in electronic computers. Then these optical beams are again passed through a pair of lenses and sent to a photodiode. This photodiode convert the optical signal back to the electrical signal.

3. SLM (SPATIAL LIGHT MODULATORS)

SLM play an important role in several technical areas where the control of light on a pixel-by-pixel basis is a key element, such as optical processing and displays.

3.1. SLM FOR DISPLAY PURPOSES

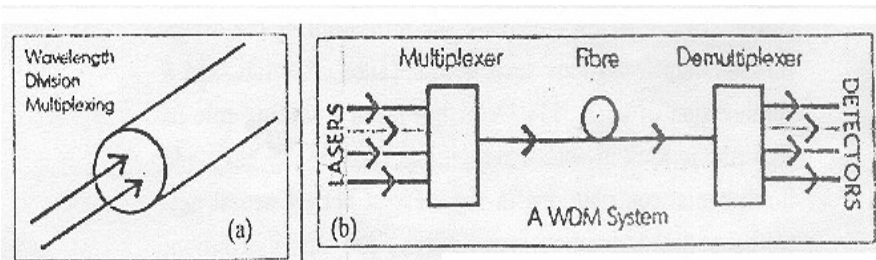
For display purposes the desire is to have as many pixels as possible in as small and cheap a device as possible. For such purposes designing silicon chips for use as spatial light modulators has been effective. The basic idea is to have a set of memory cells laid out on a regular grid. These cells are electrically connected to metal mirrors, such that the voltage on the mirror depends on the value stored in the memory cell. A layer of optically active liquid crystal is sandwiched between this array of mirrors and a piece of glass with a conductive coating. The voltage between individual mirrors and the front electrode affects the optical activity of liquid crystal in that neighborhood. Hence by being able to individually program the memory locations one can set up a pattern of optical activity in the liquid crystal layer.

4. SMART PIXEL TECHNOLOGY

Smart pixel technology is a relatively new approach to integrating electronic circuitry and optoelectronic devices in a common framework. The purpose is to leverage the advantages of each individual technology and provide improved performance for specific applications. Here, the electronic circuitry provides complex functionality and programmability while the optoelectronic devices provide high-speed switching and compatibility with existing optical media. Arrays of these smart pixels leverage the parallelism of optics for interconnections as well as computation. A smart pixel device, a light emitting diode under the control of a field effect transistor can now be made entirely out of organic materials on the same substrate for the first time. In general, the benefit of organic over conventional semiconductor electronics is that they should lead to cheaper, lighter, circuitry that can be printed rather than etched.

5. WDM (WAVELENGTH DIVISION MULTIPLEXING) :

Wavelength division multiplexing is a method of sending many different wavelengths down the same optical fiber. Using this technology, modern networks in which individual lasers can transmit at 10 gigabits per second through the same fiber at the same time.



WDM can transmit up to 32 wavelengths through a single fiber, but cannot meet the bandwidth requirements of the present day communication systems. So nowadays DWDM (Dense wavelength division multiplexing) is used. This can transmit up to 1000 wavelengths through a single fiber. That is by using this we can improve the bandwidth efficiency.

6. ROLE OF NLO IN OPTICAL COMPUTING :

The role of nonlinear materials in optical computing has become extremely significant. Non-linear materials are those, which interact with light and modulate its properties. Several of the optical components require efficient nonlinear materials for their operations. What in fact restrains the widespread use of all optical devices is the inefficiency of currently available nonlinear materials, which require large amount of energy for responding or switching. Organic materials have many features that make them desirable for use in optical devices such as

1. High nonlinearities
2. Flexibility of molecular design
3. Damage resistance to optical radiations

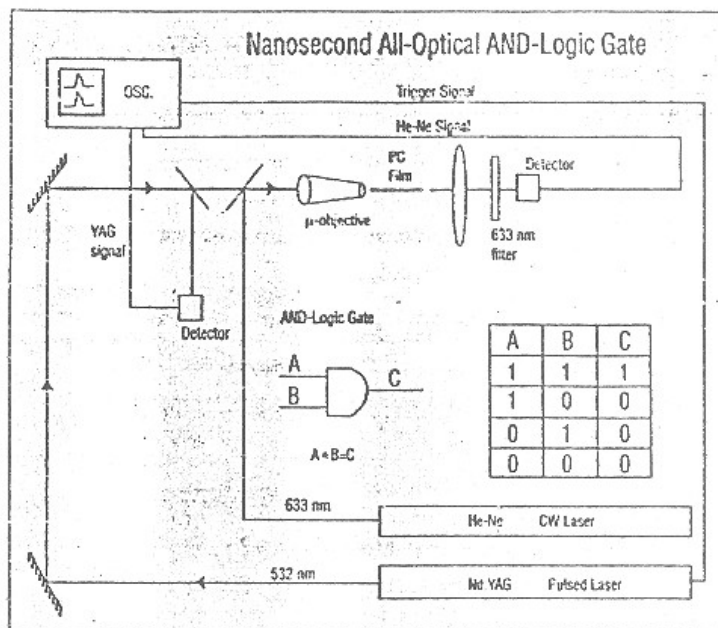
Some organic materials belonging to the classes of phthalocyanines and polydiacetylenes are promising for optical thin films and wave guides. These compounds exhibit strong electronic transitions in the visible region and have high chemical and thermal stability up to 400 degree Celsius. Polydiacetylenes are among the most widely investigated class of polymers for nonlinear optical applications. Their subpicosecond time response to laser signals makes them candidates for high-speed optoelectronics and information processing.

To make thin polymer film for electro-optic applications, NASA scientists dissolve a monomer (the building block of a polymer) in an organic solvent. This solution is then put into a growth cell with a quartz window, shining a laser through the quartz can cause the polymer to deposit in specific pattern.

7. ADVANCES IN PHOTONIC SWITCHES :

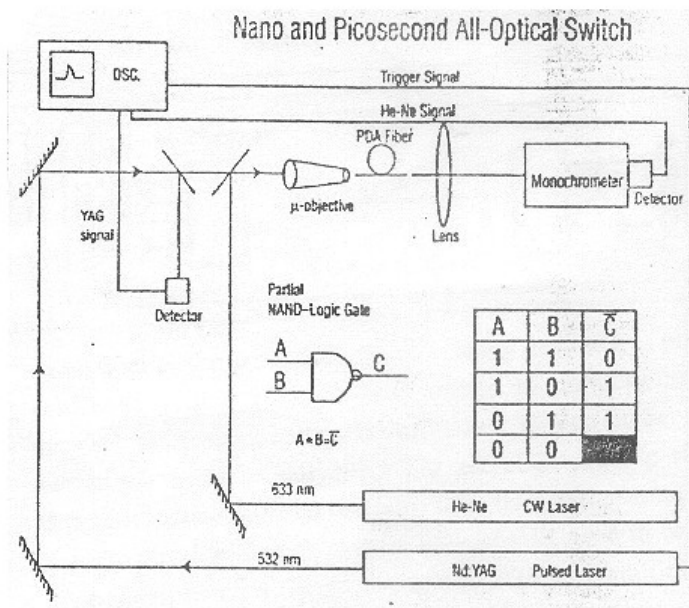
7.1 OPTICAL AND GATE :

Logic gates are the building blocks of any digital system. An optical logic gate is a switch that controls one light beam by another; it is ON when the device transmits light and it is OFF when it blocks the light. To demonstrate the AND gate in the phthalocyanine film, two focused collinear laser beams are wave guided through a thin film of phthalocyanine. Nanosecond green pulsed Nd:YAG laser was used together with a red continuous wave (cw) He-Ne beam. At the output a narrow band filter was set to block the green beam and allow only the He-Ne beam. Then the transmitted beam was detected on an oscilloscope. It was found that the transmitted He-Ne cw beam was pulsating with a nanosecond duration and in synchronous with the input Nd:YAG nanosecond pulse. This demonstrated the characteristic table of an AND logic gate.



7.2 OPTICAL NAND GATE

In an optical NAND gate the phthalocyanine film is replaced by a hollow fiber filled with polydiacetylene. Nd:YAG green picosecond laser pulse was sent collinearly with red cw He-Ne laser onto one end of the fiber. At the other end of the fiber a lens was focusing the output on to the narrow slit of a monochromator with its grating set for the red He-Ne laser. When both He-Ne laser and Nd:YAG laser are present there will be no output at the oscilloscope. If either one or none of the laser beams are present we get the output at the oscilloscope showing NAND function.



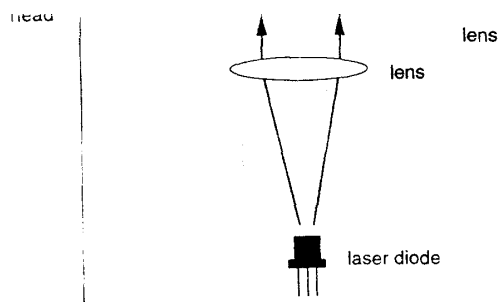
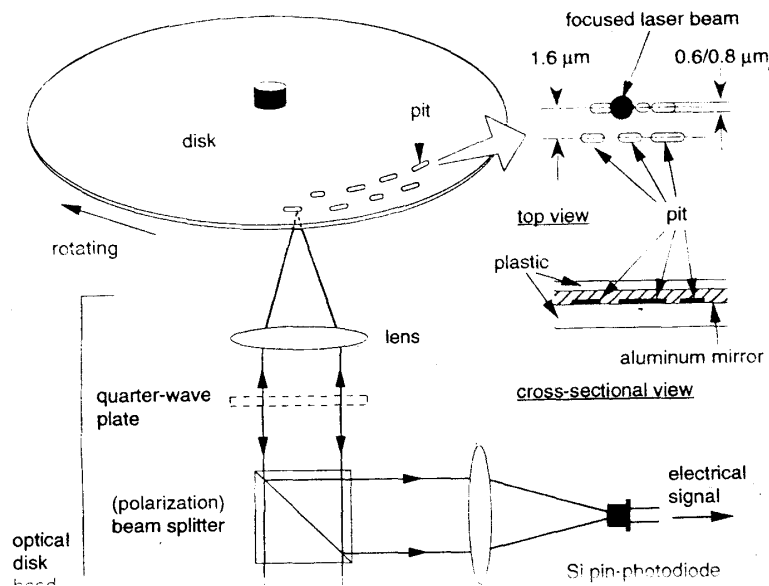
8. OPTICAL MEMORY :

In optical computing two types of memory are discussed. One consists of arrays of one-bit-store elements and other is mass storage, which is implemented by optical disks or by holographic storage systems. This type of memory promises very high capacity and storage density. The primary benefits offered by holographic optical data storage over current storage technologies include significantly higher storage capacities and faster read-out rates. This research is expected to lead to compact, high capacity, rapid-and random-access, and low power and low cost data storage devices necessary for future intelligent spacecraft. The SLMs are used in optical data storage applications. These devices are used to write data into the optical storage medium at high speed. More conventional approaches to holographic storage use ion doped lithium niobate crystals to store pages of data. For audio recordings ,a 150MBminidisk with a 2.5- in diameter has been developed that uses special compression to shrink a standard CD's640-MB storage capacity onto the smaller polymer substrate. It is rewritable and uses magnetic field modulation on optical material. The mini disc uses one of the two methods to write information on to an optical disk. With the mini disk a magnetic field placed behind the optical disk is modulated while the intensity of the writing laser is held constant. By switching the polarity of the magnetic field while the laser creates a state of flux in the optical material digital data can be recorded on a single layer. As with all optical storage media a read laser retrieves the data.

8.1 OPTICAL DISKS' WORKING :

The 780nm light emitted from AlGaAs/GaAs laser diodes is collimated by a lens and focused to a diameter of about 1micrometer on the disk. If there is no pit where the light is incident, it is reflected at the Al mirror of the disk and returns to the lens, the depth of the pit is set at a value such that the difference between the path of the light reflected at a pit and the path of light reflected at a mirror is an integral multiple of half-wavelength

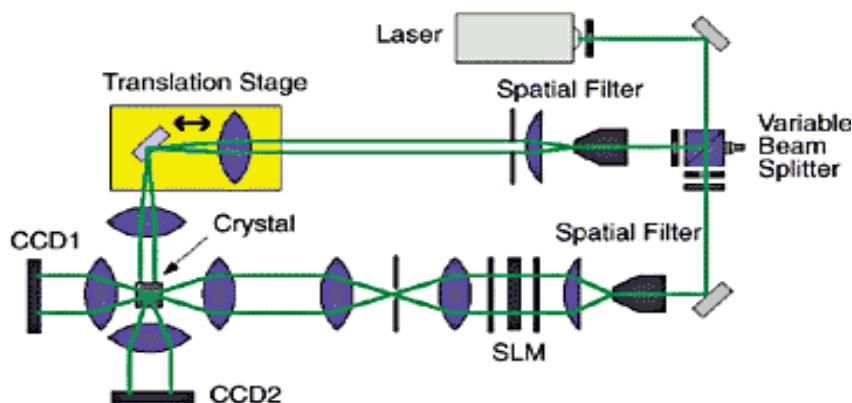
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consequently, if there is a pit where light is incident, the amount of reflected light decreases tremendously because the reflected lights are almost cancelled by interference. The incident and reflected beams pass through the quarter wave plate and all reflected light is introduced to the photodiode by the beam splitter because of the polarization rotation due to the quarter wave plate. By the photodiode the reflected light, which has a signal whether, a pit is on the disk or not is changed into an electrical signal.

8.2 HOLOGRAPHIC MEMORIES WORKING :

Conventional approaches to holographic storage use iron-doped lithium niobate crystals to store pages of data. Unlike standard magneto-optical storage devices, however, the systems developed by Pericles Mitkas at Colorado State University use the associative search capabilities of holographic memories (figure). Associative or content-based data access enables the search of the entire memory space in parallel for the presence of a keyword or search argument.



Holographic memory cubes use a spatial light modulator to simultaneously search the entire memory for a searchable object be it text, image, or something else. This

associative memory search process promises significant benefits for database searching and other applications.

Conventional systems use memory addresses to track data and retrieve the data at that location when requested. Several applications can benefit from this mode of operation including management of large multimedia databases, video indexing, image recognition, and data mining. Different types of data such as formatted and unformatted text, gray scale and binary images, video frames, alphanumeric data tables, and time signals can be interleaved in the same medium and we can search the memory with either data type. The system uses a data and a reference beam to create a hologram on one plane inside the lithium niobate. By changing the angle of the reference beam, more data can be written into the cube just like pages in a book. The current systems have stored up to 1000 pages per spatial location in either VGA or VGA resolutions. To search the data, a binary or analog pattern that represents the search argument is loaded into a spatial light modulator and modulates a laser beam. The light diffracted by the holographic cube on a CCD(Charge Coupled Device) generates a signal that indicates the pages that match the sought data. Recent results have shown the system can find the correct data 75 percent of the time when using patterns as small as 1 to 5 percent of the total page. That level goes up to 95 to 100 percent by increasing the amount of data included in the search argument.

9. APPLICATIONS :

1. High speed communications :The rapid growth of internet, expanding at almost 15% per month, demands faster speeds and larger bandwidth than electronic circuits can provide. Terabits speeds are needed to accommodate the growth rate of internet since in optical computers data is transmitted at the speed of light which is of the order of 3×10^8 m/sec hence terabit speeds are attainable.
2. Optical crossbar interconnects are used in asynchronous transfer modes and shared memory multiprocessor systems.
3. Process satellite data.

10. MERITS :

1. Optical computing is at least 1000 to 100000 times faster than today's silicon machines.
2. Optical storage will provide an extremely optimized way to store data, with space requirements far lesser than today's silicon chips.
3. Super fast searches through databases.
4. No short circuits, light beam can cross each other without interfering with each other's data.
5. Light beams can travel in parallel and no limit to number of packets that can travel in the photonic circuits.
6. optical computer removes the bottleneck in the present day communication system

11. DRAWBACKS :

1. Today's materials require much high power to work in consumer products, coming up with the right materials may take five years or more.
2. Optical computing using a coherent source is simple to compute and understand, but it has many drawbacks like any imperfections or dust on the optical components will create unwanted interference pattern due to scattering effects. Incoherent processing on the other hand cannot store phase information.

12. SOME CURRENT RESEARCHES :

High performance computing has gained momentum in recent years ,with efforts to optimize all the resources of electronic computing and researcher brain power in order to increase computing throughput. Optical computing is a topic of current support in many places , with private companies as well as governments in several countries encouraging such research work. A group of researchers from the university of southern California , jointly with a team from the university of California , los angles , have developed an organic polymer with a switching frequency of 60 Ghz . this is three times faster than the current industry standard , lithium niobate crystal baswed device. Another groupe at brown university and the IBM , Almaden research center has used ultrafast laser pulses to build ultra fast data storage devices . this groupe was able to achivie ultra fast switching down to 100 picosecond .

In japan , NEC has developed a method for interconnecting circuit boards optically using VCSEL arrays .Another researchers at NTT have designed an optical backplane with free-space opical interconnects using tunable beam deflectors and mirrors. Theproject achieved 1000 interconnections per printed circuit board;with a throughput ranging from 1 to 10 Tb/s.

12.1 Germanium Laser Breakthrough Brings Optical Computing Closer:

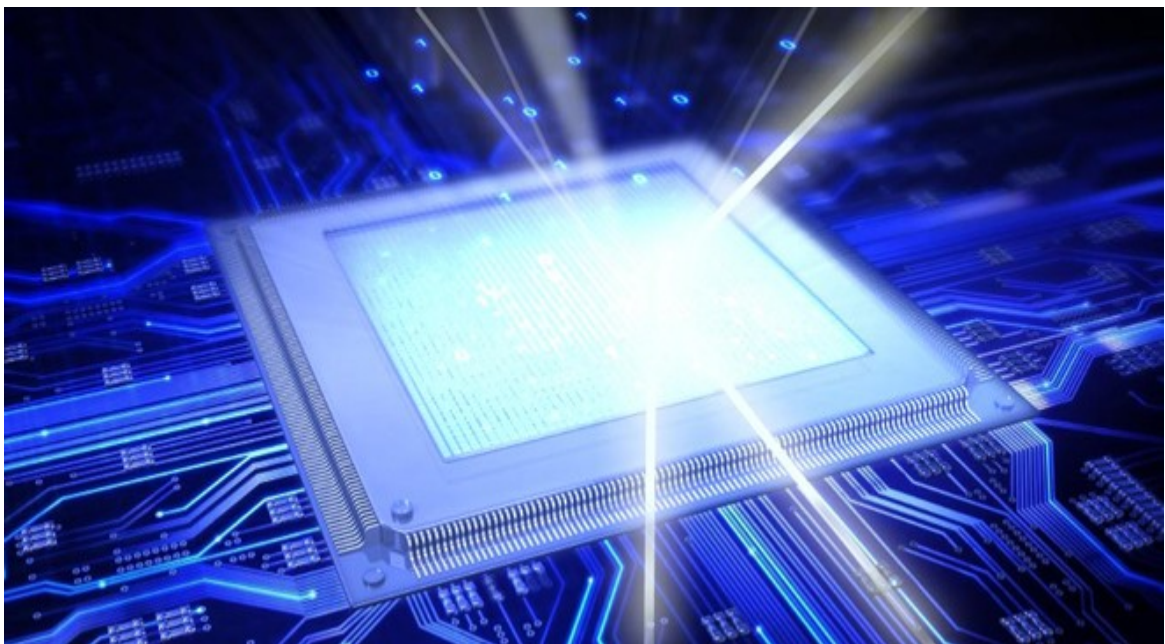
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Researchers at MIT have demonstrated the first laser that uses the element germanium.

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The laser, which operates at room temperature, could prove to be an important step toward computer chips that move data using light instead of electricity, say the researchers.



“This is a very important breakthrough, one I would say that has the highest possible significance in the field,” says Eli Yablonovitch, a professor in the electrical engineering and computer science department of the University of California, Berkeley who was not involved in the research told Wired.com. “It will greatly reduce the cost of communications and make for faster chips.”

Even as processors become more powerful, they’re running into a communications barrier: Just moving data between different parts of the chip takes too long. Also, higher bandwidth connections are needed to send data to memory. Traditional copper connections are becoming impractical because they consume too much power to transport data at the increasingly higher rates needed by next-generation chips. Copper also generates

excessive heat, and that imposes other design limits because engineers need to find ways of dissipating the heat.

Transmitting data with lasers, which can concentrate light into a narrow, powerful beam, could be a cheaper and more power efficient alternative. The idea, known as photonic computing, has become one of the hottest areas of computer research.

“The laser is just totally new physics,” says Lionel Kimerling, an MIT professor whose Electronic Materials Research Group developed the germanium laser.

While lasers are attractive, the materials that are used in lasers currently — such as gallium arsenide — can be difficult to integrate into fabs.

That’s given birth to “external lasers,” says Yablonovitch. Lasers have to be constructed separately and grafted on to the chips, instead of directly building them on the same silicon that holds the chips’ circuits. This reduces the efficiency and increases the cost.

A germanium laser solves that problem, because it could in principle be built alongside the rest of the chip, using similar processes and in the same factory.

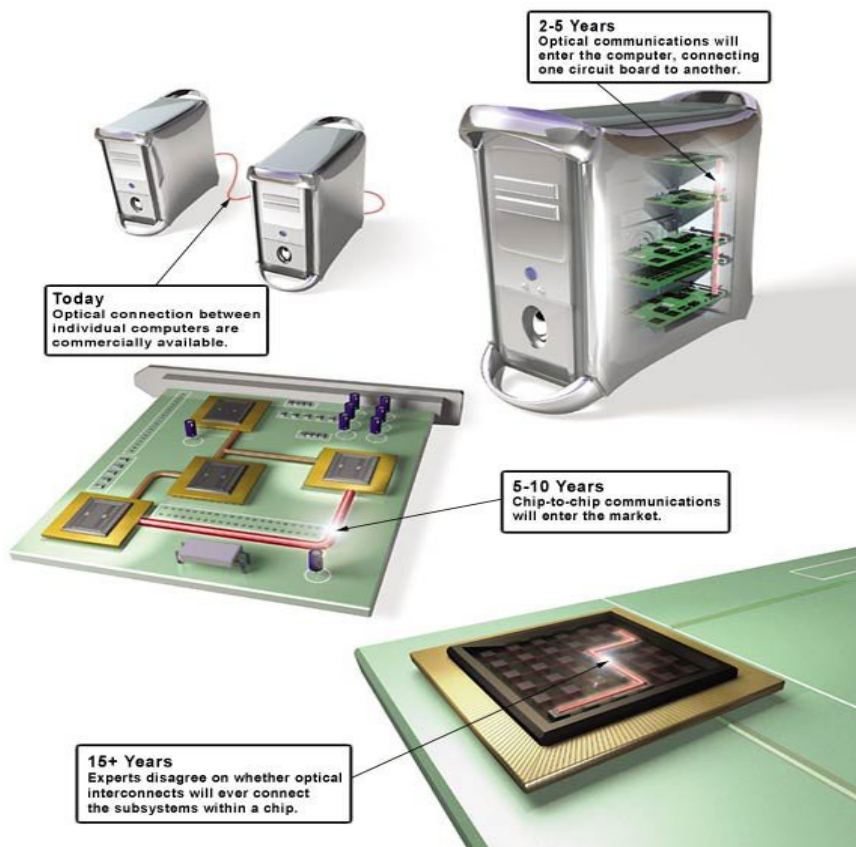
“It’s going to take a few years to learn how to integrate this type of laser into a standard silicon process,” says Yablonovitch. “But once we know that, we can have silicon communication chips that have internal lasers.”

Eventually, MIT researchers believe germanium lasers could be used not just for communications, but for the logic elements of the chips too — helping to build computers that perform calculations using light instead of electricity.

But University of California, Berkeley’s Yablonovitch says it is unlikely that light will replace electricity entirely. “I think we will be using light in conjunction with electronic logic circuits,” he says. “Light allows internal communications much more efficiently, but the logic elements themselves are likely to remain driven by electricity.”

13. FUTURE TRENDS :

The Ministry of Information Technology has initiated a photonic development program. Under this program some funded projects are continuing in fiber optic high-speed network systems. Research is going on for developing new laser diodes, photodetectors, and nonlinear material studies for faster switches. Research efforts on nanoparticle thin film or layer studies for display devices are also in progress. At the Indian Institute of Technology (IIT), Mumbai, efforts are in progress to generate a white light source from a diodecase based fiber amplifier system in order to provide WDM communication channels.



14. CONCLUSION :

Research in optical computing has opened up new possibilities in several fields related to high performance computing, high-speed communications. To design algorithms that execute applications faster, the specific properties of optics must be considered, such as their ability to exploit massive parallelism, and global interconnections. As optoelectronic and smart pixel devices mature, software development will have a major impact in the future and the ground rules for the computing may have to be rewritten.

15. REFERENCES :

1. Debabrata Goswami , “ article on optical computing, optical components and storage systems,” *Resonance- Journal of science education* pp:56-71-July 2003
2. Mc Aulay, Alastair.D , “Optical computer architectures and the application of optical concepts to next generation computers”
3. www.ieeexplore.org
4. www.sciam.com
5. www.msfc.com