1. Introduction

With today's growing dependence on computing technology, the need for high performance computers (HPC) has significantly increased. Many performance improvements in conventional computers are achieved by miniaturizing electronic components to very small micron-size scale so that electrons need to travel only short distances within a very short time. This approach relies on the steadily shrinking trace size on microchips (i.e., the size of elements that can be 'drawn' onto each chip).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 0.08 mm. 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.With the help of virtual product design and development, costs can be reduced. Hence looking for improved computing capabilities is desirable. Optical computing includes the optical calculation of transforms and optical pattern matching. Emerging technologies also make the optical storage of data a reality. 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 (Einstein's principle that signals cannot propagate faster than the speed of light) 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. In an optical computer, electrons are replaced by photons, the sub-atomic bits of electromagnetic radiation that make up light. Optics, which is the science of light, is already used in computing, most often in the fiber-optic glass cables that currently transmit data on communication networks much faster than via traditional copper wires. Thus, optical signals might be the ticket for the fastest supercomputers ever. Compared to light, electronic signals in chips travel at snail speed. Moreover, there is no such thing as a short circuit with light, so beams could cross with no problem after being redirected by pinpoint-size mirrors in a switchboard. In a pursuit to probe into cutting-edge research areas, optical technology (optoelectronic, photonic devices) is one of the most promising, and may eventually lead to new computing applications as a consequence of faster processor speeds, as well as better connectivity and higher bandwidth. Optical computing includes the optical calculation of transforms and optical pattern matching. Emerging technologies also make the optical storage of data a reality. 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. For example, a one-foot length of wire produces approximately one nanosecond (billionth of a second) of time delay. Extreme miniaturization of tiny electronic components Light does not have the time response limitations of electronics, does not need insulators, and can even send dozens or hundreds of photon signal streams simultaneously using different color frequencies. Electrical components also leads to 'cross-talk' signal errors that affect the system's reliability. These and other obstacles have led scientists to seek answers in light itself. Light does not have the time response limitations of electronics, does not need insulators, and can even send dozens or hundreds of photon signal streams simultaneously using different color frequencies. Those are immune to electromagnetic interference, and free from electrical short circuits. They have low-loss transmission and provide large bandwidth; i.e. multiplexing capability, 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, as well as more facile with stored information than magnetic materials. By replacing electrons and wires with photons, fiber optics, crystals, thin films and mirrors, researchers are hoping to build a new generation of computers that work 100 million times faster than today's machines. The fundamental issues associated with optical computing, its advantages over conventional (electronics-based) computing, current applications of optics in computers are reported here. In the second part of this report the problems that remain to be overcome and current research will be put forth.[1]

2. Why Optical Computing

Optical computing was a hot research area in the 1980s. But the work tapered off because of materials limitations that seemed to prevent optochips from getting small enough and cheap enough to be more than laboratory curiosities. Now, optical computers are back with advances in self-assembled conducting organic polymers that promise super-tiny all-optical chips . Advances in optical storage device have generated the promise of efficient, compact and large-scale storage devices . Another advantage of optical methods over electronic ones for computing is that parallel data processing can frequently be done much more easily and less expensively in optics than in electronics. Parallelism, the capability to execute more than one operation simultanously, is now common in electronic computer architectures. But, most electronic computers still execute instructions sequentially; parallelism with electronics remains sparsely used. Its first widespread appearance was in Cray supercomputers in the early 1980's when two processors were used in conjunction with one shared memory. Today, large supercomputers may utilize thousands of processors but communication overhead frequently results in reduced overall efficiency. On the other hand for some applications in input-output (lIO), such as image processing, by using a simple optical design all array of pixels can be transferred simultaneously in parallel from one point to another. Optical technology promises massive upgrades in the efficiency and speed of computers, as well as significant shrinkage in their size and cost. An optical desktop computer could be capable of processing data up to 100,000 times faster than current models because multiple operations can be performed simultaneously. Other advantages of optics include low manufacturing costs, immunity to electromagnetic interference, a tolerance for lowloss transmissions, freedom from short electrical circuits and the capability to supply large bandwidth and propagate signals within the same or adjacent fibers without interference. One oversimplified example may help to appreciate the difference between optical and electronic parallelism. Consider an imaging system with 1000 x 1000 independent points per mm2 in the object plane which are connected optically by a lens to a corresponding number of points per mm2 in the image plane; the lens effectively performs an FFT of the image plane in real time. For this to be accomplished electrically, a million operations are required. Optical technology promises massive upgrades in the efficiency and speed of computers, as well as significant shrinkage in their size and cost. An optical desktop computer could be capable of processing data up to 100,000 times faster than current models because multiple operations can be performed simultaneously. Parallelism, when associated with fast switching speeds, would result in staggering computational speeds. Assume, for example, there are only 100 million gates on a chip, much less than what was mentioned earlier (optical integration is still in its infancy compared to electronics). Further, conservatively assume that each gate operates with a switching time of only 1 nanosecond (organic optical switches can switch at sub-picosecond rates compared to maximum picosecond switching times for electronic switching). Such a system could perform more than 1017 bit operations per second. Compare this to the gigabits (109) or terabits (10 12) per second rates which electronics are either currently limited to, or hoping to achieve. In other words, a computation that might require one hundred thousand hours (more than 11 years) of a conventional computer time could require less than one hour by an optical one. But building an optical computer will not be easy. A major challenge is finding materials that can be mass produced yet consume little power; for this reason, optical computers may not hit the consumer market for 10 to 15 years. Another of the typical problems optical computers have faced is that the digital optical devices have practical limits of eight to eleven bits of accuracy in basic operations due to, e.g., intensity fluctuations. Recent research has shown ways around this difficulty. Thus, for example, digital partitioning algorithms, that can break matrix-vector products into lower-accuracy sub-products, working in tandem with error-correction codes, can substantially improve the accuracy of optical computing operations. Nevertheless, many problems in developing appropriate materials and devices must be overcome before digital optical computers will be in widespread commercial use. In the near term, at least, optical computers will most likely be hybrid optical/electronic systems that use electronic circuits to preprocess input data for computation and to post-process output data for error correction before outputting the results. The promise of all-optical computing remains highly attractive, however, and the goal of developing optical computers continues to be a worthy one. Nevertheless, many scientists feel that an all-optical computer will not be the computer of the future; instead optoelectronic computers will rule where the advantages of both electronics and optics will be used. Optical computing can also be linked intrinsically to quantum computing. Each photon is a quantum of a wave function describing the whole function. It is now possible to control atoms by trapping single photons in small, superconducting cavities. So photon quantum computing could become a future possibility.[2]

3. Devices Used For Optical Computing

3.1 Logic Gates

Logic gates are implemented optically by controlling the population inversion that occurs to provide lasing. A controlling laser is used to control population inversion thus causing switching to occur.

3.2 Holographic Truth Table

Destructive interference will decide whether light to be emitted or not based on phase relationship Logic based on gratings

1 is represented by vertical grating causing light

0 is represented by horizontal grating causing darkness

3.3 Holographic Storage

Holographic data storage has 4 components

- Holographic material; thin film on which data is to be stored
- Spatial Light Modulator (SLM); 2D array of pixels, each of which is a simple switch to either block or pass light.
- Detector array; 2D array of detector pixels, either as Charge-coupled device (CCD) camera or CMOS detector pixels to detect existence of light
- Reference arm; arm carrying the laser source to produce the reference beam.

3.4 Optical NAND Gate

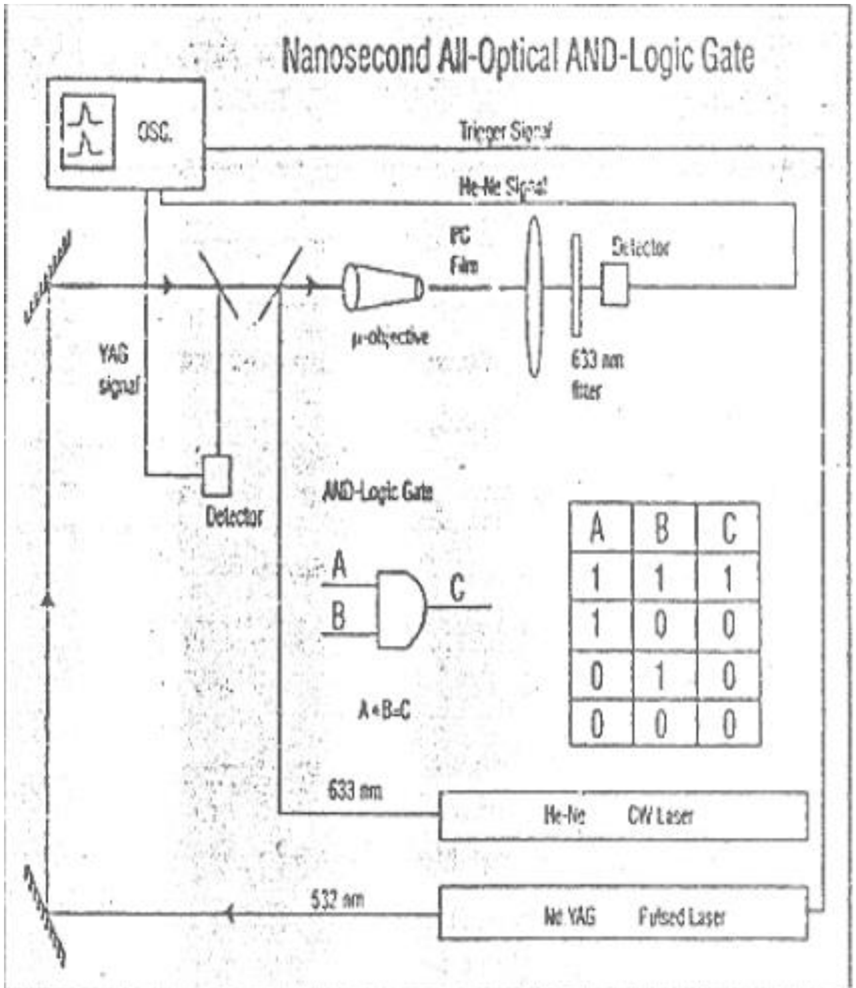

FIGURE-3.4

In an optical NAND gate the phthalocyanine film is replaced by a hollow fiber filled with Polydiacetylenes. Nd: YAG green picoseconds 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 monochromatic 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.

3.5 Interconnections in Optical Computing

- Optical interconnection technologies are relatively mature.
- Fiber optic cables and optical transceivers are widely used.
- Applications of optical communications like fiber channel and computer networking are already being used.
- Although there is a basic speed limitation is optoelectronic conversion delays.
- WDM is used to get around this limitation.
- Chip to Chip and On-Chip interconnection possibilities are still being examined.
- Promising but there are problems regarding dense organization of optical processing units.

3.6 Optical processor

When an analog signal is processed digitally it must first be converted into a discrete form using an analog-to-digital converter (ADC) before it can be processed.Generally the signal is then processed with a discrete Fourier transform (DFT), or another discrete signal processing algorithm, and converted back to an analog form with a digital-to analog converter (DAC) Processing an analog signal in a digital architecture with an optical Fourier signal processor with an optical coprocessor. The above mentioned procedure is depicted in the following[1].

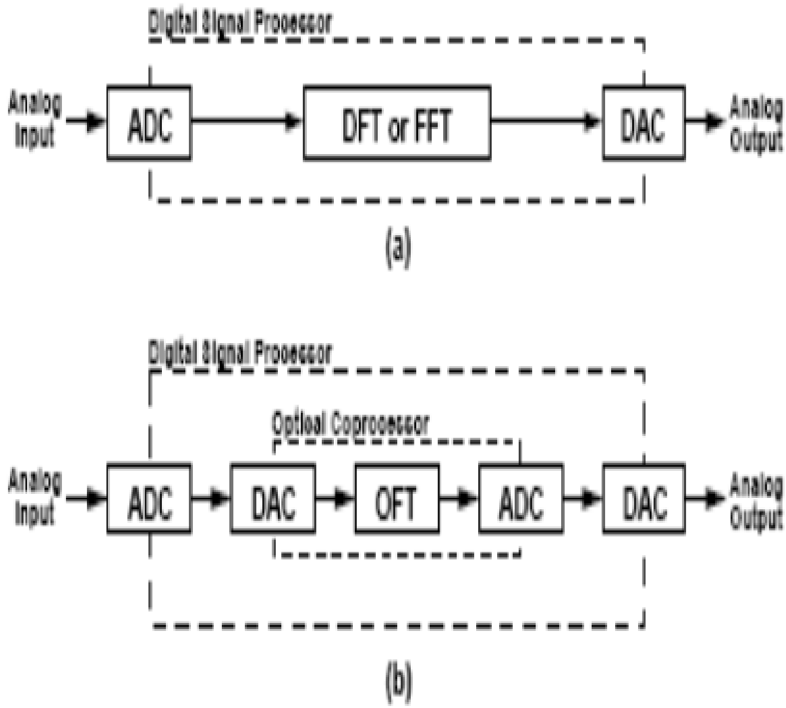
Digital Signal Processor
Analog Input
ADC
DFT or FFT
DAC
Analog Output
(a)
Digital Signal Processor
Optical Coprocessor
Analog Input
ADC
DAC
OFT
ADC
DAC
Analog Output
(b)

FIGURE -3.6

4. 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 infact restrains the widespread use of all optical devices is the in efficiency 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 sub picoseconds 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 cellwith a quartz window, shining a laser through the quartz can cause the polymer to deposit in specific pattern.

5. 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. Conventional lasers are known as 'edge emitters' because their laser light comes .out from the edges. Also, their laser cavities run horizontally along their length. A vertical cavity surface emitting laser (VCSEL - pronounced 'vixel'), however, gives out laser light from its surface and has a laser cavity that is vertical hence the name. VCSEL is a semiconductor vertical cavity surface emitting microlaser 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. They emit at 850 nm and have rather low thresholds (typically a few rnA). They are very fast and can give mW of coupled Power into a 50 micron core fiber and are extremely radiation hard. VCSELS can be tested at the wafer level (as opposed to edge emitting lasers which have to be cut and cleaved before they can be tested) and hence are relatively cheap. In fact, VCSELs can be fabricated efficiently on a 3-inch diameter wafer. A schematic .of VCSEL is shown in Figure The principles involved in the operation of a VCSEL are very similar to those of regular lasers. As shown in Figure, 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 semiconductor with differing compositions create these mirrors, and each mirror reflects a narrow range of wavelengths back into the cavity in order to cause light emission at just one wavelength.

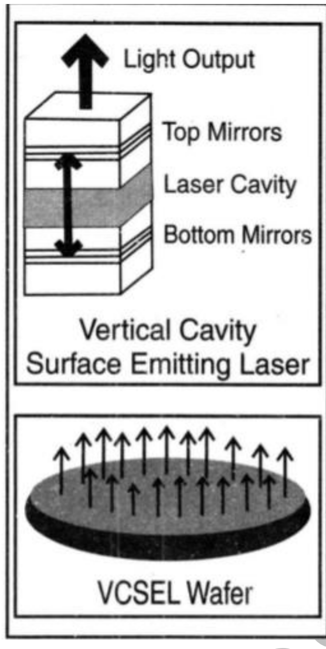

FIGURE-5.1

Spatial light modulators (SLMs) 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, for inputting information on light beams, and displays. 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 the 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. Figure shows a reflective 256x256 pixel device based on SRAM technology. Several technologies have contributed to the development of SLMs. These include micro-electro-mechanical devices, such as, acousto optic modulators (AOMs), and pixelated electro-optical devices, such as liquid-crystal modulators (LCMs). Figure shows a simple AOM operation in deflecting light beam direction. Encompassed within these categories are amplitude only, phase-only, or amplitude-phase modulators. Broadly speaking, an optical computer is a computer in which light is used somewhere. This can means fiber optical connections between electronic components, free space connections, or one in which light functions as a mechanism for storage of data, logic or arithmetic. Instead of electrons in silicon integrated circuits, the digital optical computers will be based on photons. Smart pixels, the union of optics and electronics, both expands the capabilities of electronic systems and enables optical systems with high levels of electronic signal processing. Thus, smart pixel systems add value to electronics through optical input/output and interconnection, and value is added to optical systems through electronic enhancements which include gain,

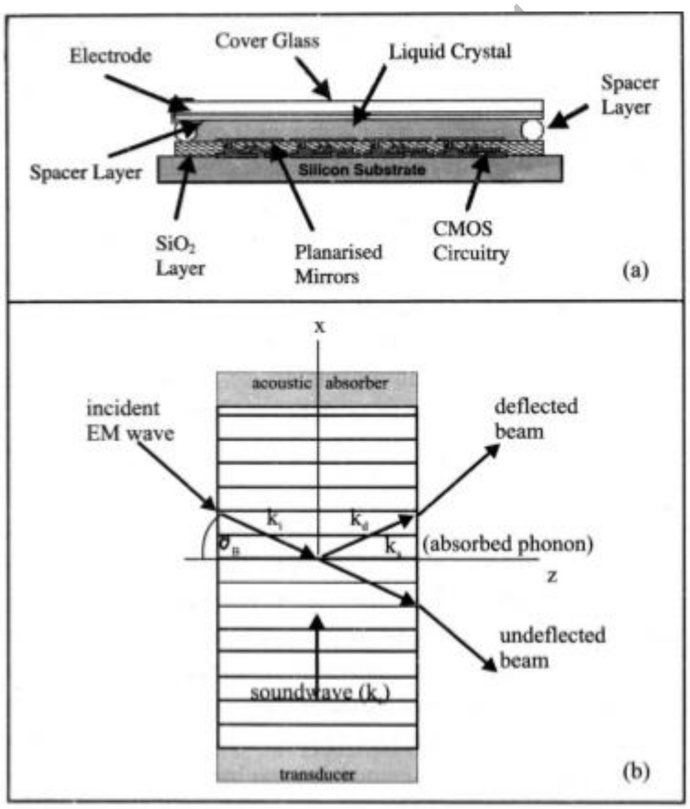

FIGURE-5.2

feedback control, and image processing and compression. 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 lever- age the parallelism of optics for interconnections as well as computation. A smart pixel device, a light emitting diode (LED) under the control of a field-effect transistor (FET), 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 (when mass-production techniques take over) lead to cheaper, lighter, circuitry that can be printed rather than etched. Scientists at Bell Labs have made 300-micron-wide pixels using polymer FETs and LEDs made from a sandwich of organic materials, one of which allows electrons to flow, another which acts as highway for holes (the absence of electrons); light is produced when electrons and holes meet. The pixels are quite potent, with a brightness of about 2300 candela/m2, compared to a figure of 100 for present flat-panel displays . A Cambridge University group has also made an all organic device, not as bright as the Bell Labs version, but easier to make on a large scale[1].

6. Optical computing Today

Currently, optics is used mostly to link portions of computers, or more intrinsically in devices that have some optical application or component. For example, much progress has been achieved, and optical signal processors have been successfully used, for applications such as synthetic aperture radars, optical pattern recognition, optical image processing, fingerprint enhancement, and optical spectrum analyzers. The early work in optical signal processing and computing was basically analog in nature. In the past two decades, however, a great deal of effort has been expended in the development of digital optical processors. Much work remains before digital optical computers will be widely available commercially, but the pace of research and development has increased through the 1990s. During the last decade, there has been continuing emphasis on the following aspects of optical computing:

- Optical tunnel devices are under continuous development varying from small caliber endoscopes to character recognition systems with multiple type capability.
- Development of optical processors for asynchronous transfer mode.
- Development architectures for optical neural networks.
- Development of high accuracy analog optical processors, capable of processing large amounts of data in parallel.

Since photons are uncharged and do not interact with one another as readily as electrons, 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. On the other hand, signals in adjacent optical 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 field of optical computing is progressing rapidly and shows many dramatic opportunities for overcoming the limitations described earlier for current electronic computers. The process is already underway whereby optical devices have been incorporated into many computing systems. Laser diodes as sources of coherent light have dropped rapidly in price due to mass production. Also, optical CD-ROM discs are now very common in home and office computers. Current trends in optical computing emphasize communications, for example the use of free-space optical interconnects as a potential solution to alleviate bottlenecks experienced in electronic architectures, including loss of communication efficiency in multiprocessors and difficulty of scaling down the IC technology to sub-micron levels. Light beams can travel very close to each other, and even intersect, without observable or measurable generation of unwanted signals. Therefore, dense arrays of interconnects can be built using optical systems. In addition, risk of noise is further reduced, as light is immune to electromagnetic interferences. Finally, as light travels fast and it has extremely large spatial bandwidth and physical channel density, it appears to be an excellent media for information transport and hence can be harnessed for data processing. This high bandwidth capability offers a great deal of architectural advantage and flexibility. Based on the technology now available, future systems could have 1024 smart pixels per chip with each channel clocked at 200MHz (a chip I/O of 200Gbits per second), giving aggregate data capacity in the parallel optical highway of more that 200Tbits per second; this could be further increased to 1000Tbits. Free-space optical techniques are also used in scalable crossbar systems, which allow arbitrary interconnections between a set of inputs and a set of outputs. Optical sorting and optical crossbar inter-connects are used in asynchronous transfer modes or packet routing and in shared memory multiprocessor systems.[1]

7. Applications

The following are the various applications of optical computing.

- 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.
- Optical crossbar interconnects are used in asynchronous transfer modes and shared memory multiprocessor systems.
- Process satellite data.
- Optical Computing in VLSI Technology: Many researchers have been investigating suitable optical logic devices, interconnection schemes, and architectures. Furthermore, optics may provide drastically new architectures to overcome some architectural problems of conventional electrical computers.
- Optical computing as expanders: The optical expander described utilizes high-speed and high-space-bandwidth product connections that are provided by optical beams in three dimensions.

8. Conclusion

Research in optical computing has opened up new possibilities in several fields related to high performance computing, high-speed communications. The acceptability of digital optical computing systems as off-the-shelf or dedicated system is still not very high. Optical computing is mostly analogue when electronic computing is digital. The digital optical Computers were not able to compete with the electronic due to the lack of appropriate optical components. Optical processing is useful when the information is optical and that no electronics to optics transducers are needed.[1]

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[2] D. H. Hartman, "Digital high speed interconnects: a study of the optical alternative" Opt. Engg.Vol.25, p1086, 1986.