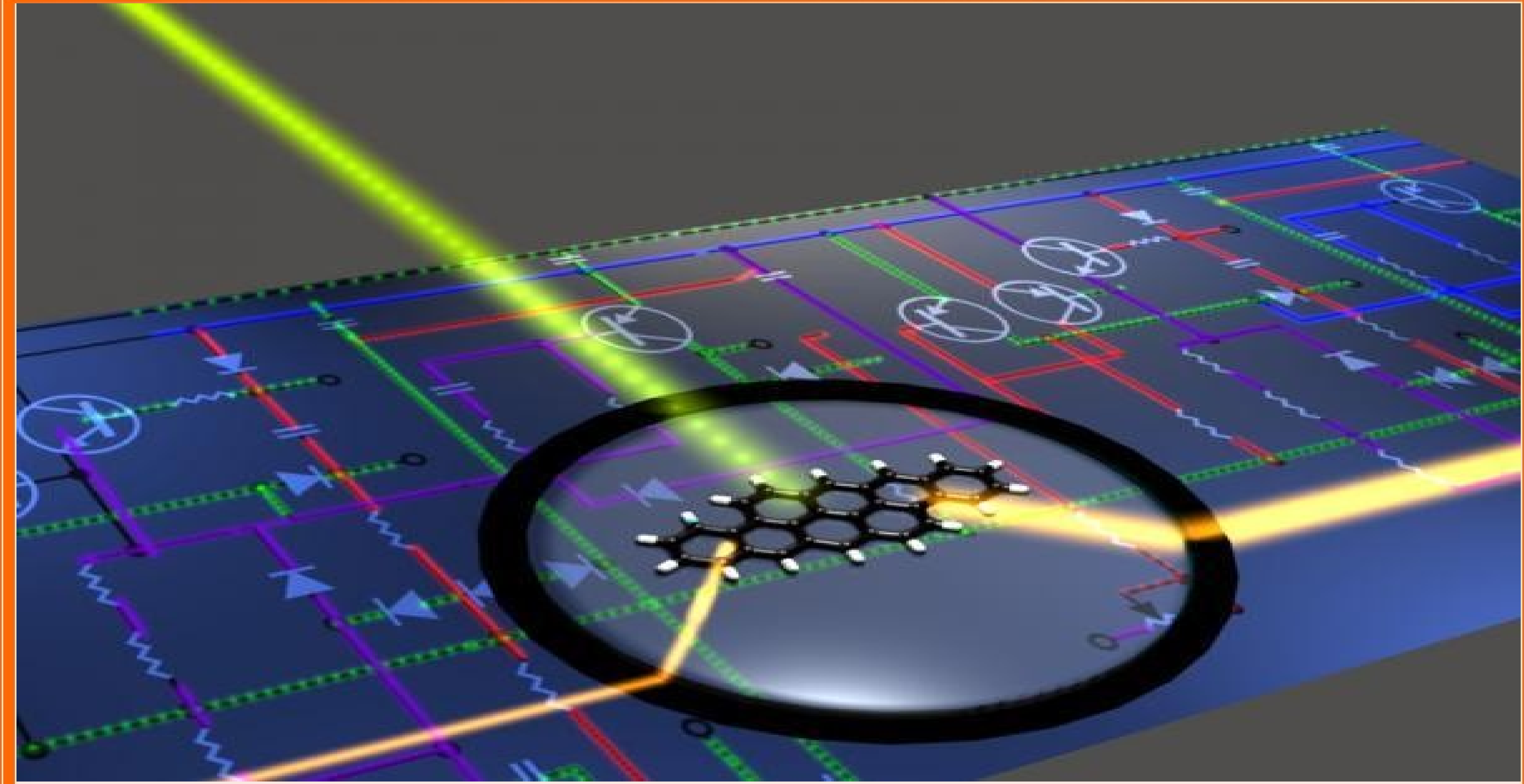
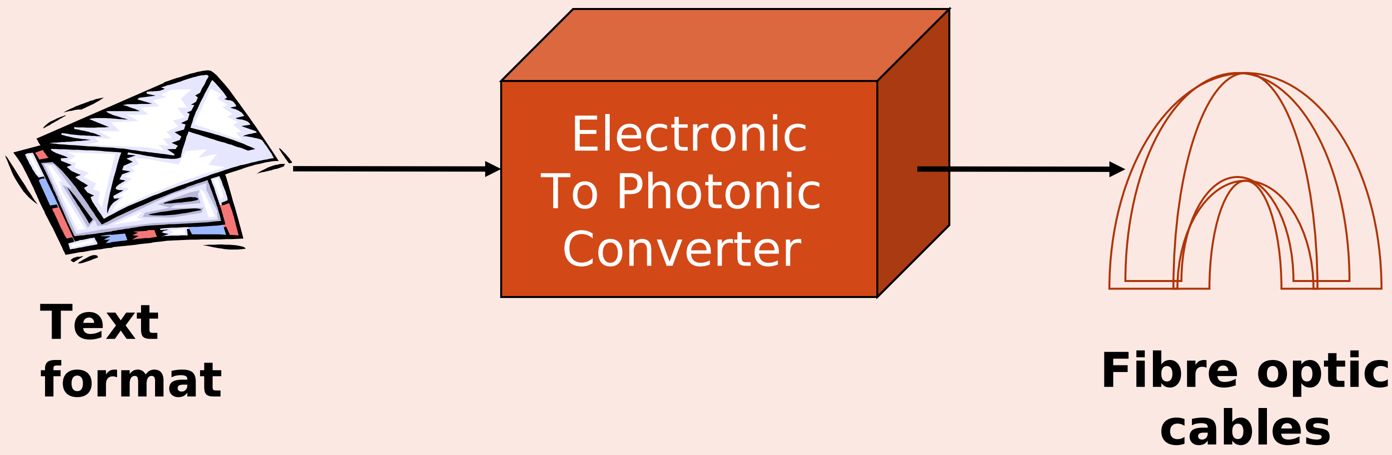


OPTICAL COMPUTING

WHAT IS OPTICAL COMPUTING?

Optical Computing is that computing strategy in which the computer or processing unit performs computations & other operations, stores & transmits data using only light.



Electrons	→	Photons
Mouse	→	Optical Mouse
Keyboard	→	Optical Keyboard
Metallic Wires	→	Optical Fibre Cables
Processor	→	Optical Processor
Monitor	→	Optical Display
Buses	→	Optical Buses
Electronic Logic Gates	→	Optical Logic Gates

WHY OPTICAL COMPUTING?

- In silicon computers, the speed of computers was achieved by miniaturizing electronic components.

- It is also estimated that the number of transistor switches that can be put onto a chip doubles every 18 months.

- So further miniaturization of size introduces several problems such as dielectric breakdown, hot carriers, and short channel effects etc.

- In electronic computer the solid state transmission media limits both the speed and volume of signal.

- Optical technology promises massive upgrades in the efficiency and speed of computers, as well as significant shrinkage in their size and cost.

CONTINUED…

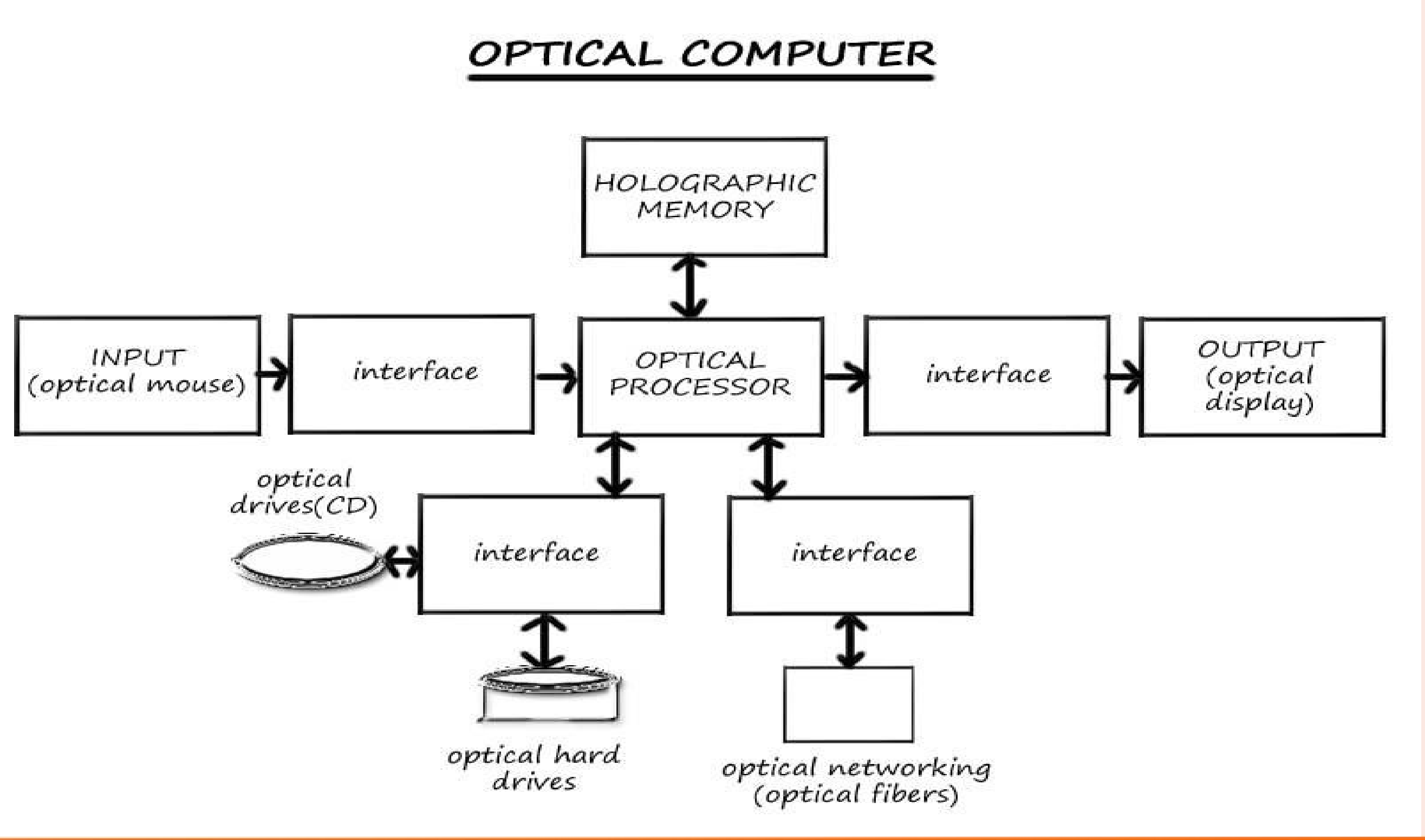
- Light travel 10 time faster than electron. So using light the data transmission rate can be increased .

- Optical data processing can be done as parallel processes.

- Parallelism is the capability of the system to execute more than one operation simultaneously.

- Optical materials have a superior storage density and accessibility over magnetic materials.

An optical computer is a device that uses the photons in visible light or infrared (IR) beams, rather than electric current, to perform digital computations.



HOW DOES IT WORK?

- Light(Photon) in the place of electron.

- Uses optical components like Optical Transistor, Optical Gate and Switch, Holographic Memory, Input Output Devices etc.

- Transistors, logic gates etc are simulated using optics.

- There are switches that are activated by beams of light rather than by pulse of electricity.

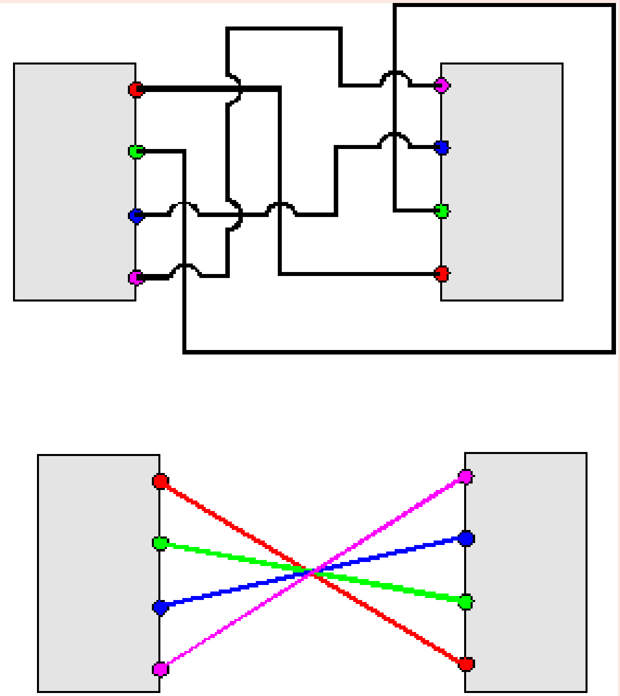
- All-optical components require a high level of laser power to function as required.

- Send pulses of light instead of pulses of electricity

ADVANTAGES

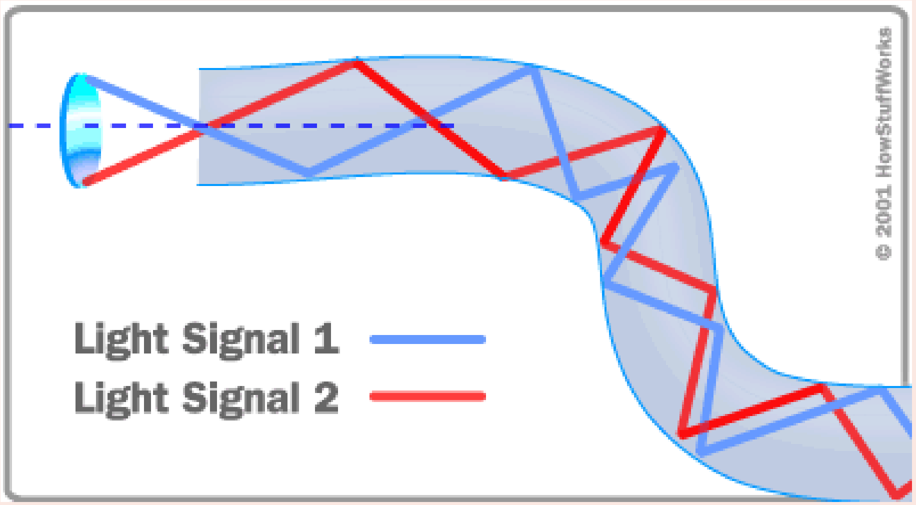
- ❑ Increase in the speed of computation.
- ❑ Immune to electromagnetic interference.
- ❑ Free from electrical short circuits.
- ❑ Have low-loss transmission and large bandwidth.
- ❑ Capable of communicating several channels in parallel without interference.
- ❑ Possess superior storage density and accessibility
- ❑ No power loss due to excess of heating.
- ❑ Life of the hardware of optical computer is more.

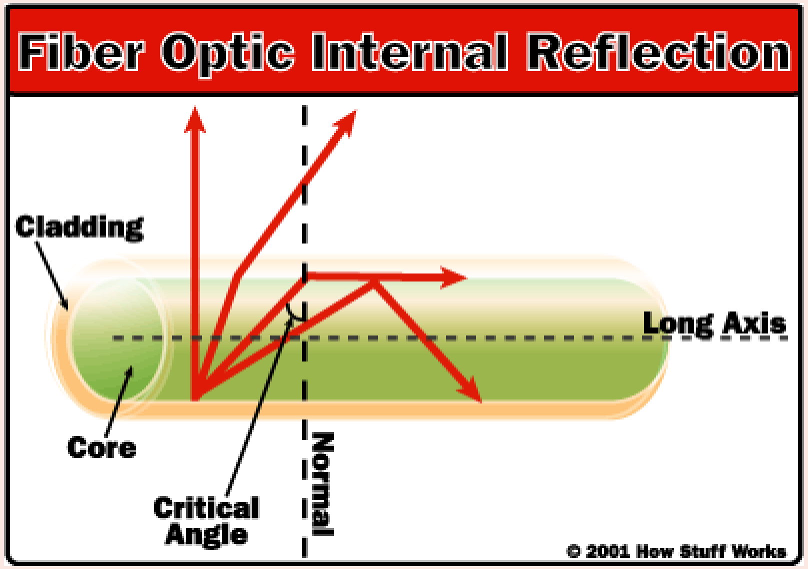
OPTICAL CROSSOVERS



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

PARALLEL COMMUNICATION

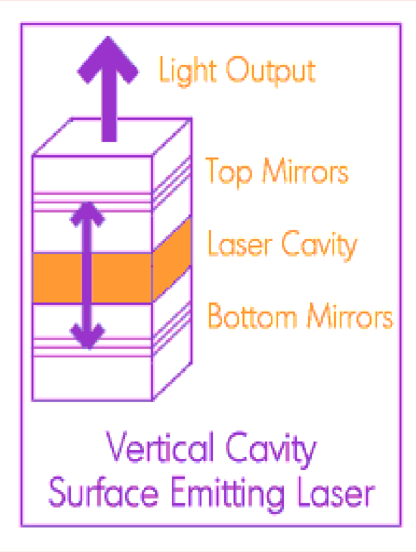


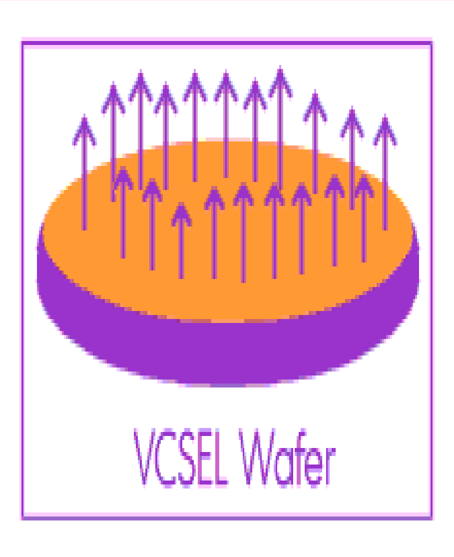


OPTICAL COMPONENTS

VCSEL- Vertical **C**avity **S**urface **E**mitting **M**icro **L**aser

- ❑ Semiconductor vertical cavity surface emitting laser diode.
- ❑ Emits light in a cylindrical beam vertically from the surface of a fabricated wafer.





VCSEL - continued

- Offers significant advantages when compared to the edge-emitting lasers.

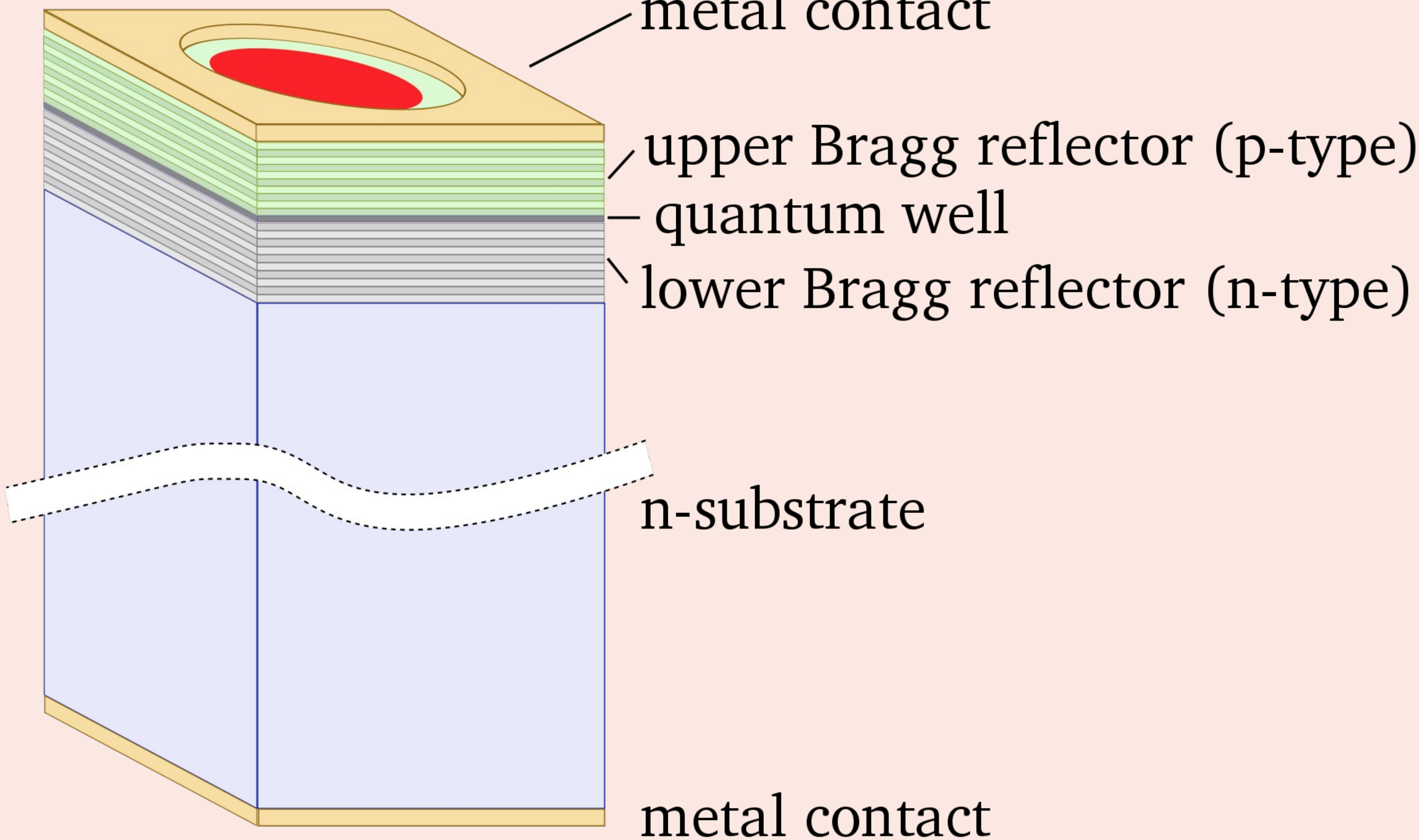
- Two special semiconductor materials → an active layer.

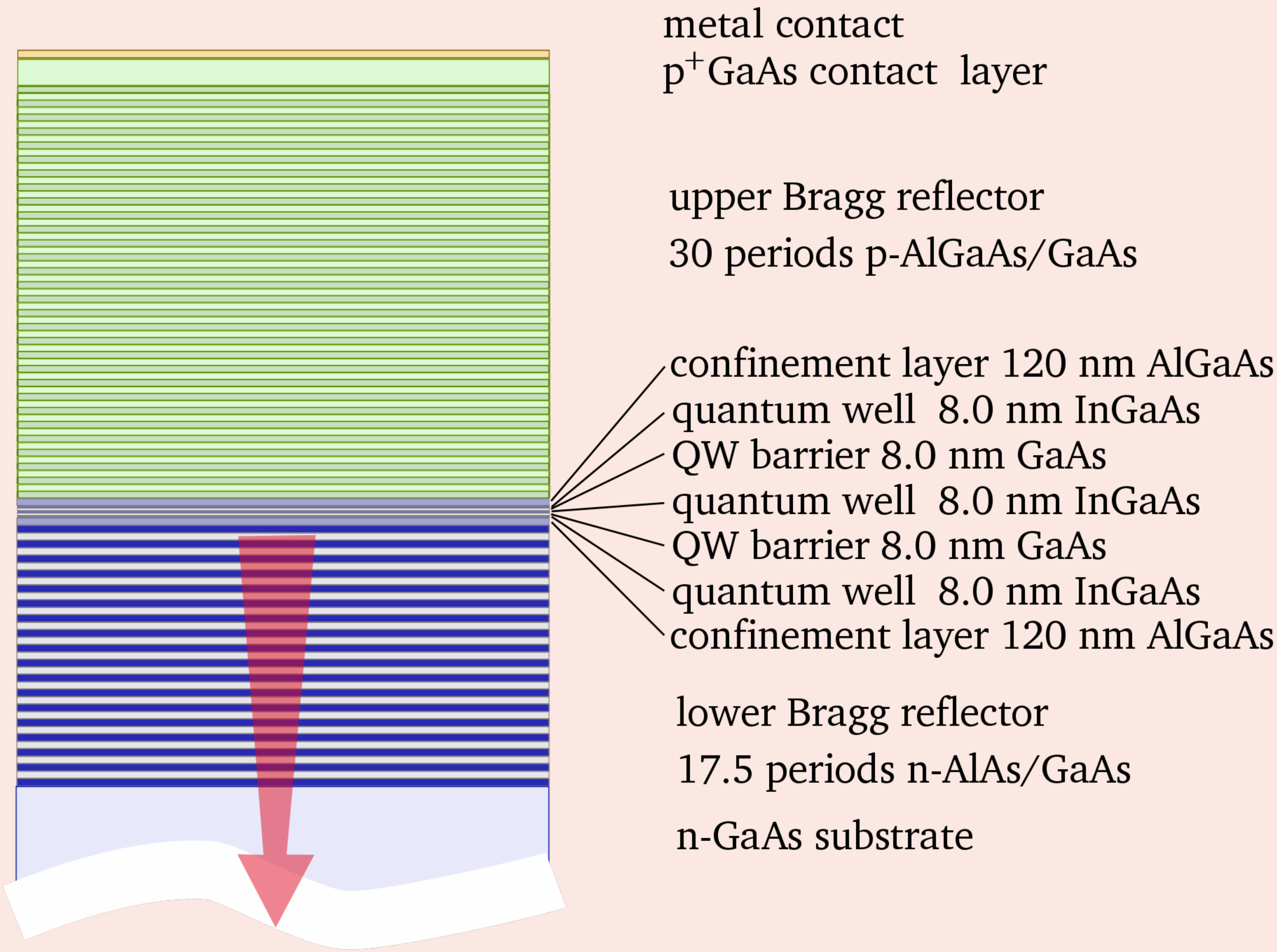
- Several layers of partially reflective mirrors above and below the active layer.

- Each mirror reflects a narrow range of wavelengths back in to the cavity.

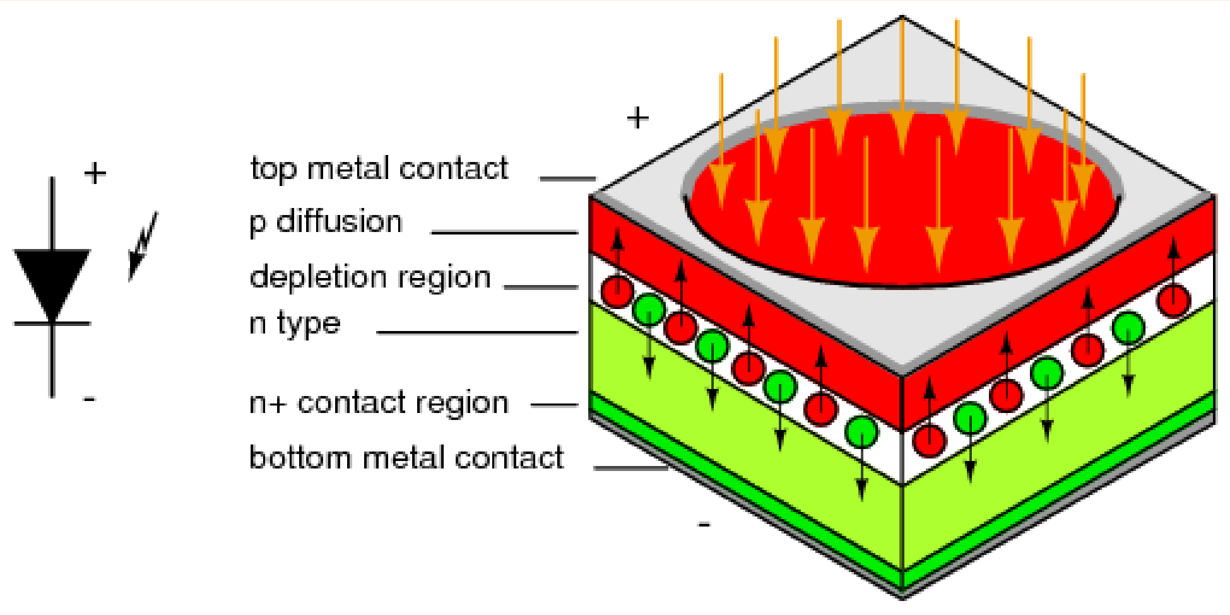
- Cause light emission at just one wavelength.

- Polymer waveguide.


metal contact
upper Bragg reflector (p-type)
quantum well
lower Bragg reflector (n-type)
n-substrate
metal contact


metal contact
p^+GaAs contact layer
upper Bragg reflector
30 periods p-AlGaAs/GaAs
confinement layer 120 nm AlGaAs
quantum well 8.0 nm InGaAs
QW barrier 8.0 nm GaAs
quantum well 8.0 nm InGaAs
QW barrier 8.0 nm GaAs
quantum well 8.0 nm InGaAs
confinement layer 120 nm AlGaAs
lower Bragg reflector
17.5 periods n-AlAs/GaAs
n-GaAs substrate

PHOTODIODE

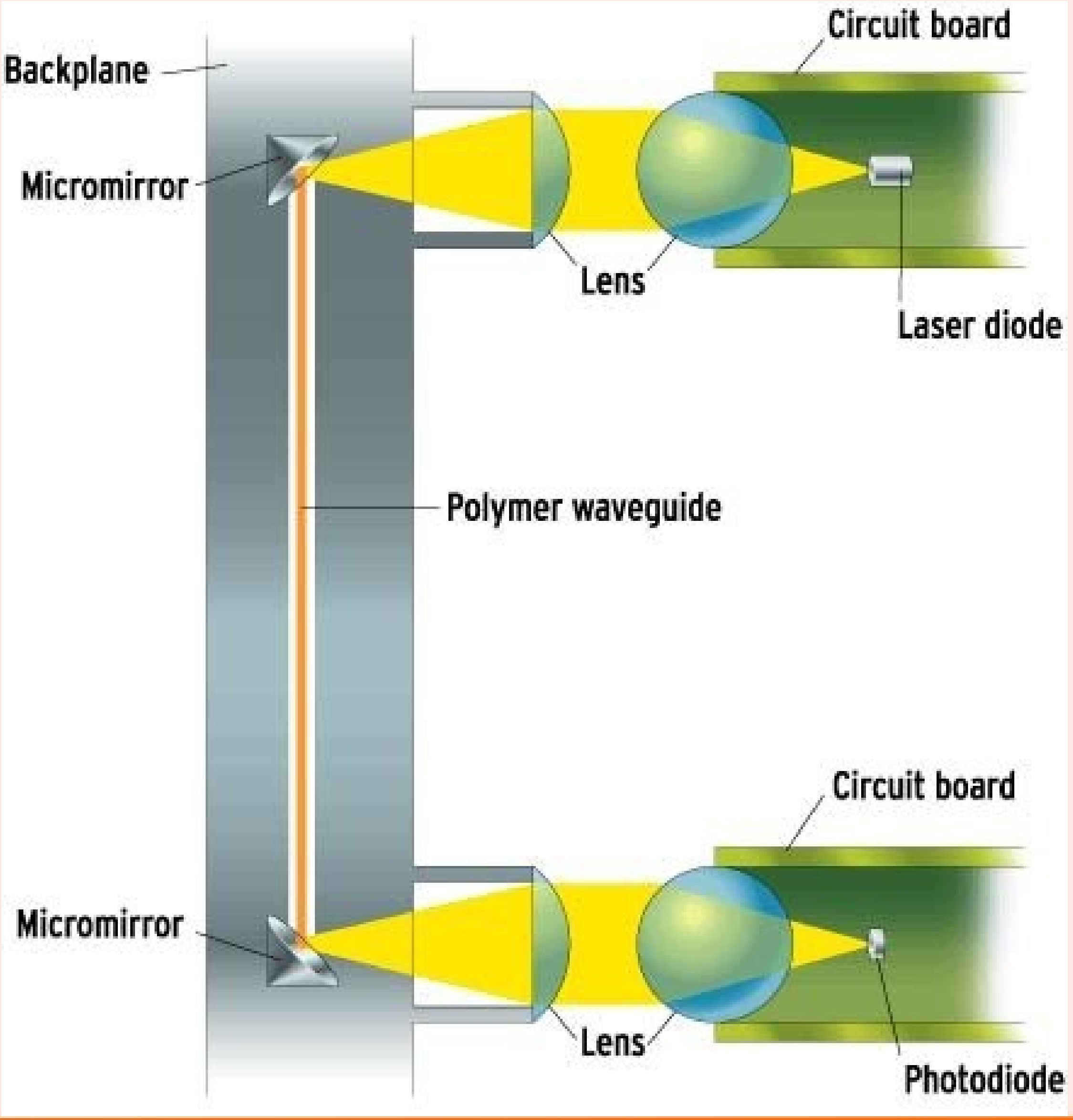


- A type of photo detector capable of converting light into either current or voltage.

- Similar to PN junction diode.

- When a photon of sufficient energy strikes the diode, it excites an electron.
- Creates a free electron and a hole.
- If the absorption occurs in the junction's depletion region, or one diffusion length away from it,
- these carriers are swept from the junction by the built-in field of the depletion region.
- Thus holes move toward the anode, and electrons toward the cathode, and a photocurrent is produced.

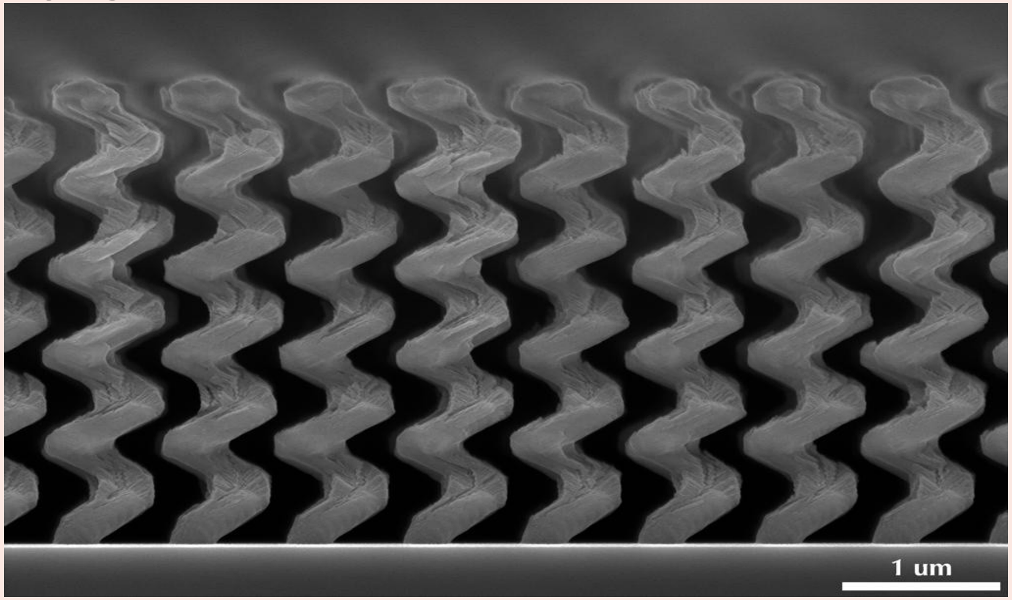
OPTICAL INTERCONNECTION OF CIRCUIT BOARDS USING VCSEL AND PHOTODIODE



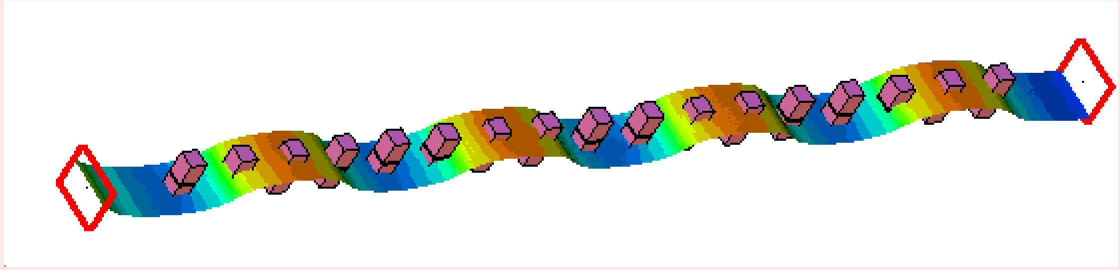
PHOTONIC CRYSTALS

- ❑ Crystals designed to replace transistors in optical computers.

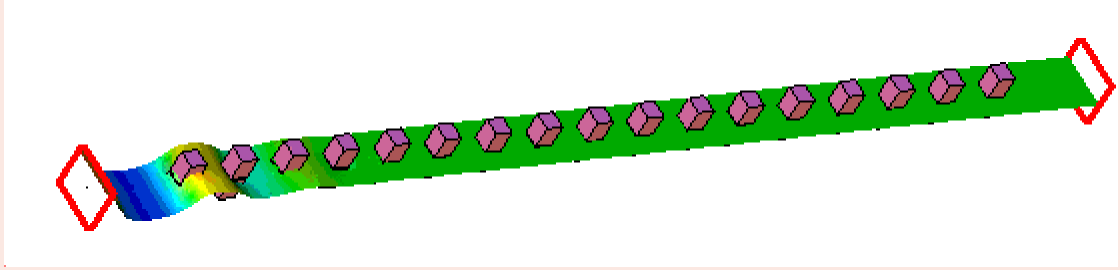
- ❑ Optical nanostructures that are designed to affect the motion of photons.



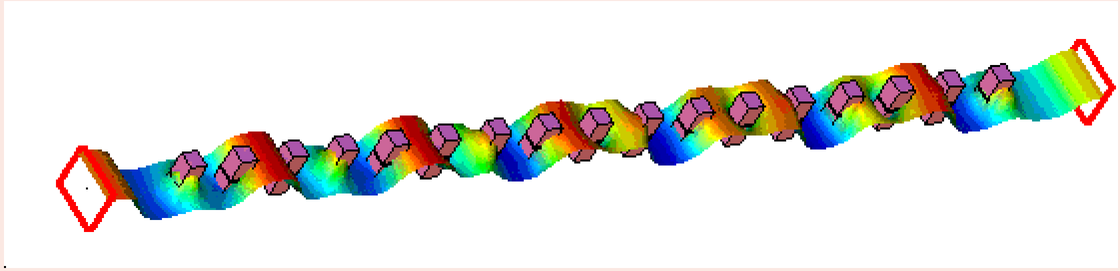
Wave Propagation at frequencies below the band gap



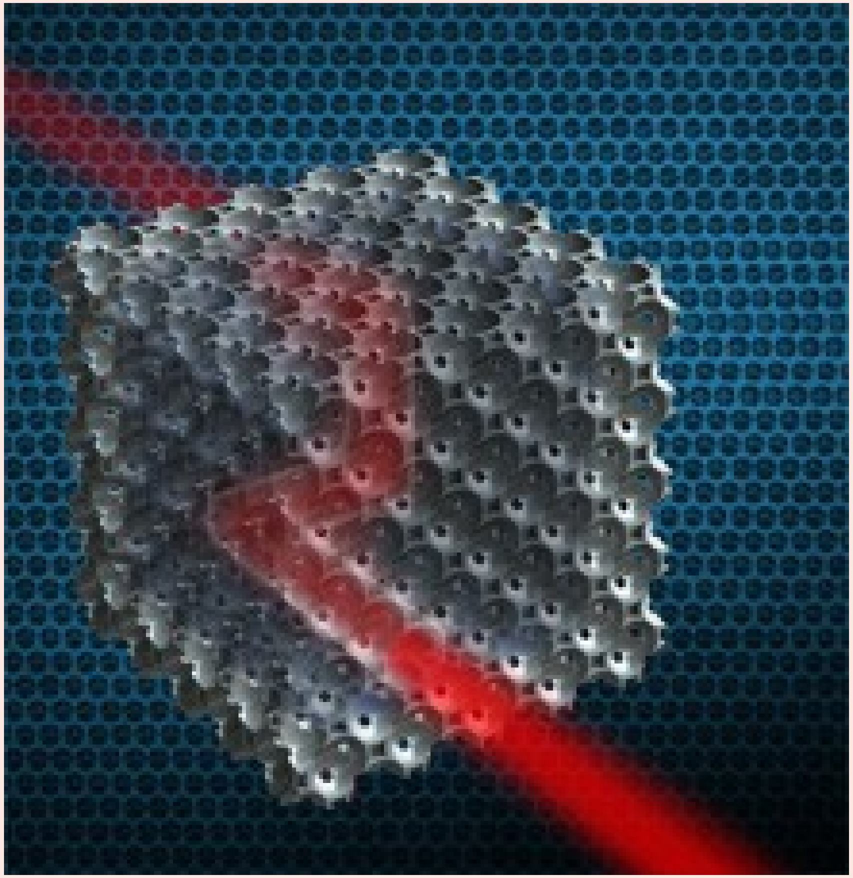
Wave propagation at frequencies in the band gap



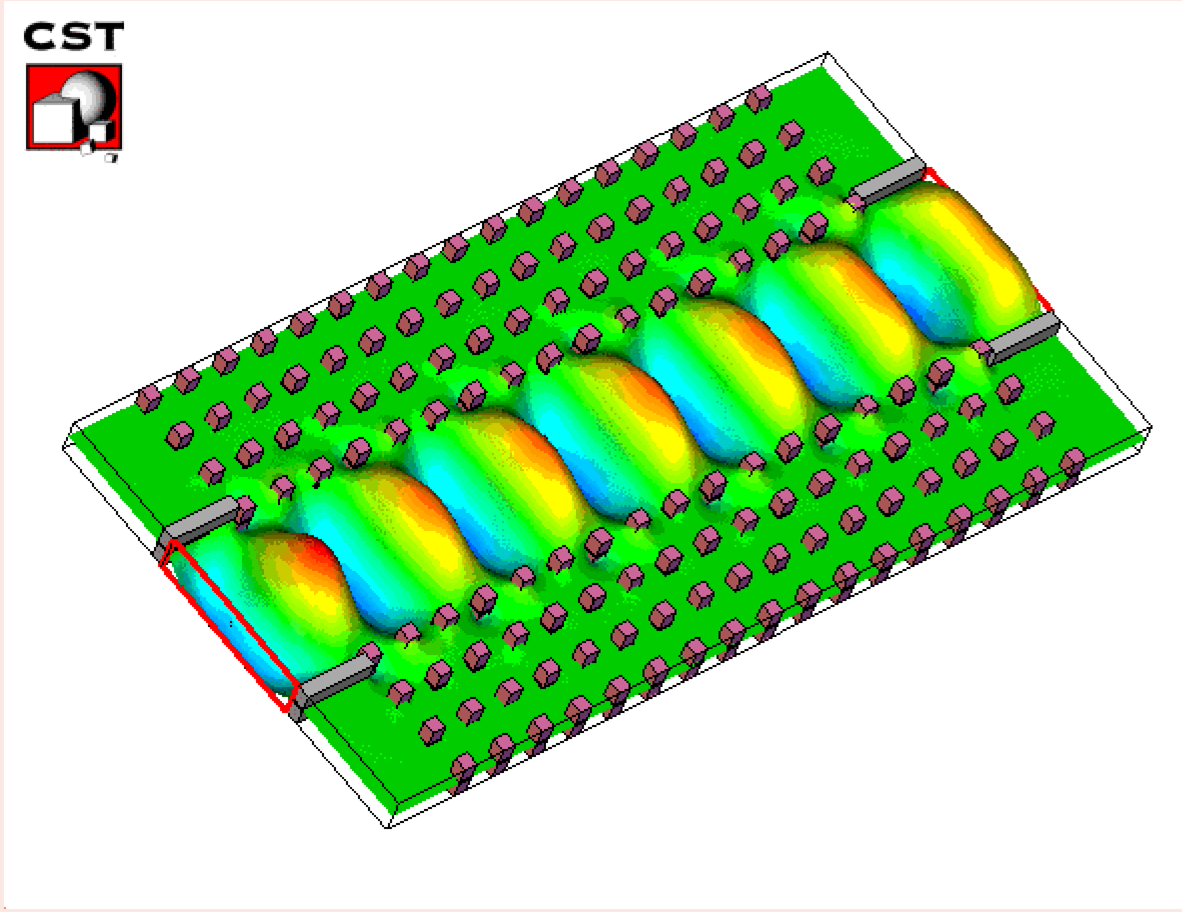
Wave Propagation at frequencies above the band gap



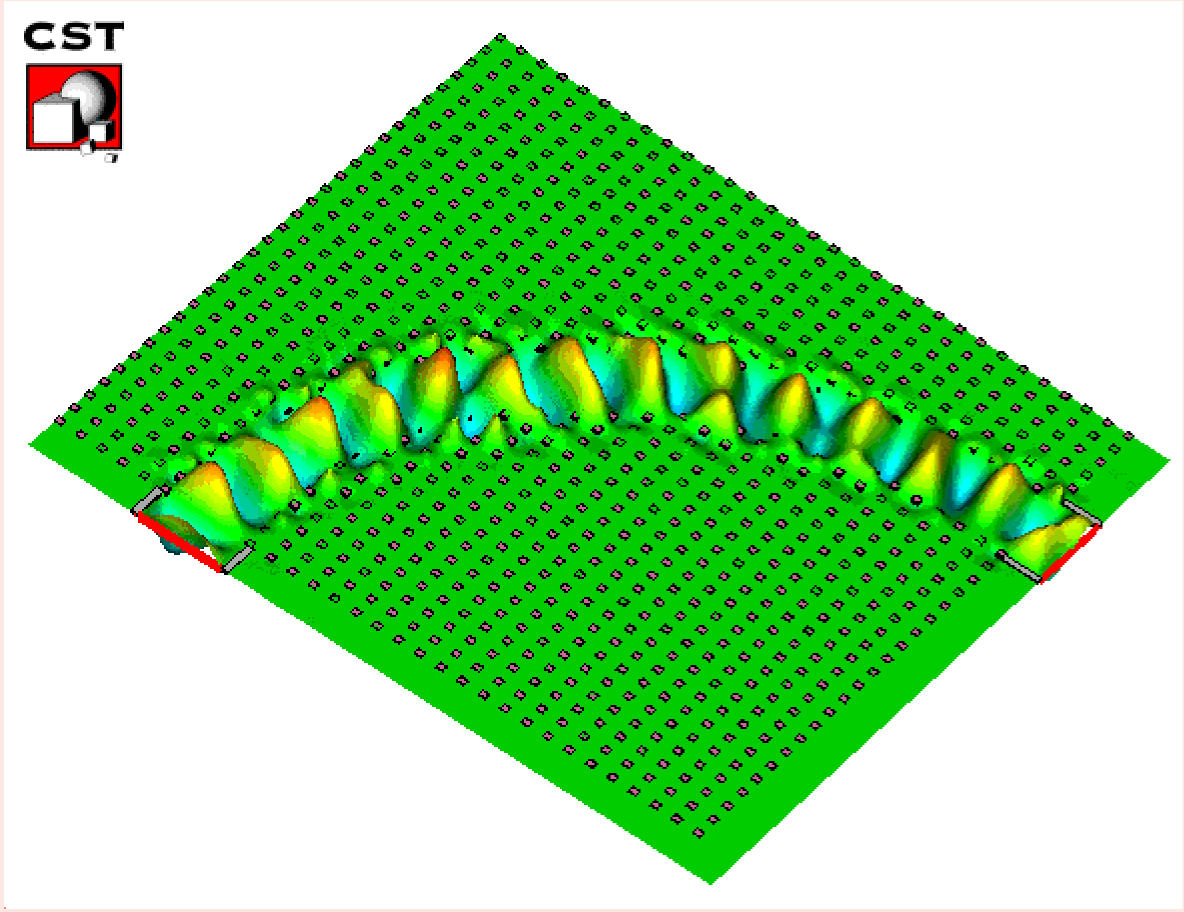
3D optical waveguide



Photonic Crystal with line defect



Photonic crystal with a bend defect

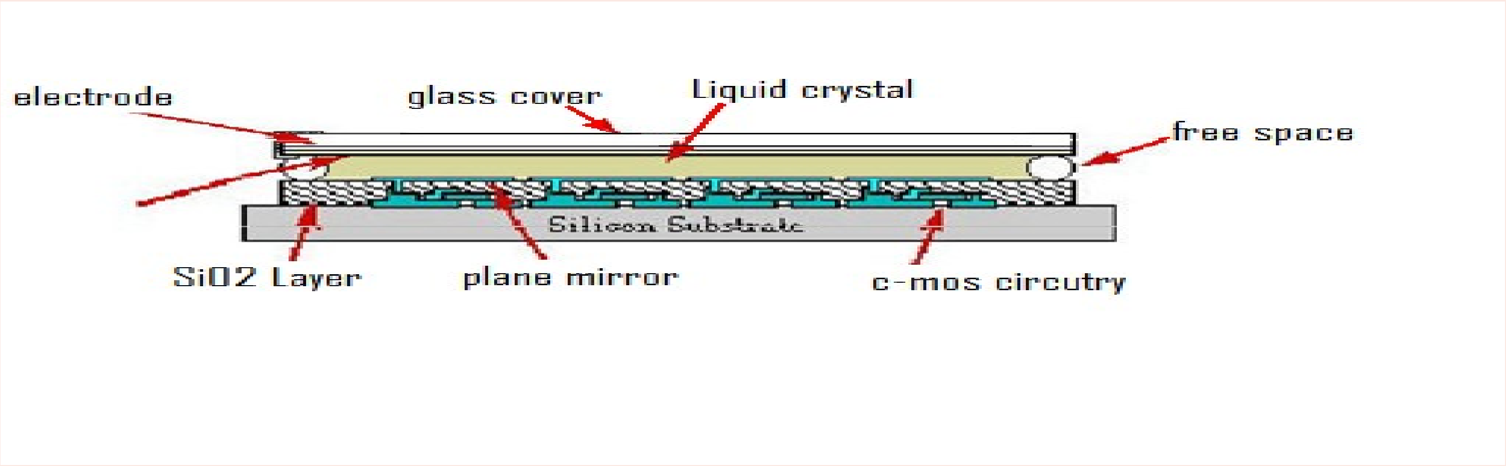


SLM- Spatial Light Modulator

- **SLMs** play an important role in optical processing, for inputting information on light beams, and displays.

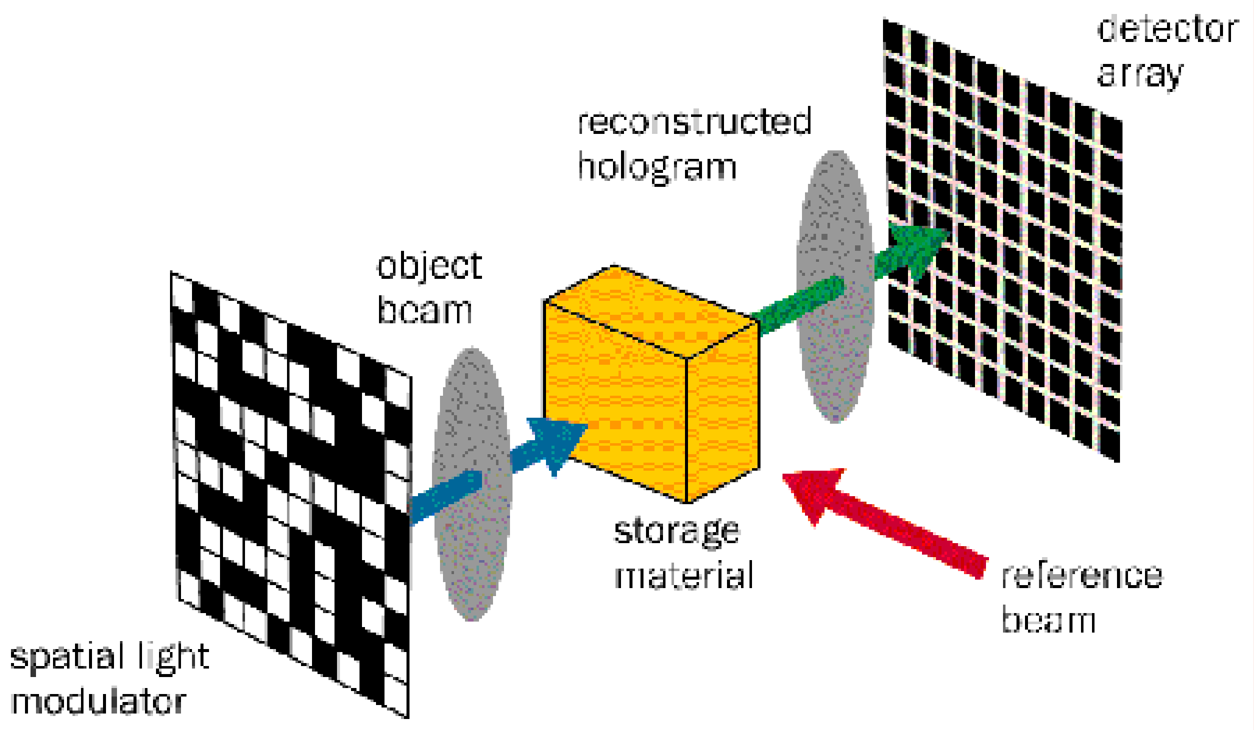
- A set of memory cells laid out on a regular grid and value in each cell contribute to manipulate the behaviour of optical activity.

- Cells are electrically connected to metal mirrors, such that the voltage on the mirror depends on the value stored in



- SLM modulates the intensity and phase of the light beam.

- SLMs are used extensively in holographic data storage setups to encode information into a laser beam.


detector
array
reconstructed
hologram
object
beam
storage
material
reference
beam
spatial light
modulator

SMART PIXELS

- Smart pixels, the union of optics and electronics.

- Expands the capabilities of electronic systems and enables optical systems with high levels of electronic signal processing.

- The electronic circuitry provides complex functionality and programmability

- The optoelectronic devices provide high-speed switching.

- Some examples
  - LED- Light Emitting Diode under the control of a FET- Field Effect Transistor.

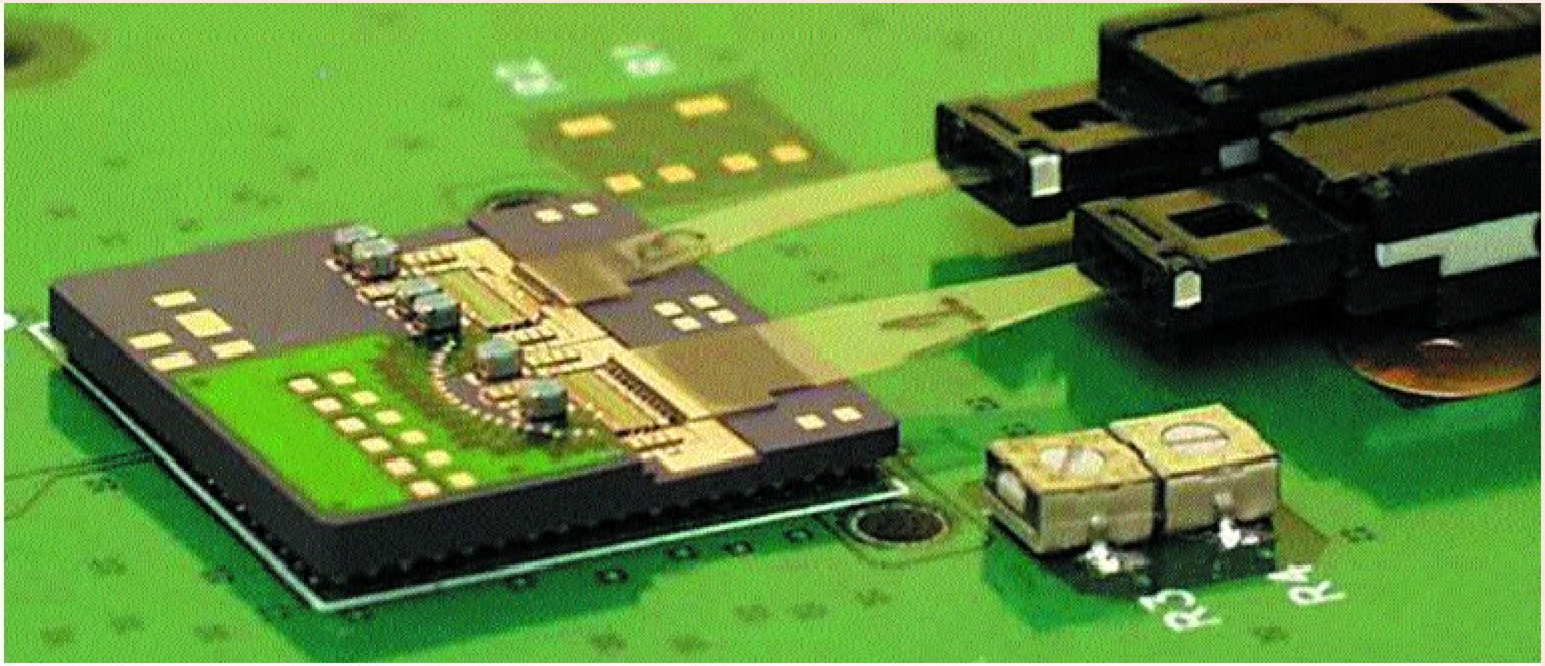


Figure 1. In this optoelectronic device, signals from a computer on the left drive arrays of surface emitting lasers that output signals through 12-channel polymer waveguides (Polyguide) and connectors to the optical-fiber ribbon. Return signals pass through photodetectors back to the computer.

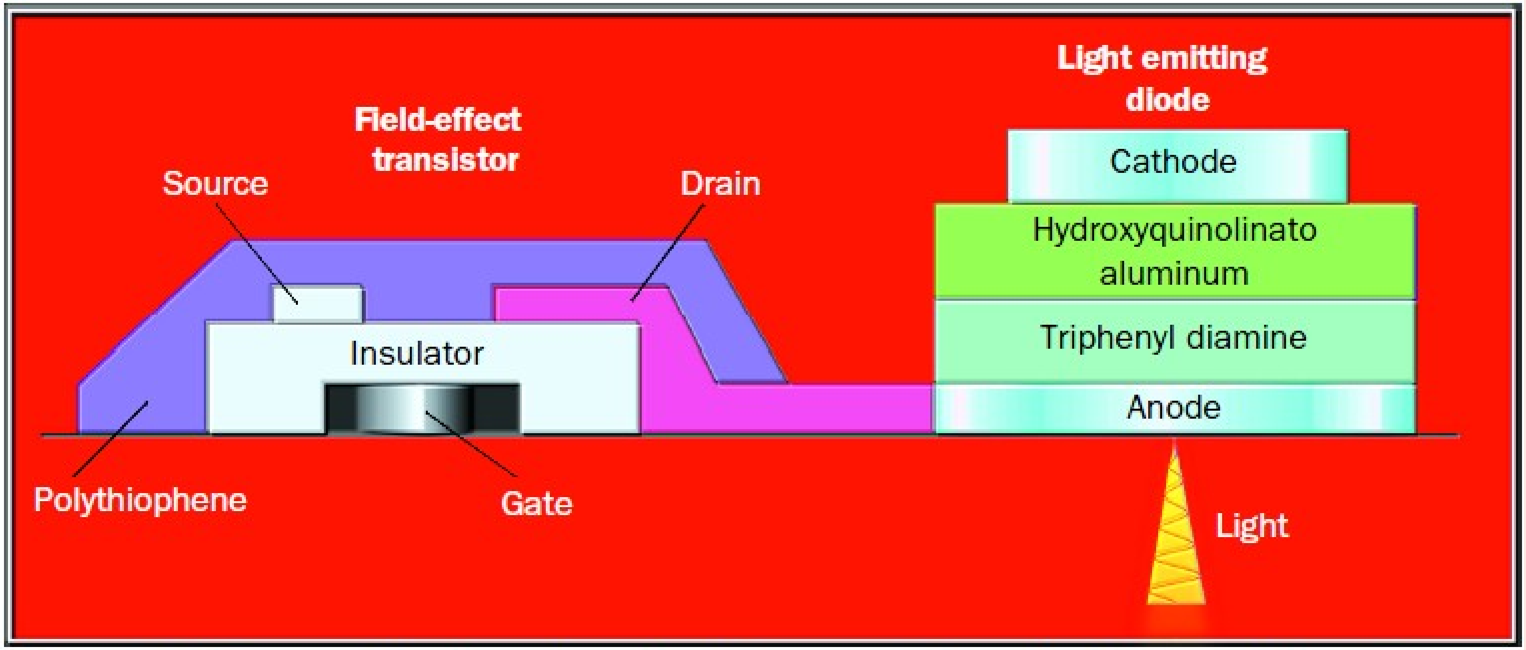


Figure 2. This smart pixel, made entirely from organic materials, consists of a light-emitting diode controlled by a field-effect transistor. As well as being bright (important for use in flat-panel displays), it can be printed rather than etched.

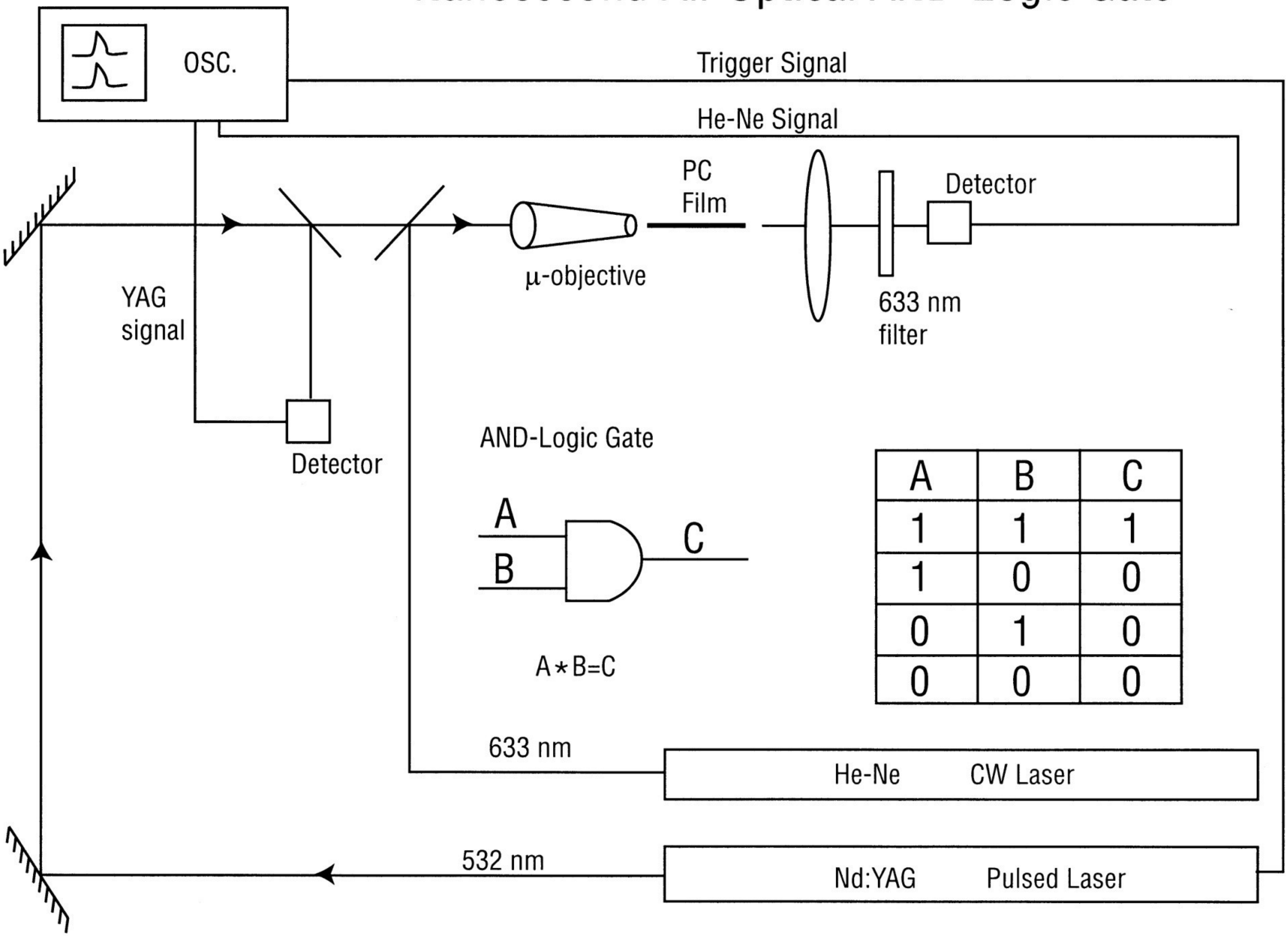
LOGIC GATES

- Logic gates are the building blocks of any digital system.

- An optical logic gate is a switch that controls one light beam with another.

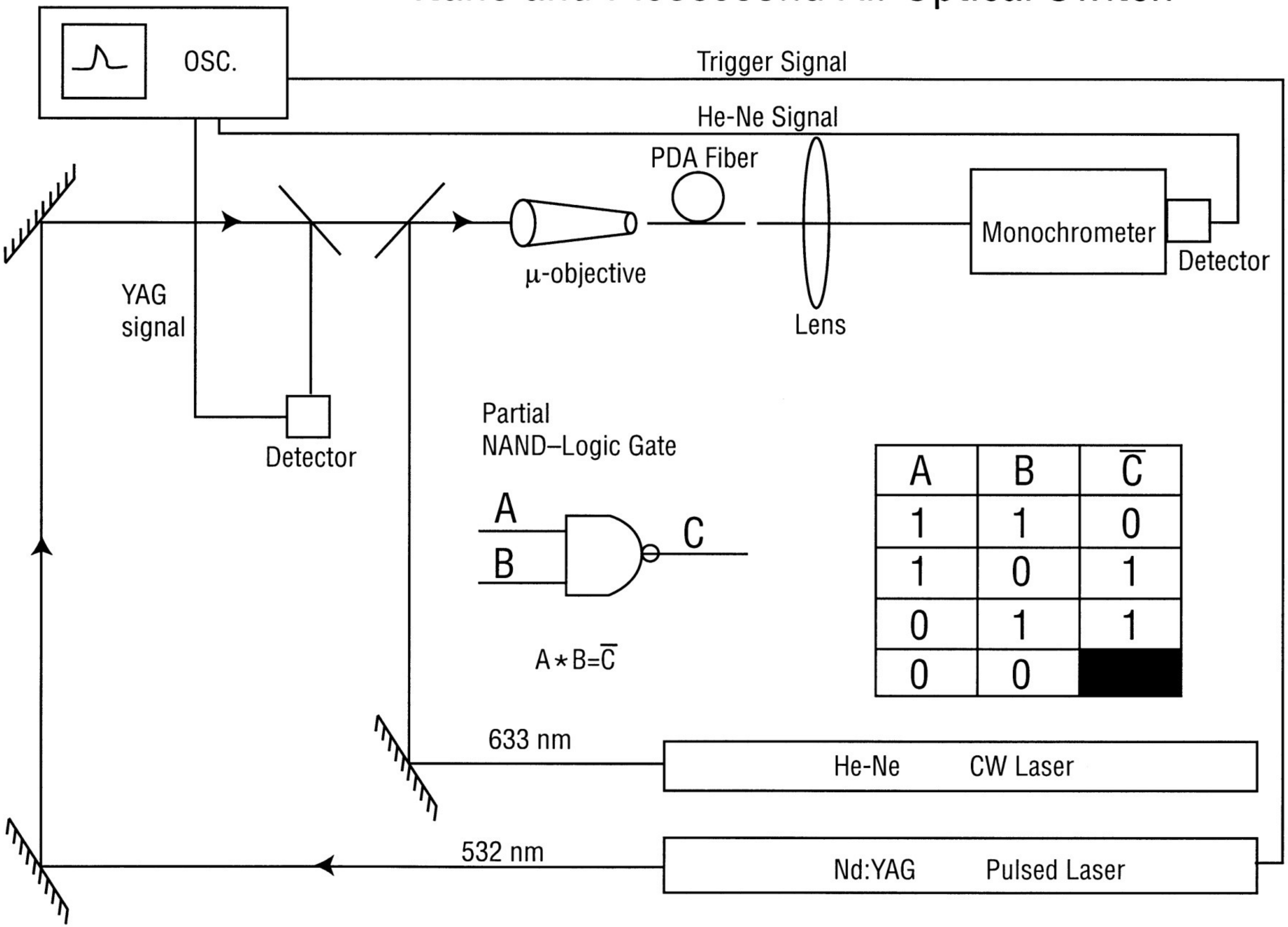
- It is "on" when the device transmits light, and "off" when it blocks the light.

Nanosecond All-Optical AND-Logic Gate



A	B	C
1	1	1
1	0	0
0	1	0
0	0	0

Nano and Picosecond All-Optical Switch



A	B	$\overline{C}$
1	1	0
1	0	1
0	1	1
0	0	

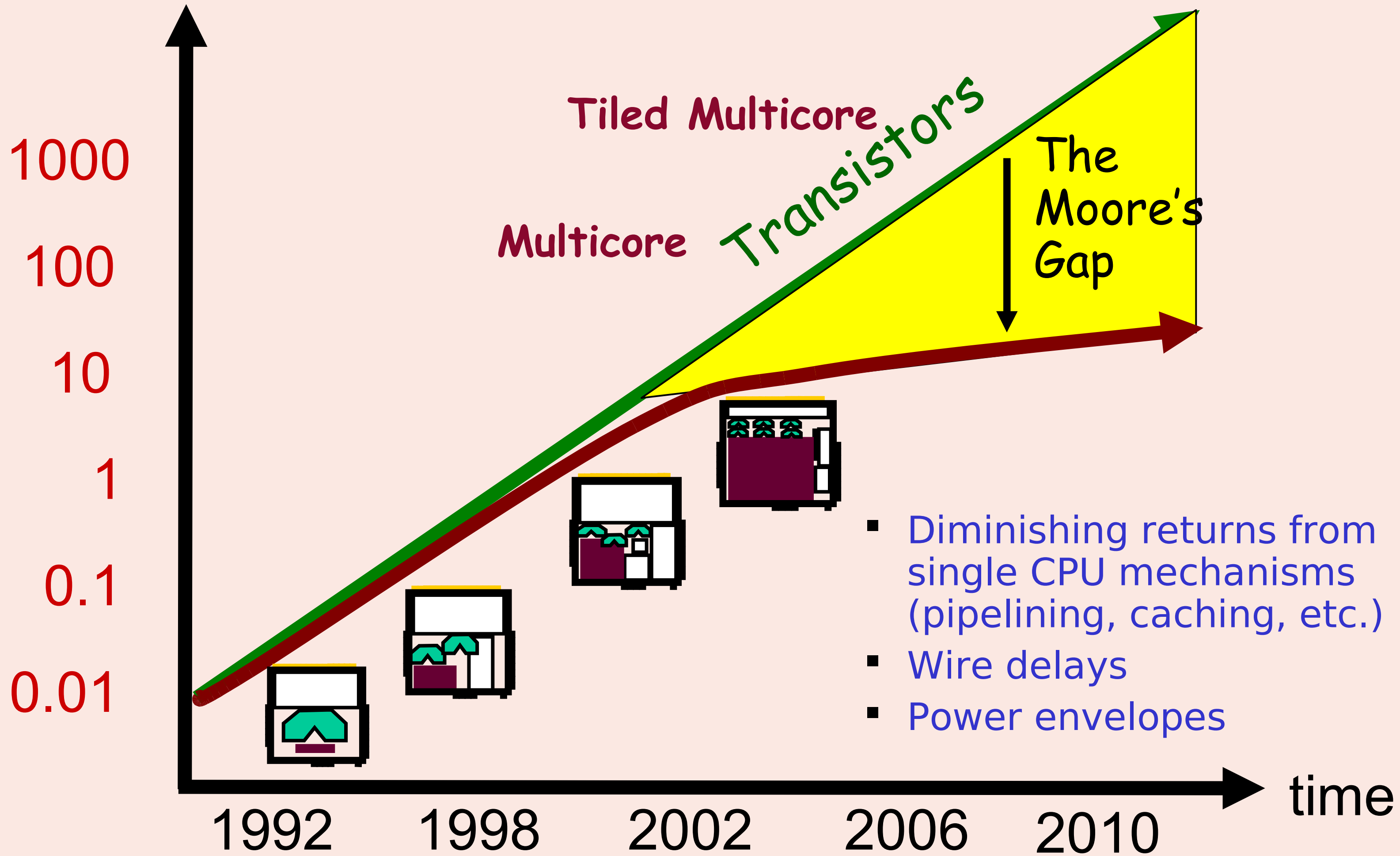
USE OF OPTICS IN COMPUTING

- Optical fibres are used to communicate internally; like communicating with peripherals etc.

- The use of free-space optical interconnects as a potential solution to alleviate bottlenecks experienced in electronic.

- Optical sorting and optical crossbar inter-connects are used in asynchronous transfer modes.

"Moore's Gap"



- Diminishing returns from single CPU mechanisms (pipelining, caching, etc.)
- Wire delays
- Power envelopes

Multicore Scaling Trends

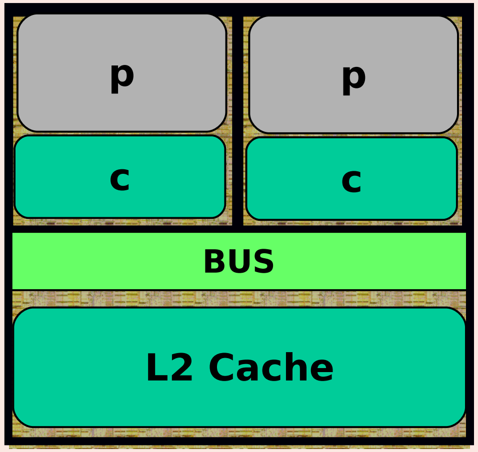
Today

A few large cores on each chip

Diminishing returns prevent cores from getting more complex

Only option for future scaling is to add more cores

Still some shared global structures: bus, L2 caches

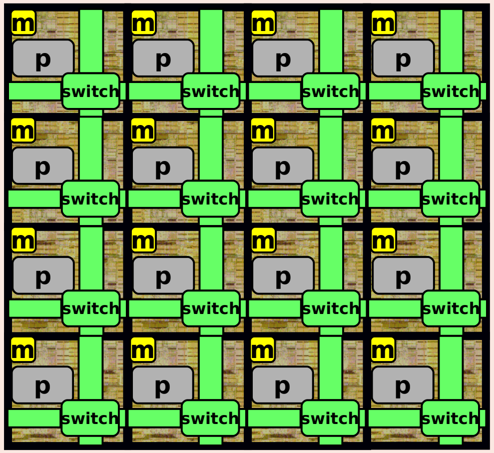


Tomorrow

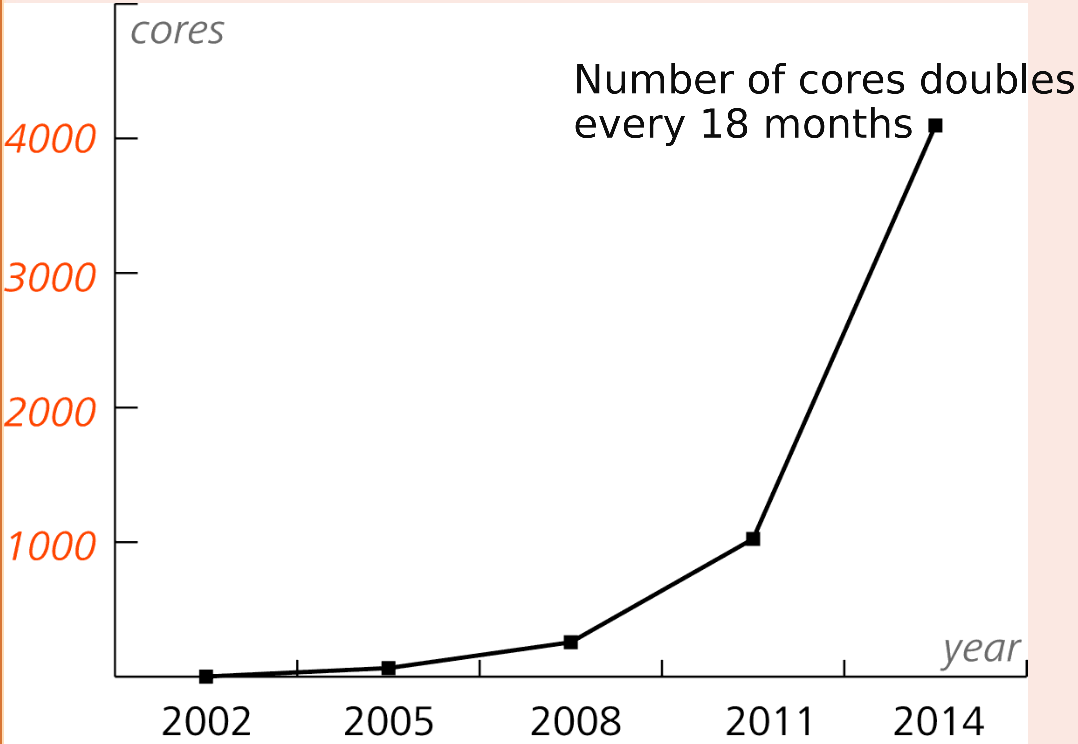
100’s to 1000’s of simpler cores [S. Borkar, Intel, 2007]

Simple cores are more power and area efficient

Global structures do not scale; all resources must be distributed



The Future of Multicore

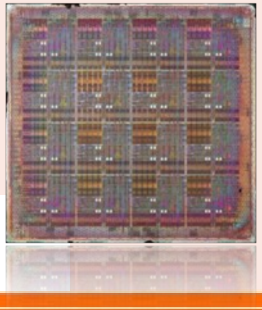


Parallelism replaces clock frequency scaling and core complexity

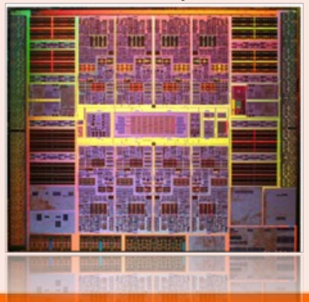
Resulting Challenges…

Scalability
Programming
Power

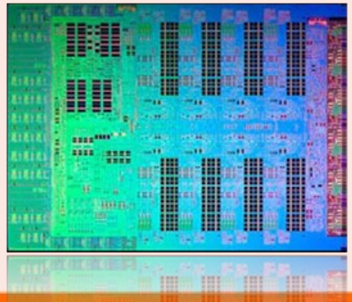
MIT RAW



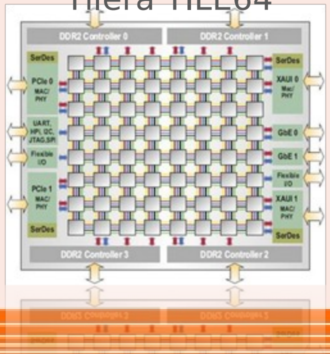
Sun Ultrasparc T2



IBM XCell 8i



Tilera TILE64



Multicore Challenges

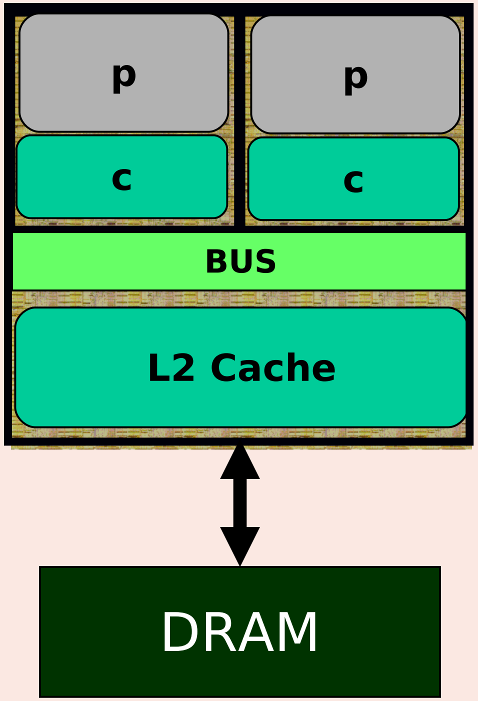
- Scalability
  - How do we turn additional cores into additional performance?
    - Must accelerate single apps, not just run more apps in parallel
    - Efficient core-to-core communication is crucial
  - Architectures that grow easily with each new technology generation

- Programming
  - Traditional parallel programming techniques are hard
  - Parallel machines were rare and used only by rocket scientists
  - Multicores are ubiquitous and must be programmable by anyone

- Power
  - Already a first-order design constraint
  - More cores and more communication ➔ more power
  - Previous tricks (*e.g.* lower Vdd) are running out of steam

Multicore Communication Today

Bus-based Interconnect



Single shared resource

Uniform communication cost

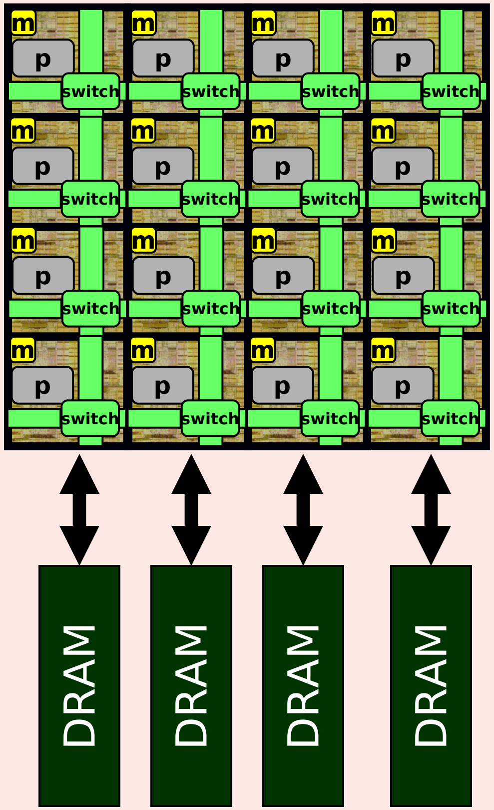
Communication through memory

Doesn’t scale to many cores due to contention and long wires

Scalable up to about 8 cores

Multicore Communication Tomorrow

Point-to-Point Mesh Network



- Examples: MIT Raw, Tilera TILEPro64, Intel Terascale Prototype
- Neighboring tiles are connected
- Distributed communication resources
- Non-uniform costs:
  - Latency depends on distance
  - Encourages direct communication
- More energy efficient than bus
- Scalable to hundreds of cores

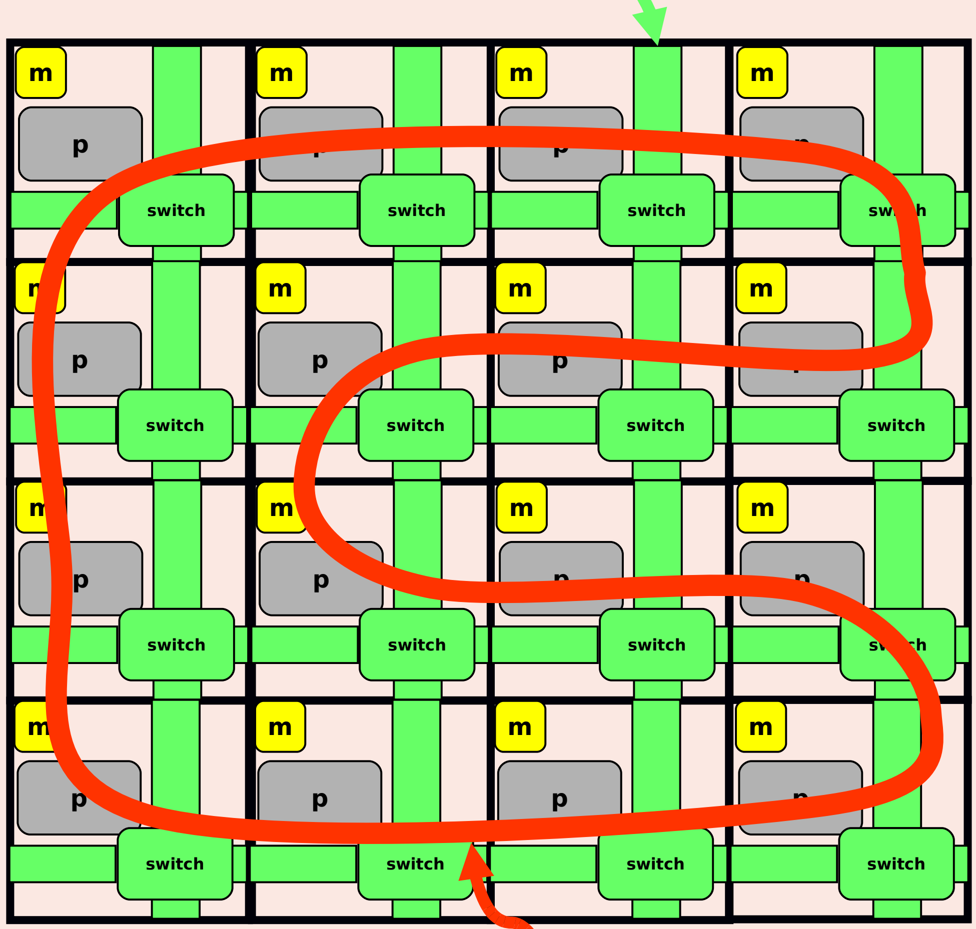
Improving Programmability

Observations:

- A cheap broadcast communication mechanism can make programming easier
  - Enables convenient programming models (e.g., shared memory)
  - Reduces the need to carefully manage locality
- On-chip optical components enable cheap, energy-efficient broadcast

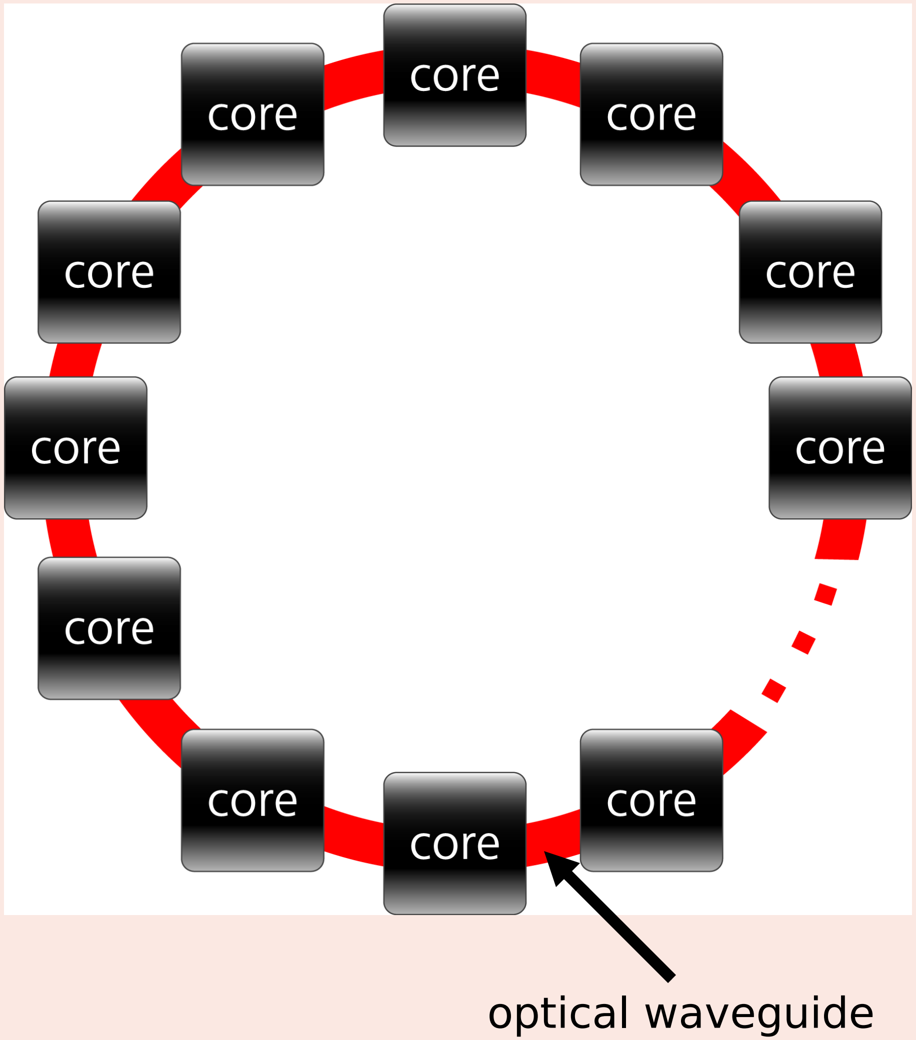
ATAC Architecture

Electrical Mesh Interconnect



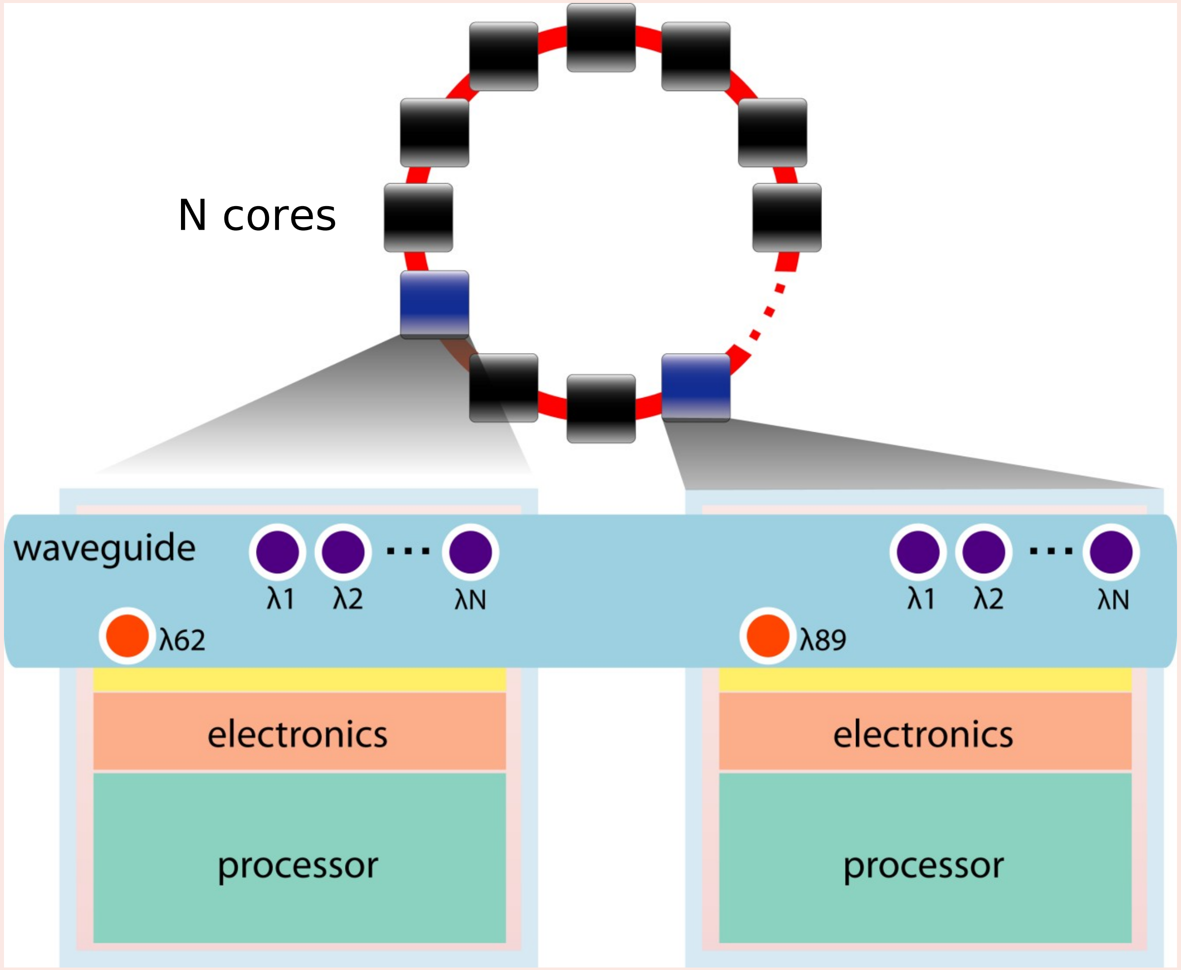
Optical Broadcast WDM Interconnect

Optical Broadcast Network



- Waveguide passes through every core
- Multiple wavelengths (WDM) eliminates contention
- Signal reaches all cores in <2ns
- Same signal can be received by all cores

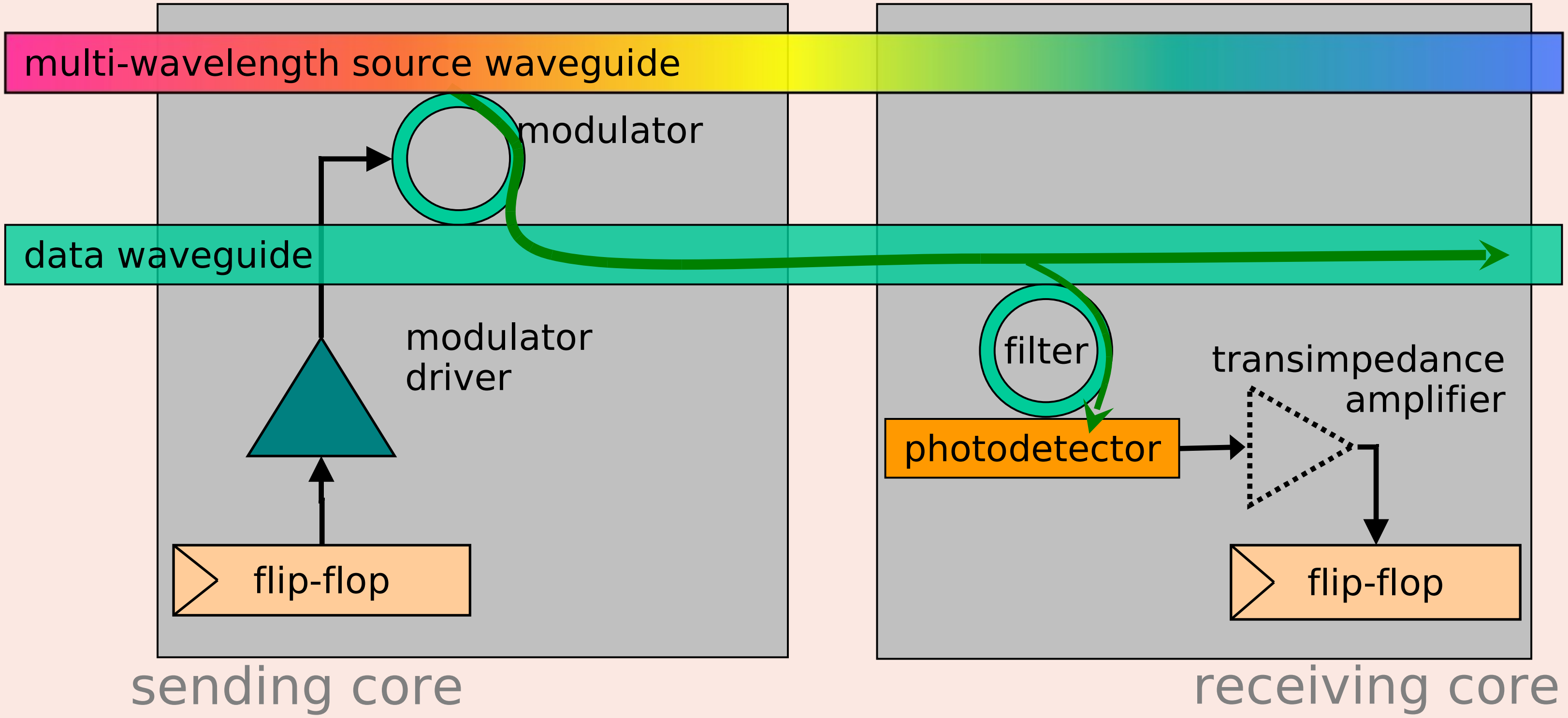
Optical Broadcast Network



- Electronic-photonic integration using standard CMOS process
- Cores communicate via optical WDM broadcast and select network
- Each core sends on its own dedicated wavelength using modulators
- Cores can receive from some set of senders using optical filters

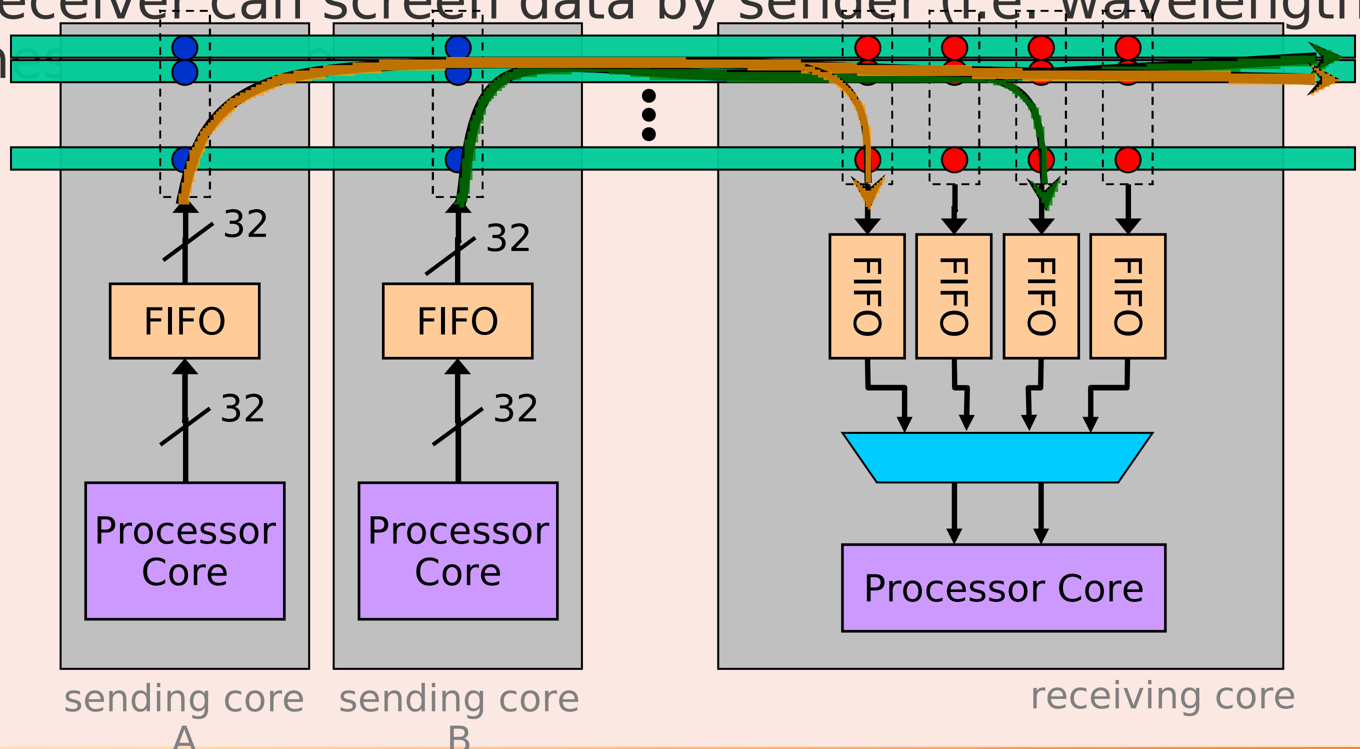
Optical bit transmission

- Each core sends data using a different wavelength ➔ no contention
- Data is sent once, any or all cores can receive it ➔ efficient broadcast



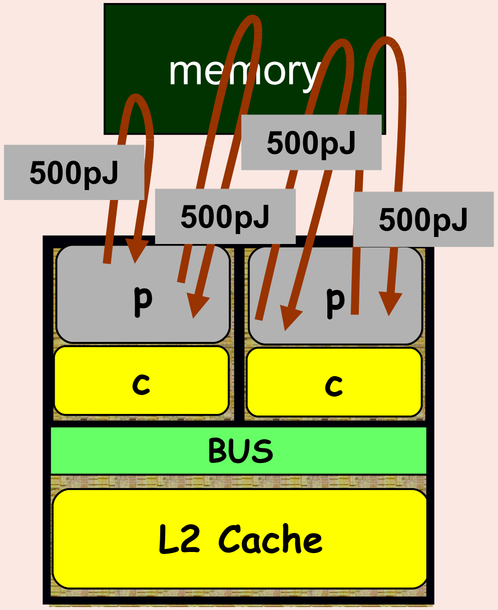
Core-to-core communication

- 32-bit data words transmitted across several parallel waveguides
- Each core contains receive filters and a FIFO buffer for every sender
- Data is buffered at receiver until needed by the processing core
- Receiver can screen data by sender (i.e. wavelength) or mes

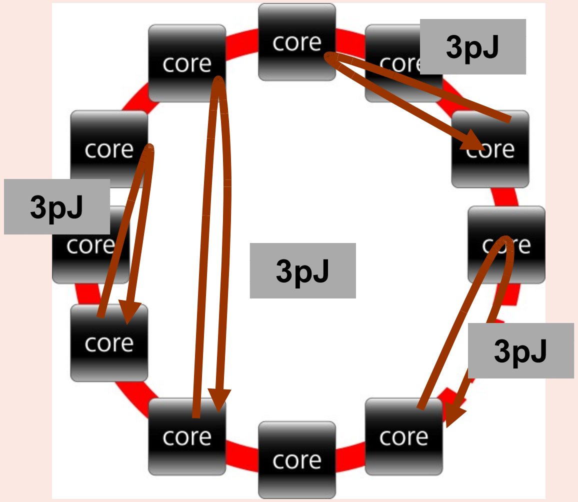


Communication-centric Computing

- ATAC reduces off-chip memory calls, and hence energy and latency
- View of extended global memory can be enabled cheaply with on-chip distributed cache memory and ATAC network



Bus-Based Multicore

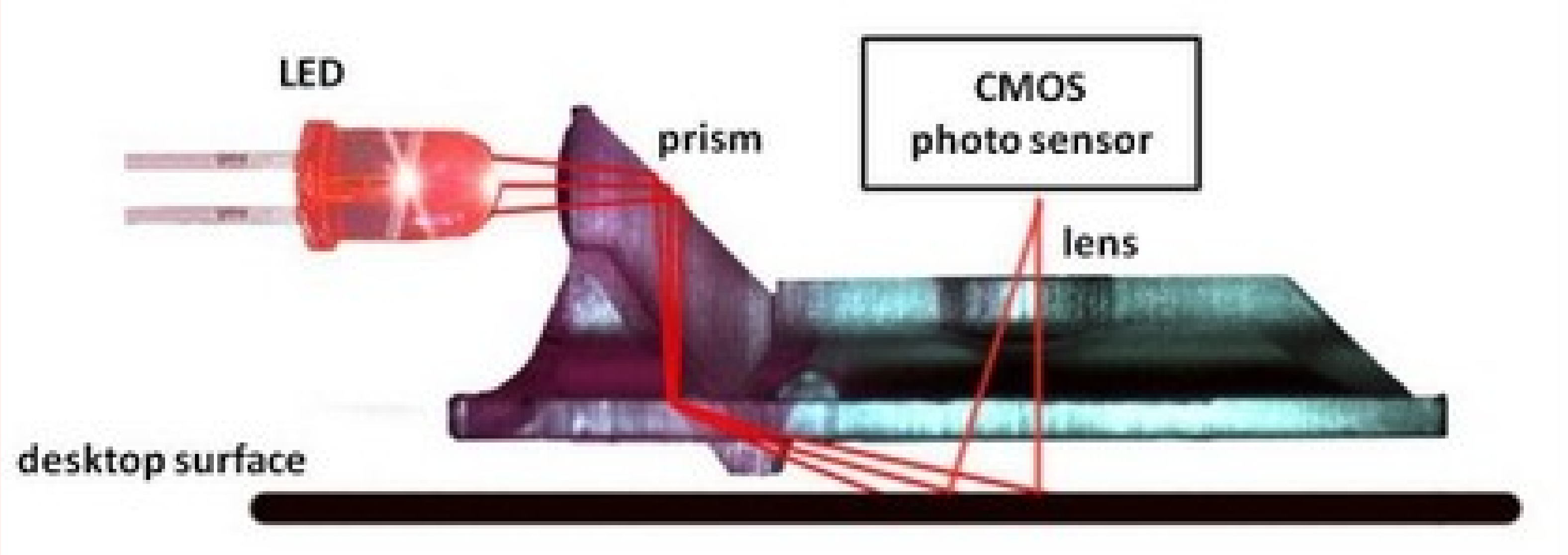


ATAC

Operation	Energy	Latency
Network transfer	3pJ	3 cycles
ALU add operation	2pJ	1 cycle
32KB cache read	50pJ	1 cycle
Off-chip memory read	500pJ	250 cycles

OPTICAL INPUT DEVICES

Optical Mouse



- An optoelectronic sensor to take successive pictures of the surface on which the mouse operates
- A small LED provides light underneath the mouse, helping to highlight slight differences in the surface underneath the mouse.
- Those differences are reflected back into the camera, where digital processing is used to compare the pictures and determine the speed and direction of movement.

Optical Mice

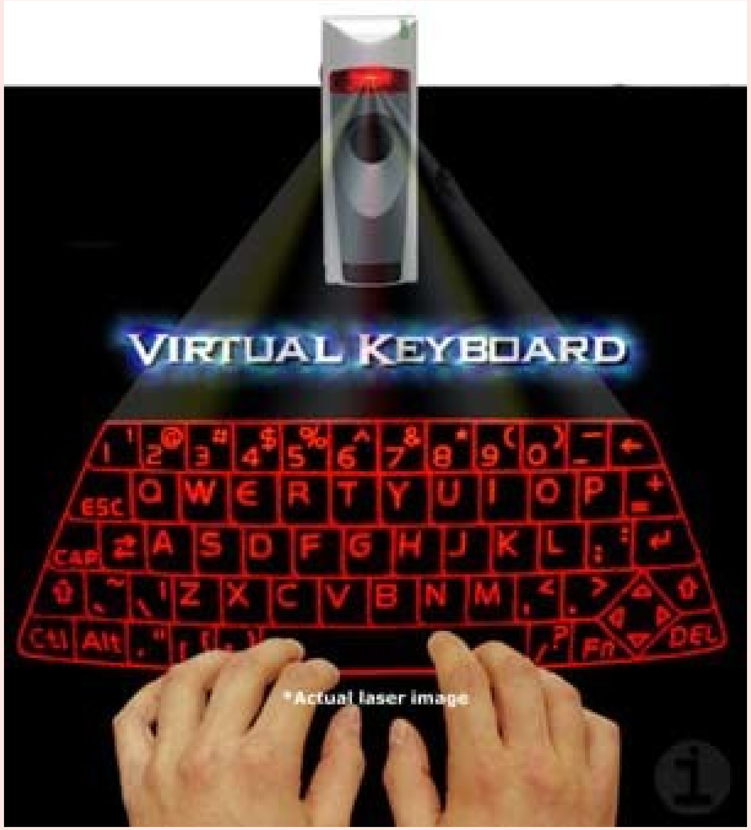
Optical Keyboard

- It can be projected and touched on any surface.

- A sensor or camera in the projector picks up finger movements.

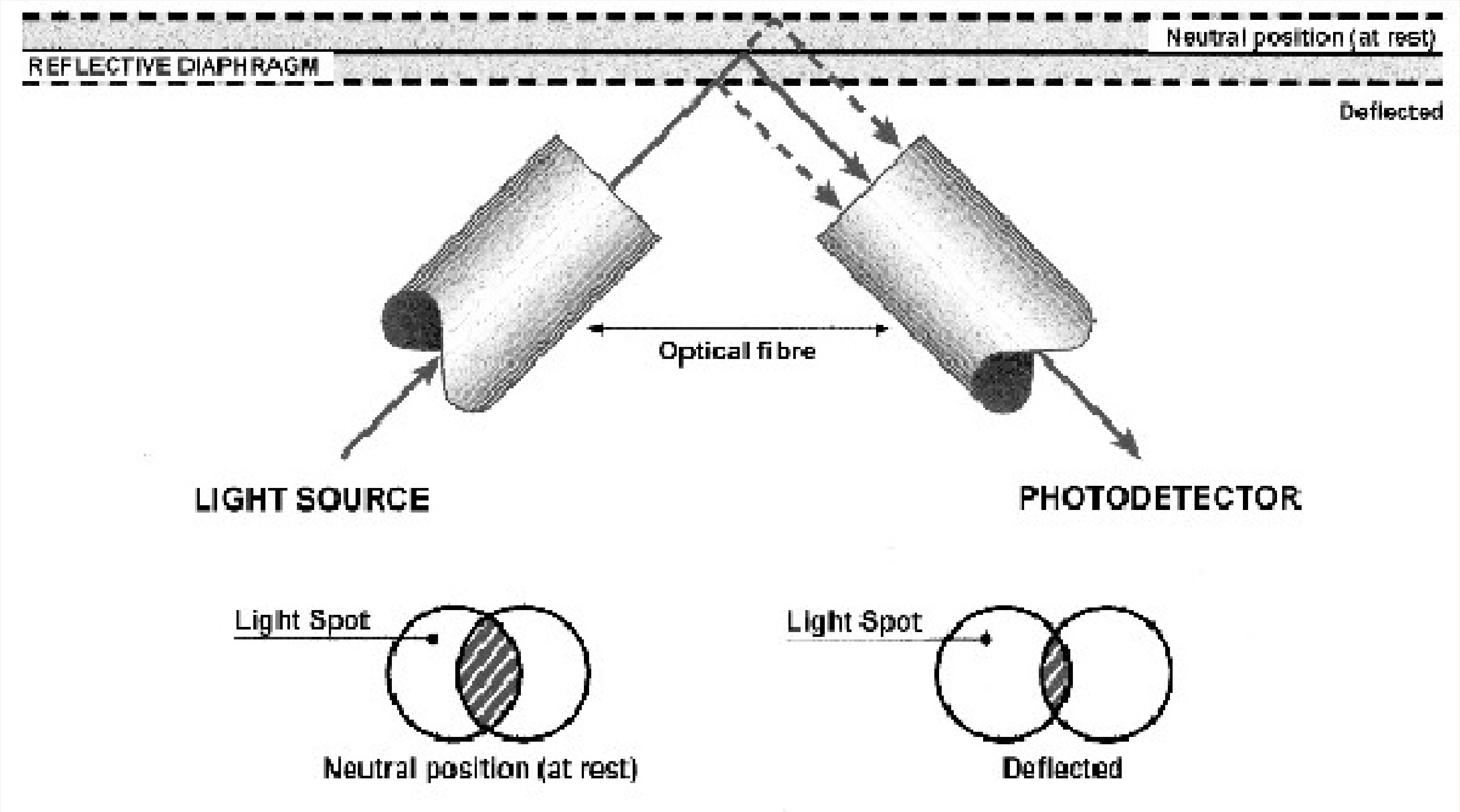
- The camera associated with the detector detects co-ordinates and determine actions or characters to be generated.

Optical Keyboard



Virtual Keyboard

Optical Microphone



Optical Microphone- continued…

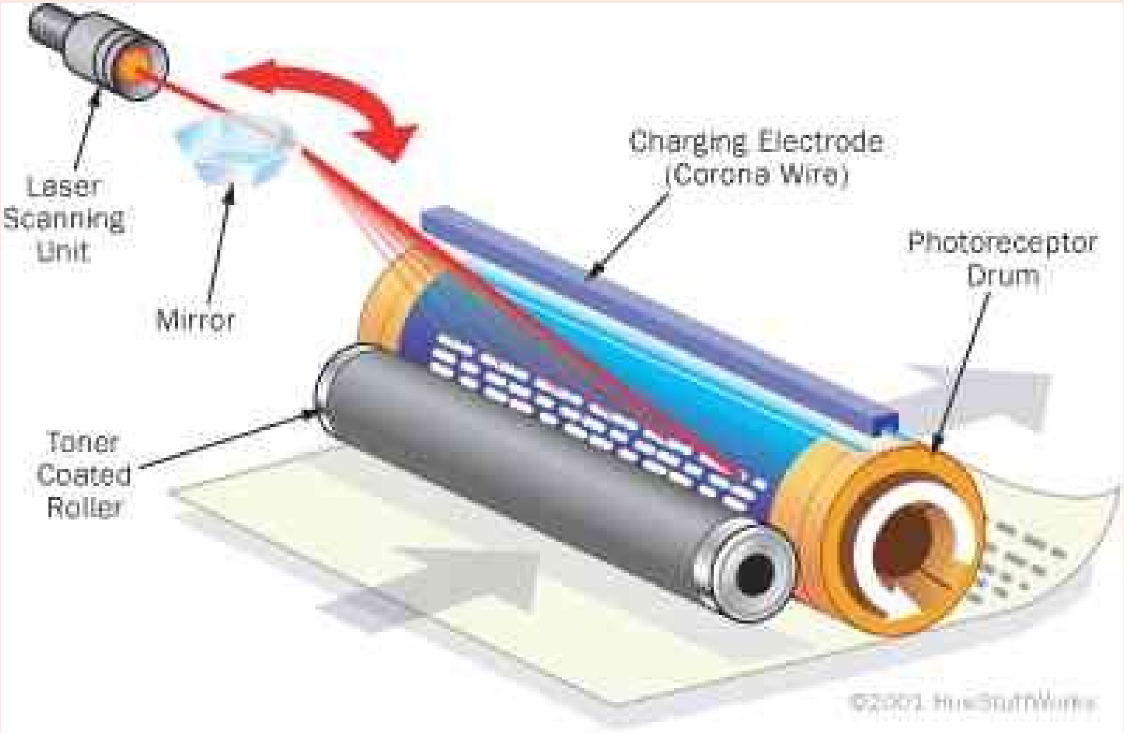
- The main principle of the optical microphone is to detect the vibration of a membrane using light.

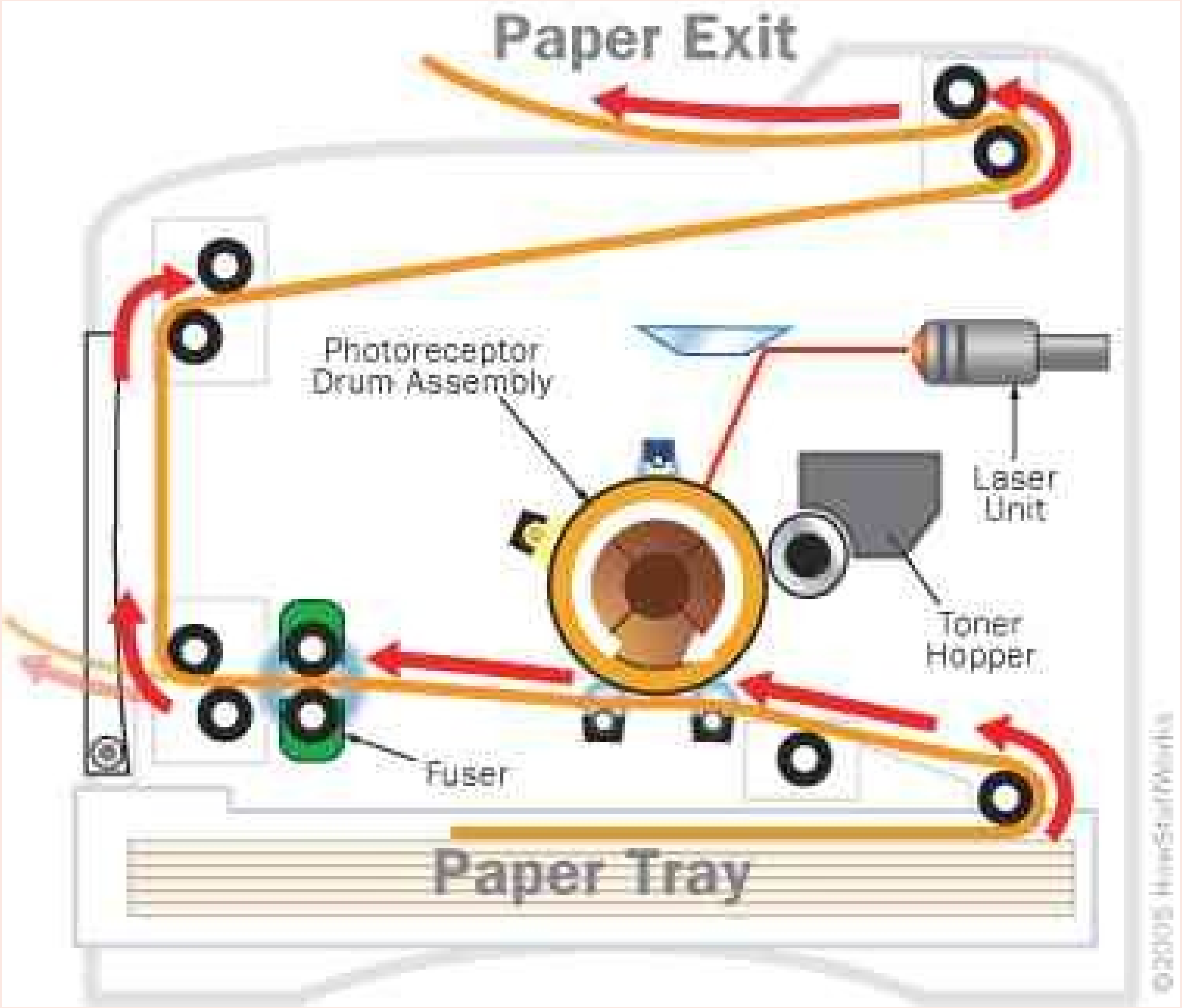
- When sound waves agitate the membrane it starts to vibrate, resulting in a toggling of the light spot on the receiving fiber.

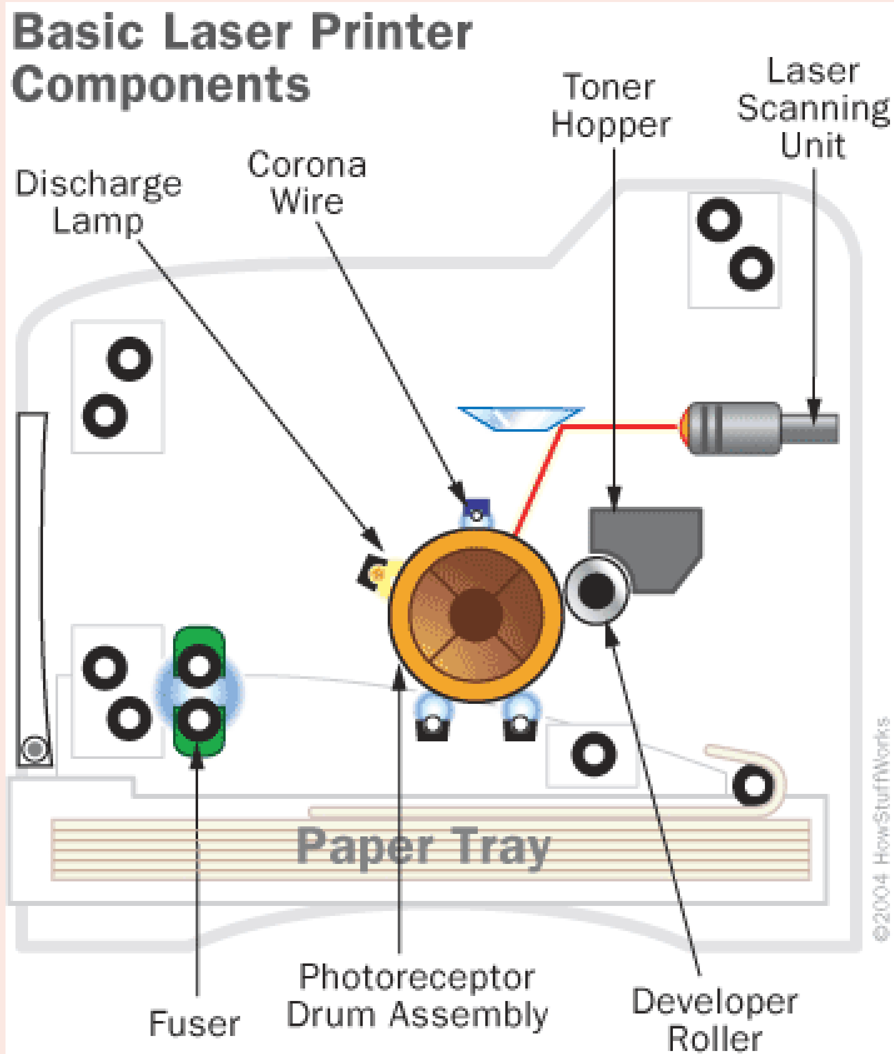
- Consequentially a different intensity can be detected at the photo diode and is transformed into an electrical signal.

OPTICAL OUTPUT DEVICES

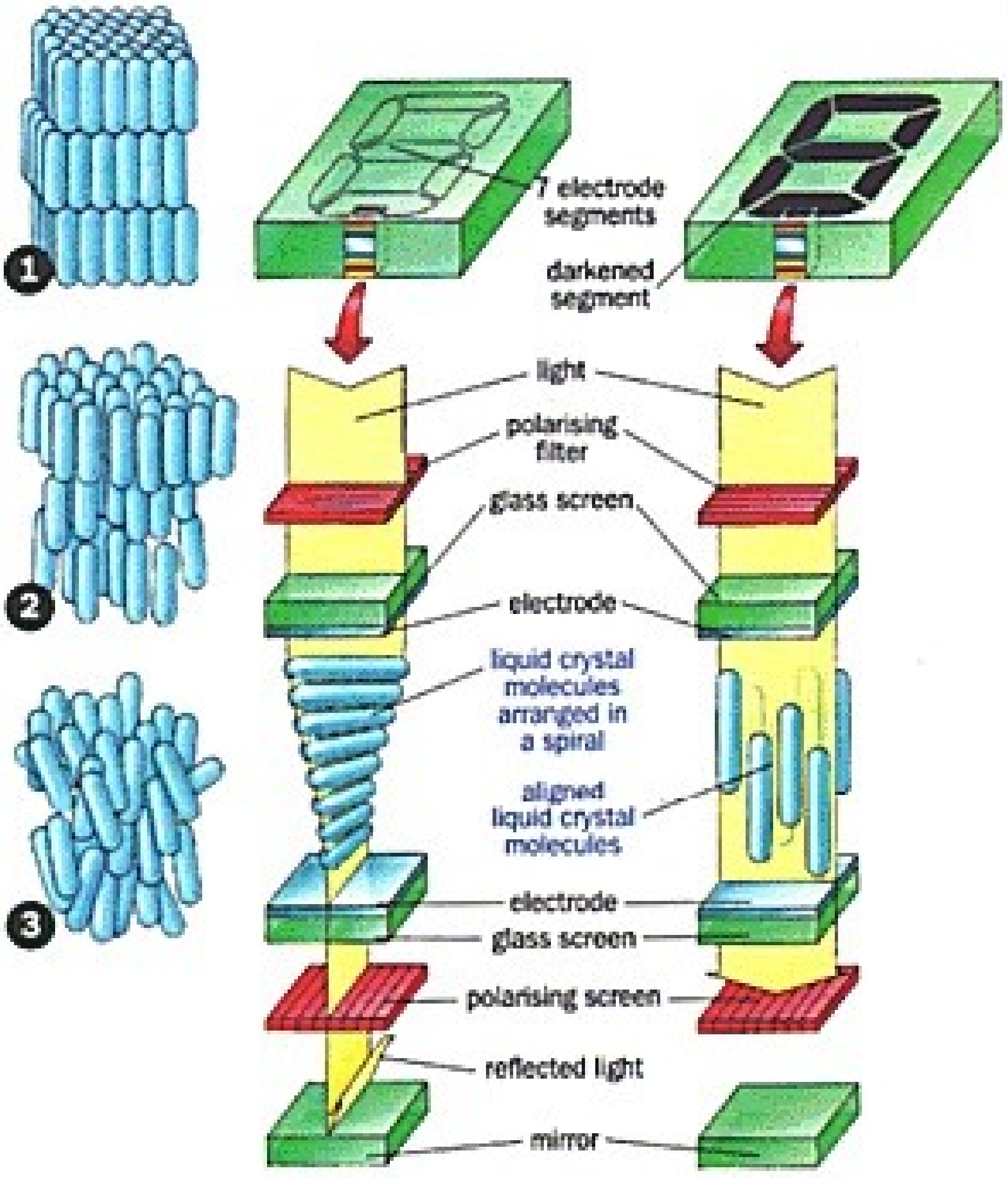
Laser Printer




Paper Exit
Photoreceptor Drum Assembly
Laser Unit
Toner Hopper
Fuser
Paper Tray
©2005 HowStuffWorks

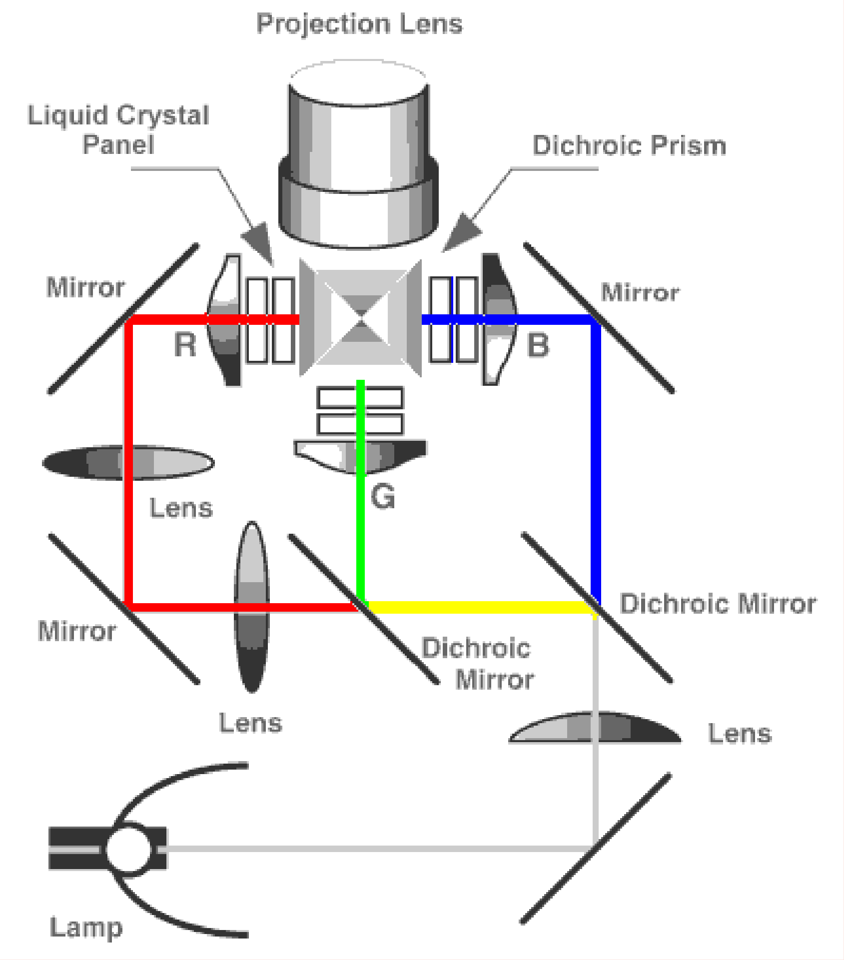

Basic Laser Printer Components
Toner Hopper
Laser Scanning Unit
Discharge Lamp
Corona Wire
Paper Tray
Fuser
Photoreceptor Drum Assembly
Developer Roller
©2004 HowStuffWorks

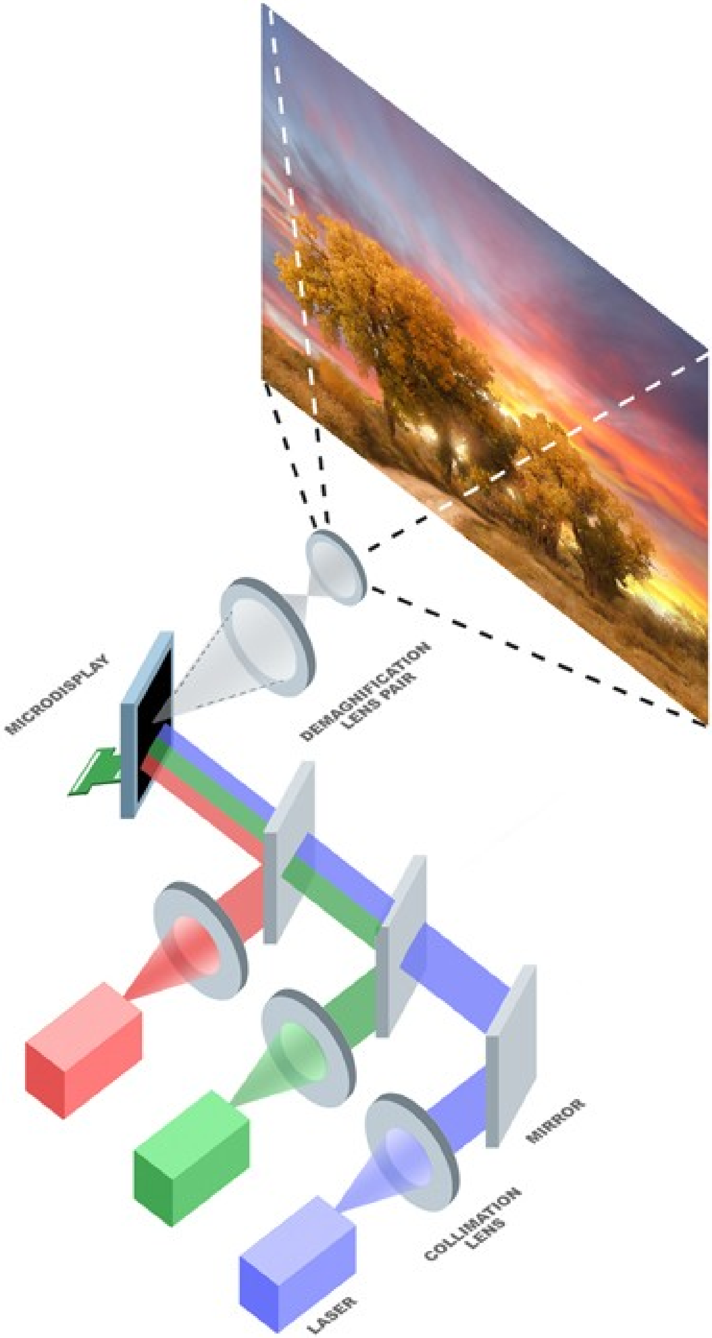
LCD display



7 electrode segments
darkened segment
light
polarising filter
glass screen
electrode
liquid crystal molecules arranged in a spiral
aligned liquid crystal molecules
electrode
glass screen
polarising screen
reflected light
mirror

Optical Projector





- The RGB output from some other device (usually a computer) forms the RGB input to the projector.
- This input controls the red, green and blue coloured LASERs in the projector.
- The LASER beams are mixed on the micro-display (formed by liquid crystal panel & dichroic prism).
- The magnification lens pair displays the magnified image on to some surface as per need.

TYPES OF OPTICAL COMPUTER

- Optical Analogue

  These include 2-D Fourier transform, optical correlators, and optical matrix-vector processors.

- Optoelectronics

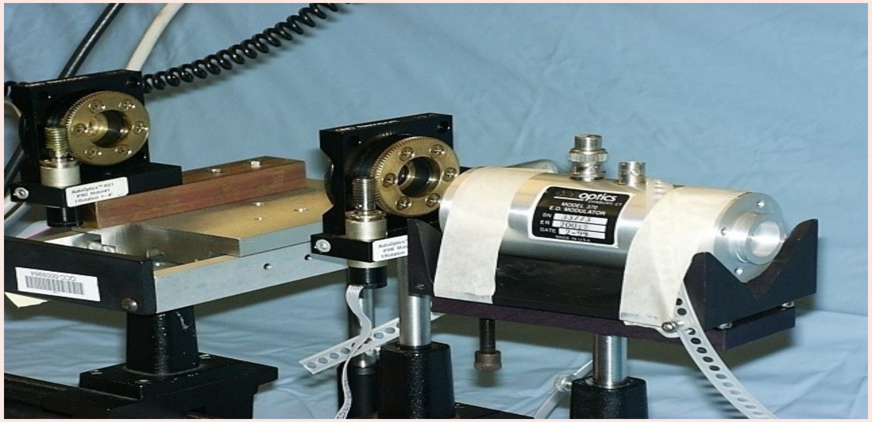
  This type of computing device would be to shorten the pulse delay in chips and other logic elements by using optical interconnections.

- Optical parallel digital computers

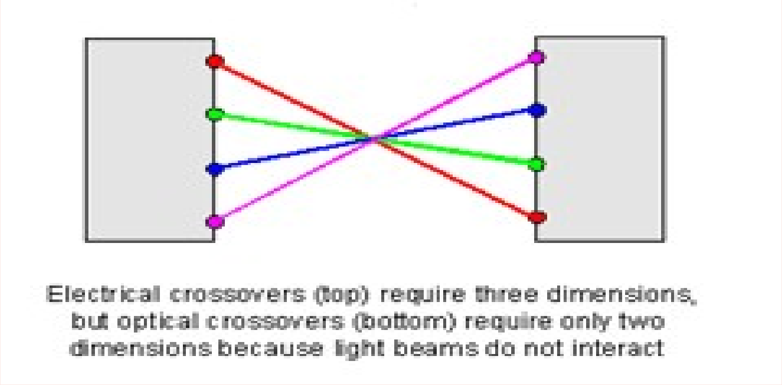
These would use the inherent parallelism of optical devices along with digital electronics for flexibility.

- Optical neural computer

Neural computers compute in the sense that they have streams of input and output bits. They do not require anything resembling ordinary programming, if programming is done at all it is by dynamically changing the degree to which the individual nodes are connected.



Few Examples of Optical Computing



USE OF OPTICS IN MEMORY STORAGE

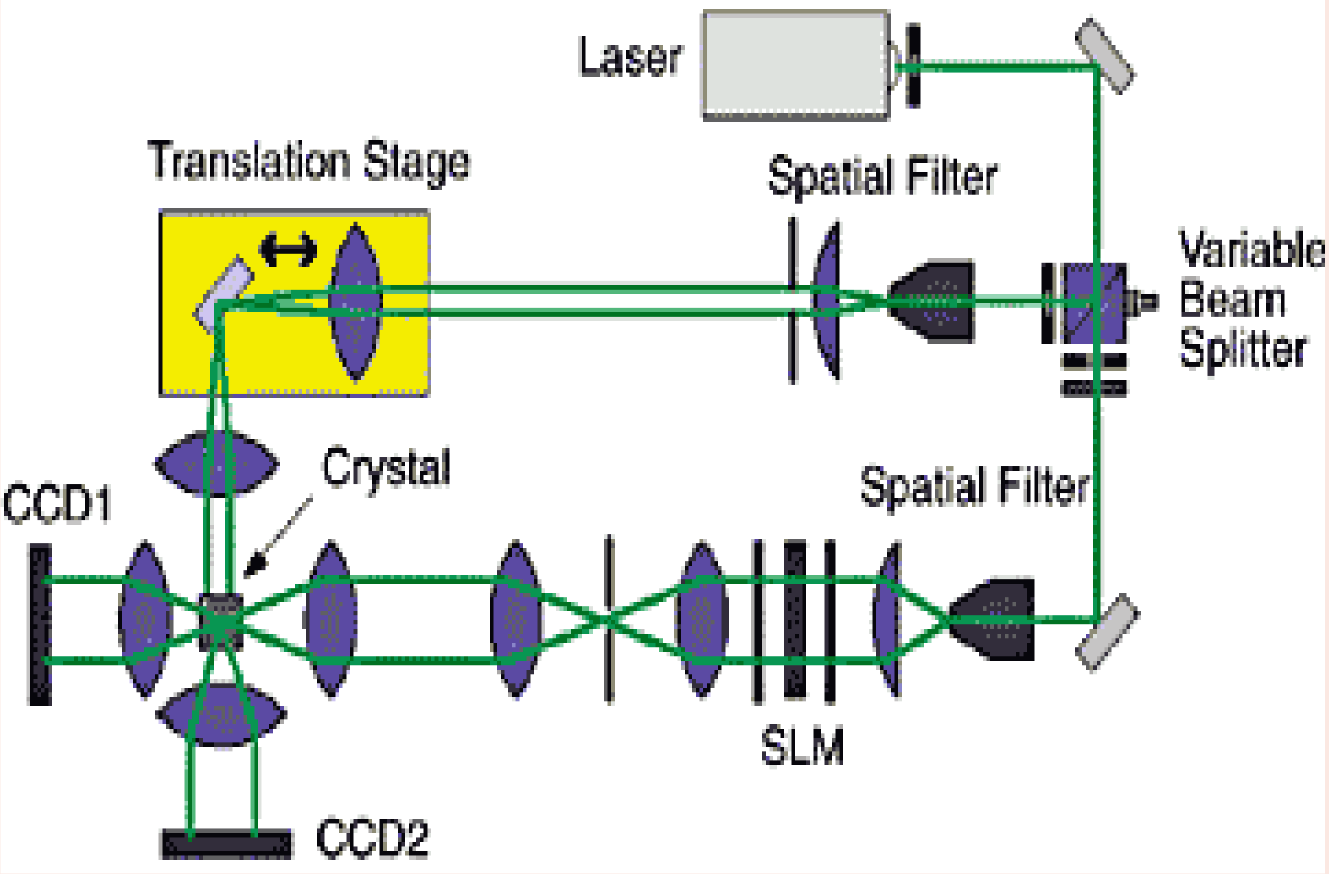
- Mass storage, which is implemented by optical disks or by holographic storage systems.

- The primary benefits offered by holographic optical data storage over current storage technologies include significantly higher storage capacities and faster read-out rates.

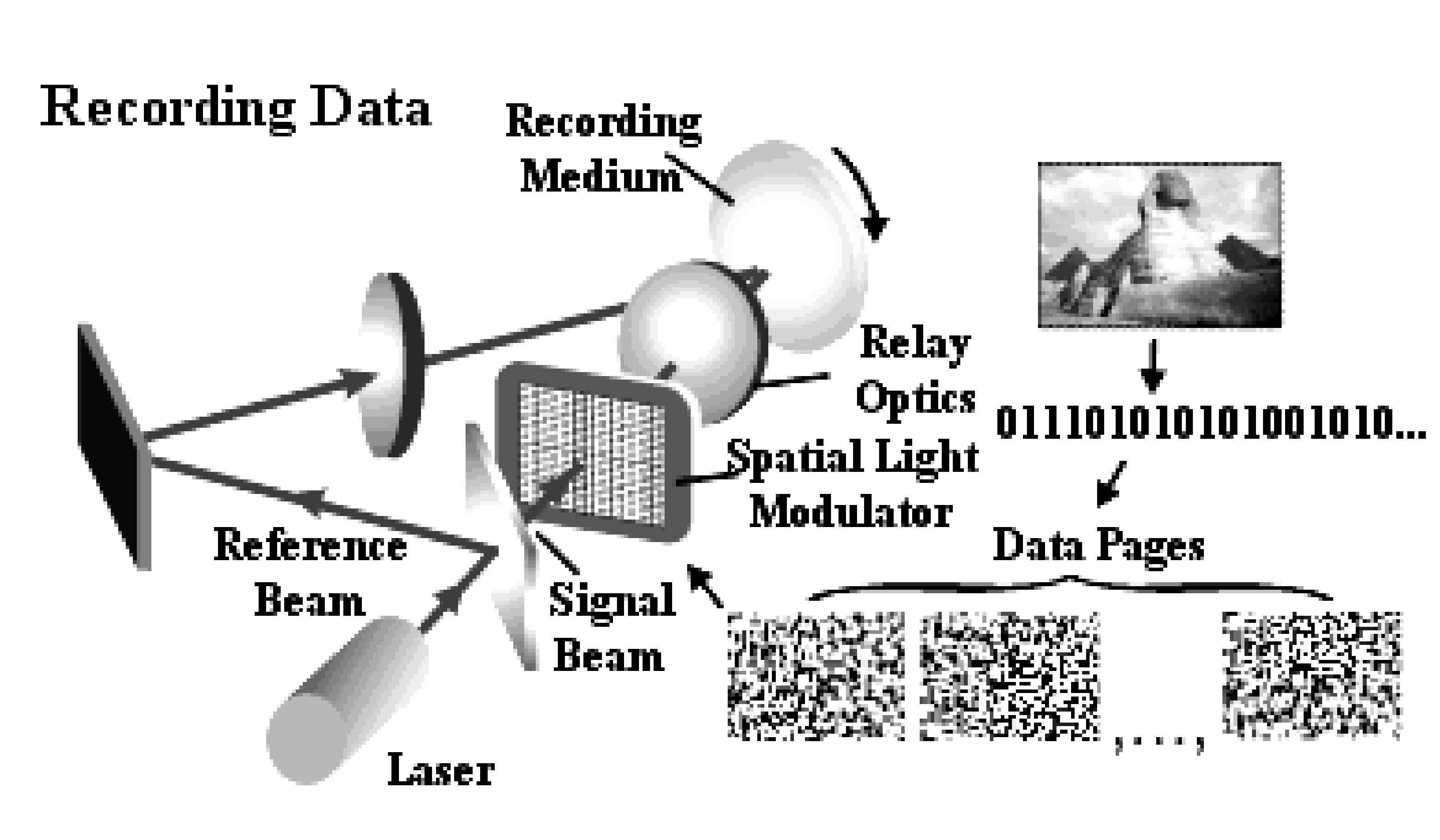
- A holographic memory can store data in the form of a hologram within a crystal.

- The analogue nature of these devices means that data can be stored at much higher density than data written by conventional devices.

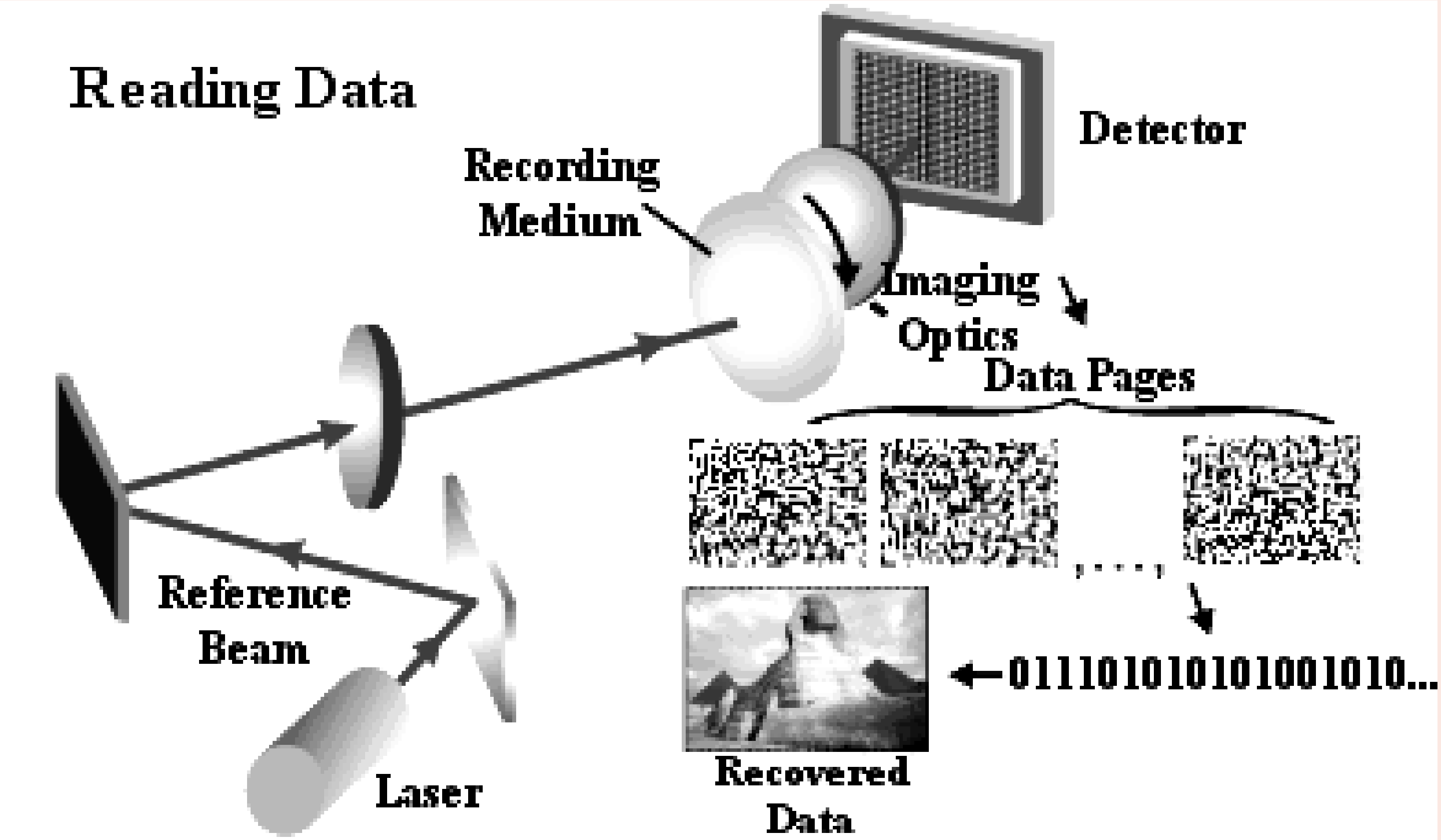
Process of Memory Storage using Optical Computing



Recording of data on to the Holographic medium



Reading of data from the Holographic medium



APPLICATIONS

- Optical Digital Signal Processing.
- Rocket Science.
- Process Satellite data.
- Optical crossbar interconnects are used in asynchronous transfer modes and shared memory multiprocessor systems.
- High speed communications.
- Multi-core processing.

CHALLENGES

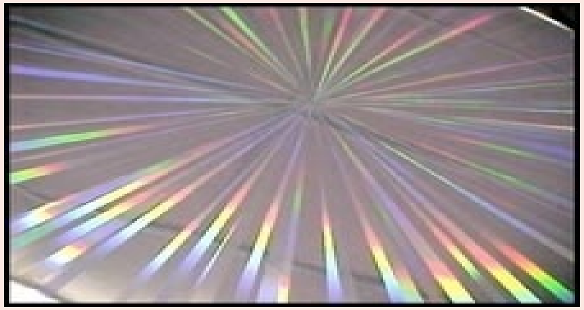
- Development technology.
- Fabrication technology.
- Cost devices and components.
- Software environment.

CURRENT WORKS AND IMPROVEMENTS

By NASA

- The thin films being developed.

- Can perform switching, signal processing and frequency doubling



THIN FILM TRANSISTOR

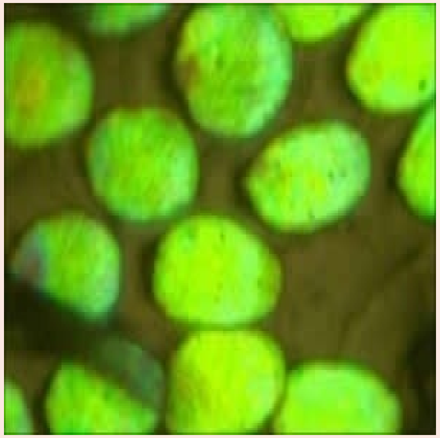
IBM milestone demonstrates optical device to advance computer performance

- IBM announced that its researchers have built a device capable of delaying the flow of light on a silicon chip, a requirement to one day allow computers to utilize optical communications to achieve better performance.

Era of High-Speed Optical Computing is Approaching by Oregon State University

- OSU Department of Physics found that existing plasmonic nanowires can be combined with a “gain material” – solid or liquid luminescent media that emit light – to squeeze the light to tiny areas, comparable in size with transistors in modern processors, and to further control the speed of the light pulses and manipulate them.

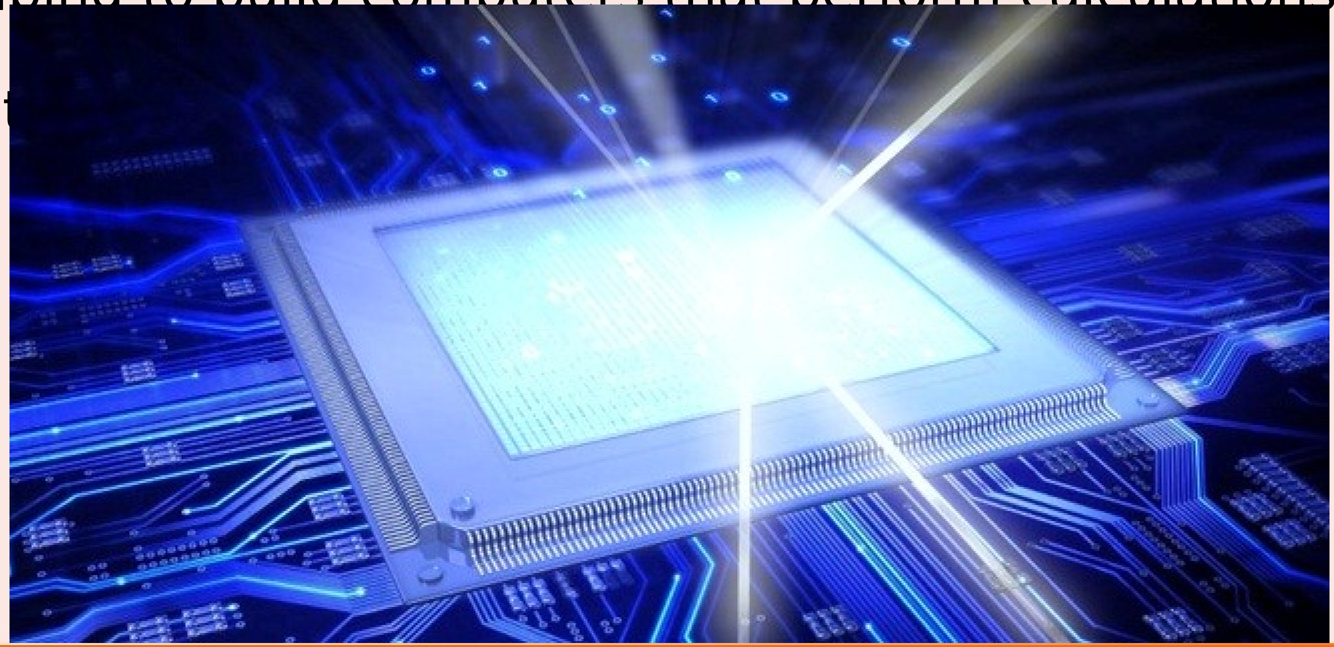
Brazilian Beetle Lights the Way for Optical Computers of the Future



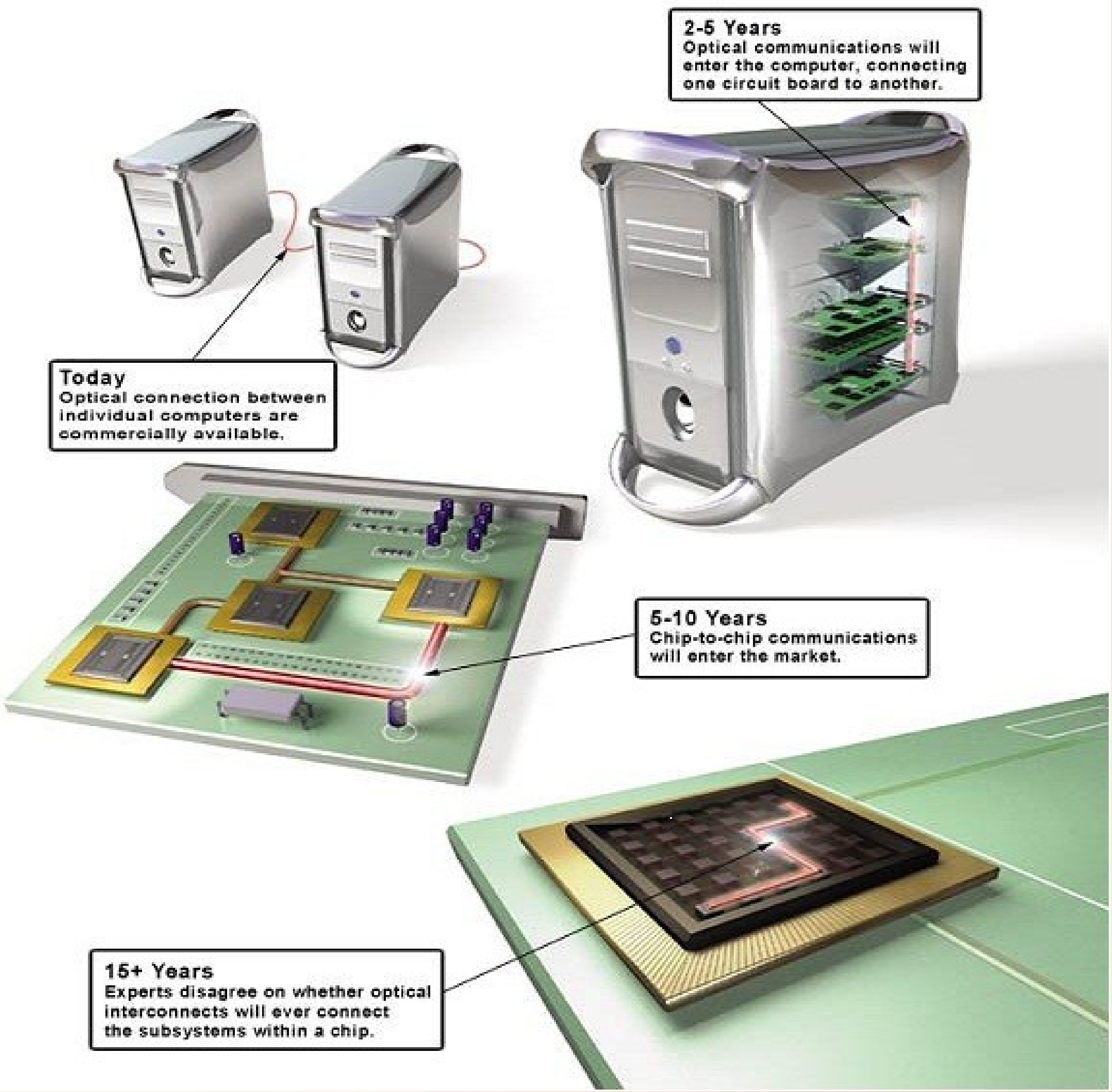
- University of Utah chemists determined the beetle glows iridescent green because it evolved a crystal structure in its scales that is like the crystal structure of diamonds. Such a structure is considered an ideal architecture for "photonic crystals".

Germanium Laser Breakthrough Brings Optical Computing Closer

- Researchers at MIT.
- A germanium laser could, in principle, be built alongside the rest of the chip in the same factory.
- 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 inst



Future Trends



CONCLUSION

- Optical technology promises massive upgrades in the efficiency and speed of computers, as well as significant shrinkage in their size and cost.

- Even though pure Optical computer has many challenges, the hybrid opto-electrical computer can be expected very soon, and in near future pure optical computer too.

ANY QUERIES??


Thank You!