Technical Seminar on
Optical Computing Technology
Introduction

- “Optical computing is the science of making computing work better using optics and related technologies”
- Some researchers use “optoelectronic computing”
Why Do We Need Optical Computers?

- Rapid growth of the Internet
- Network speeds currently limited by electronic circuits
- Terabit speeds are required
- Traditional silicon circuits have a physical limit
Silicon Machines...

...versus Optical Computers
Types of Optical Computer

- **Optical Analog**

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

- **Optoelectronics**

  *In this type of computing device would be to shorten the pulse delay in chips and other logic elements by using optical interconnections.*
Types of Optical Computer

- **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.
MATERIALS FOR OPTICAL COMPUTER

- Materials belong to the classes of phthalocyanines and polydiacetylenes are used.
- Phthalocyanines are large ring-structured porphyrins for which large and ultrafast nonlinearities have been observed. These compounds exhibit strong electronic transitions in the visible region and have high chemical and thermal stability up to 400°C.
- Subsequently, 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.
MATERIALS FOR OPTICAL COMPUTER

A comparison of a scanning electron micrographs of 1 mm thick films of copperphthalocyanine deposited by physical vapor transport in the 3M PV'TOS flight (STS-20) and ground control experiments

A comparison of a ground-grown polydiacetylene film with a microgravity-grown one.
How Does It Work?

- Photonic circuits
- Organic compounds
- No short-circuiting possible
- No heat dissipation
- Speed of light in photonic circuits will be close to speed of light in vacuum
- Light beams can travel in parallel
  They can transfer data in parallel.
Devices used for optical computing

Logic gates:

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

- Holographic truth table
  - Destructive interference will 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
figure for Nano second All optical AND –logic gate
Devices used for optical computing

**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
Devices used for optical computing

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
Devices used for optical computing

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
figure for Processing an analog signal with (a) a digital signal processor, and (b) a digital
Devices used for optical computing

Smart Pixel Technology

Different Approaches to Smart Pixels

- Monolithic integration:
  - Materials incompatibility (III-V’s and Si)
  - Si-SiGe-Ge-GaAs to lattice matching and strain relief

- Hybrid integration:
  - Flip-chip bonding
  - Difficulty of optical access
  - Remove substrate prior to (epi-lift-off) or after integration
  - Use transparent substrate (Silicon-on-Sapphire)
  - Use longer wavelengths (980 nm, 1310 nm)
VCSEL/PD/Microlens array integration approach (Honeywell)

- Start: GaAs substrate
- Epi growth, and characterization
- VCSEL/PD fabrication
- Wafer-scale testing and qualification
- Wafer bonding: superstrate attached
- Substrate removal
- Backside processing: via/ISO/metal
- Directly integrated micro-lenses
- Wafer-scale backside testing
- Dicing
- Integration with Si-ASIC
- Smart-pixel array testing

Producible: wafer-scale processing/testing
Application of Optical Computing

Optical Computing in Communication

- *Wavelength division multiplexing*
- *Optical Amplifiers & DWDM*
- *Storage area network*
- *Fiber Channel Topologies*
  
  Basic topologies
  
  *F C-AL (Fiber Channel Arbitration Loop):*
  
  Cost effective, low performance solution

  Switched:
  
  Better performance, more expensive

  Hybrid topologies
  
  Uses loops and switches as building blocks
  
  Any interconnection network scheme can be realized
SAN

- **Storage Area Network** is a marketing term for networks built using Fiber Channel Technology.
- IBM, Sun, Compaq and others are selling Fiber Channel equipment since early 1996.
Application of Optical Computing

- **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-bandwidthproduct connections that are provided by optical beams in three dimensions.
What’s Beyond the Optical Limit?

- **Quantum computing**
  - Allows particles to be in more than one state at a time
  - Each particle in a quantum computer to hold more than one bit of information.

- **A quantum computer is, thus far, only a hypothetical machine**
  - Expected between 2030 and 2050
CONCLUSION

- 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 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.
THANK YOU