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# On Chip Optical Interconnect for High Speed Communication System

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**Abstract:** Interconnect is the most dominant factor determining system performance in integrated circuit. As technology is scaled down, device size have been shrunk on chip, copper based electrical interconnects are facing many problems like dispersion, attenuation, ringing and reflections. New design challenges are continuously emerging, conventional interconnects are not able to fulfil design requirement. Electrical interconnects have high failure rate at connecting nodes such as processors, memories and input/output ports. Optical interconnect plays vital role in removing the bottlenecks of existing interconnects and offers no. of advantages such as increasing interconnect channels, integration and reconfigurability. In this line of thought this paper discusses limitations & drawbacks of electrical interconnect. The electrical and optical interconnect are compared based on different criteria. The simulation result of transient analysis shows that optical interconnect gives better result at global interconnect level.

**Keywords:** optical interconnect, copper interconnect.

## 1. INTRODUCTION

Enhancements in integrated circuits (IC) technology have fuelled Electronics industry. The complexity of integrated circuits (Moore’s Law) and performance has been achieved through continuous inventions and revolutionary advances in the chip manufacturing process ,where the circuit elements are fabricated, and these elements are appropriately connected within the circuit. Chip interconnections or interconnects, serve as global wiring, connecting circuit elements and distributing power. Interconnects are used to connect components on a VLSI chip, to connect multi chip modules on a system board.[3] Copper-based electrical interconnects are facing many challenges which are dispersion, reflections and ringing, attenuation and its variation with frequency. The high-speed signals can be distorted due to these factors. The attenuation of high frequency signals results in a need to use high-power line-drivers, which causes thermal management issues.[3] Therefore, it is necessary to consider alternate interconnect scheme for future integrated circuits. The most novel candidate is optics based interconnects. Optical interconnect due to its high bandwidth, very less signal attenuation and cross talk, is an ideal alternative to tackle the challenges imposed by electrical interconnects for both off-chip and possibly on-chip applications.

## 2. COPPER INTERCONNECT

The manufacturers have been already identified the advantages of using the copper interconnects, but considering copper only became a priority in the 1980s as the feature size decreased[1]. The most important benefit of using copper in the integrated circuits is that copper has low resistivity than aluminum which has been the dominant interconnects material [1]. The use of a low resistivity material like copper decreases the interconnect delay, which, in turn, increases the IC speed. The intrinsic speed limit of any integrated circuit is determined by the frequency at which its transistors can be turned on and off. As smaller transistors have basically higher clock frequencies, advances in IC speed have been achieved by scaling down of the feature sizes. The speed limit of advanced ICs is decided by the delay in signal propagation in the metal interconnect lines, which is determined by the time constant of the line[1]. The time constant is the product of the resistance of the line and the capacitance between the line and all adjacent lines. RC time constant of interconnect can be reduced by reducing the resistivity of the interconnect material, using a dielectric with a low permittivity or making the line lengths as small as possible. Copper, which has a resistivity $\rho$ of only 1.7$\mu\Omega$.cm, provides almost 40% reductions in resistivity over aluminum, which has a $\rho$ of 2.7$\mu\Omega$.cm; typical aluminum alloys can have $\rho$ as high as 3$\mu\Omega$.cm [1]. Since the RC time constant is directly proportional to the resistivity, a 40% reduction in the RC time constant can be gained by using copper rather than aluminum. By combining the copper interconnect with a dielectric material with a low permittivity, the interconnect RC delay can decrease up to 50% of that for Al/SiO2. The another advantages of using copper include that copper has twice the thermal conductivity of aluminum and copper has ten to 100 times more resistance to electromigration failures as compared aluminum[1]. The most important limitations of copper interconnects are considered to be delays (latency), data-rates and power dissipation.

The limitations of conventional electrical interconnects has been discussed during the last decade [3]. The negative aspects of these limitations are dominating. The negative aspects are wire resistance, causing delay and dispersion,

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and high capacitance, causing large power dissipation at large voltage swings. The limitations of electrical interconnects have lead to a search for alternative techniques, such as Optical interconnects.

### 3. OPTICAL INTERCONNECT

A promising approach to the interconnect problems is the use of an optical interconnect layer. Optical interconnection refers to the data transmission in which the data signal is transmitted as a modulation of optical carrier wave (light) through an optically transparent media such as optical fibre, planar optical waveguide or air. Optical interconnect are free from any capacitive loading effects. They do not suffer from crosstalk. The speed of propagation of a signal is determined by the speed of light and the refractive index of the optical transmission medium only. They do not suffer from electromigration-induced failure. optical interconnections operate at much higher speeds allowing the multiplexing of a large number of I/O signals. They can carry a large amount of information. Optical interconnects provide the opportunity of No pick–up of electrical noise while transmission.

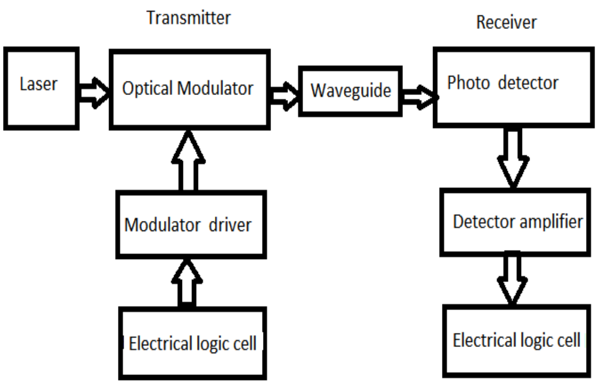


Fig. 1 Optical Link Implementation

The most simple optical interconnect is a point to point optical link connecting two electrical systems. It consists of a unit converting an electrical signal into an optical signal,medium to carry optical signal and a unit converting it back into electrical signal. In optical link medium is an optical waveguide which confines light along an optical transmission line. The most promising way of converting an electrical signal into light is directly modulating a light source. For high speed optical interconnect, this would be a laser. In case of many links on a chip, would require a dedicated laser per link. Integrating many small laser sources on a chip generate a significant amount of heat. So promising alternative is continuous wave light source(CW) and subsequently modulating a signal onto it.
An on-chip optical link as in fig.1 contains the following components:- (a) A off chip Laser source which is coupled to the modulators; (b) Optical modulator which is used to change a property of light often of an optical beam such as a laser beam. Silicon optical modulators have been generally used. (c) an optical waveguide is used to confine light along a path on chip. Most probably a silicon strip waveguide or a rib waveguide is used for a 2-D confinement; (d) photo-detector which generates current proportional to the incoming light intensity and (e) a detector amplifier followed by gain stages.

Transmitter
The transmitter in an optical interconnects system contains optical modulator and modulator driver. The modulator performs conversion between electrical and optical signal into two steps. In first stage optical properties of the medium are changed by electrical signal ( i.e. absorption coefficient or refractive index). The second stage consists of amplitude or phase modulation of optical signal by varying optical properties. The driver circuit is used to drive the modulator. It is set of cascaded Inverter known as CMOS super-buffer.

Light sources
The number of optoelectronic sources are available for optical interconnect application. The choice of source is fundamentally based on component type (i.e LED, VCSEL, MQW modulator), emission wavelength and mounting. In case of high speed optical interconnect, it would be a laser. For many links on a chip, this would require a dedicated laser per link. But integrating many small lasers on a chip generate a significant amount of heat. Hence alternative is to use continuous wave light source and modulate signal onto it.

Waveguide
Photonic integrated circuits can combine many functions on a single chip. Th key to this is to transport light efficiently between functional elements of the chip. The most effective way for this is to use optical waveguide which confine light to propagate along a line shaped path on chip. A well known example of waveguide is an optical fibre which consists of a core with high refractive index surrounded by a lower refractive index. There are different ways to construct a high index waveguide core. The most straightforward materials are glasses, polymers and different types of semiconductor. For compact optical waveguide, there is high index contrast between core and cladding. This makes semiconductors extremely attractive. SOI structure is used for compact and short waveguide applications. Polymers are used for longer links.

Receiver

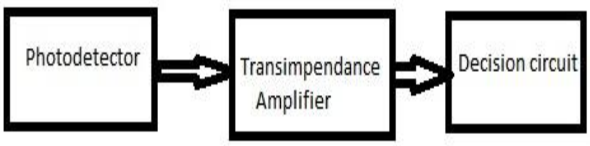


Fig. 2 Receiver

At the end of the optical link the optical signals need to be converted to the electrical signal. This task is to be done by receiver. It consists of photo-detector followed by


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trans-impedance amplifier. Integrated photo-detector converts the incident optical power into a photo-current. The trans- impedance amplifier performs optical-electrical conversion on the photonic interconnection layer. The selection of photo-detectors depends upon performance metrics such as on speed, responsivity and its dark current. The most commonly used photo-detector is Si-Ge or III-V semiconductors. In this paper Si-Ge, p-i-n type and metal semiconductors are considered due to fast response and good quantum efficiency.

## 4. RESULT AND DISCUSSION

The optical interconnect based on directly modulated laser is simulated as shown in fig.3.

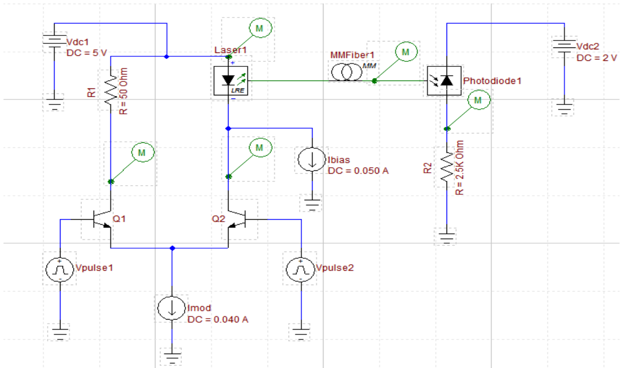


Fig. 3 Optical link setup

The driver circuit provides 50mA bias current and modulation current of 40mA. The transistor Q1 & Q2 is biased with Vpulse 1 and Vpulse2 of 2.5V. The dc current source Idc2 draws laser bias current of 50mA. The transient analysis for the circuit is performed for 10ns. The laser diode current is switching between 50-90mA as shown in fig. 4.

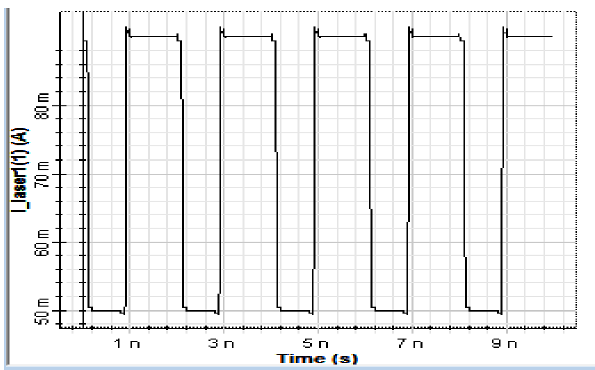


Fig. 4 laser current Vs time

The fig. 5 shows laser power versus time output waveform. The emission frequency of laser is 193.1 THz. The laser output is connected to multi-mode optical fiber of length 1cm.The fiber output is connected to photo diode. The fiber output is connected to photo diode and output voltage is obtained at the load resistor R2, through which the photo diode current flows..

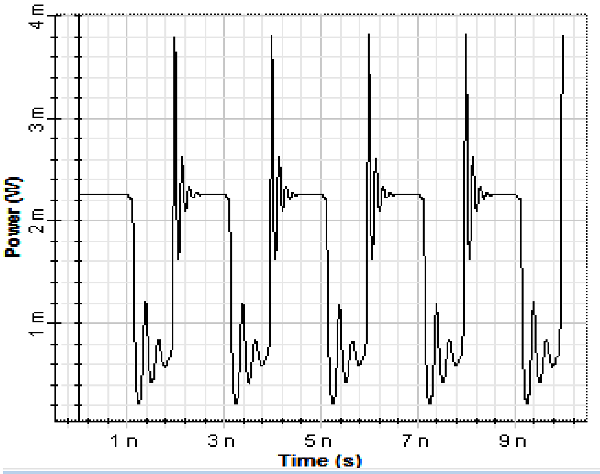


Fig. 5 laser power Vs time

The fig.6. Shows Input and output waveform optical interconnect simulation for 1cm data length.

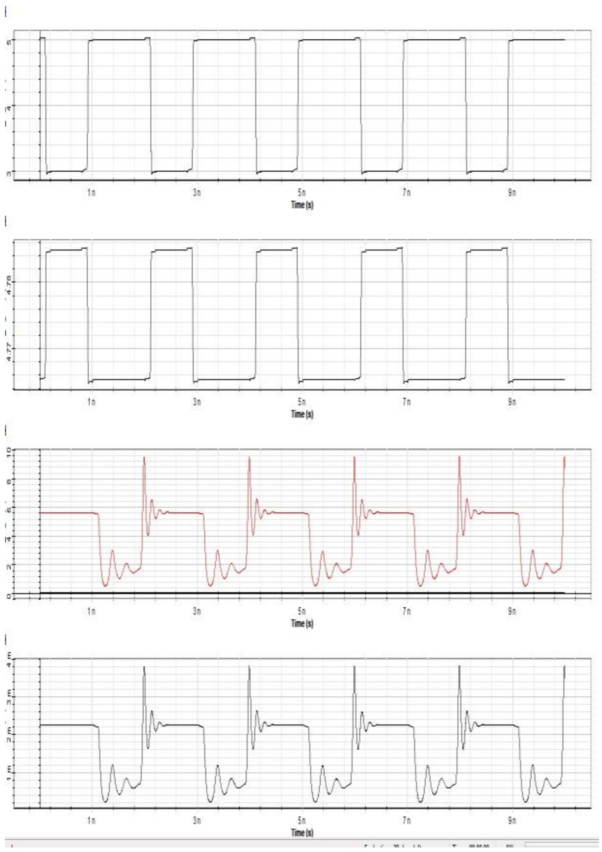

Fig. 6 Transient characteristic

## 5. CONCLUSION

In this paper performance characteristics of optical interconnect and copper interconnect are discussed considering different evaluation criteria. It has identified the primary challenges for optical interconnect to compete with copper interconnect. Optical interconnect seems promising solution for high speed communication system offering high bandwidth and low energy consumption. The

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simulation result shows that optical interconnect are better than conventional interconnect at global interconnect level. As technology is scaling down overall delay is reducing in case of optical interconnect.

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