ISSN (Print) : 2319-5940
ISSN (Online) : 2278-1021

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 2, Issue 5, May 2013

Performance Comparison between Optical and Copper Interconnects

Mahesh Kumar[1], Karamjit Singh Sandha[2]

Student, M.E. ECE, Thapar University, Patiala, India[1]

Asst. Professor Dept. of E.C.E., Thapar University, Patiala, India[2]

Abstract: This paper gives performance comparison between optical and copper interconnects in terms of delay for global interconnect level. As the technology is scaled down, device dimensions have been shrunk on the chip, the conventional copper interconnects are not able to fulfil different design requirements. The optical interconnects can be considered as a substitute for copper interconnects. In this paper delay of optical and copper interconnects is simulated using SPICE simulation for different technology nodes at global interconnect length. The results of this paper show that optical interconnects give better results as compared to conventional copper interconnect for global interconnect length.

Keywords: Optical interconnects, copper interconnects, delay, technology nodes and CMOS.

I INTRODUCTION

As the technology is scaled, various design advancements are considered in interconnect designing process based on the criteria of delay uncertainty, power consumption, bandwidth and noise. Conventional copper interconnects are not able to fulfil these requirements. Copper based interconnects are facing many challenges. Optical interconnects can be considered as a proper alternative to meet these requirements. Optical interconnects provide better results in terms of delay as compared to conventional copper interconnects.

Optical interconnects have been considered as an alternative solutions to chip-chip and chip-board interconnects where bandwidth and delay are the major parameters [1],[2]. Their applicability has also been considered for intra-chip communication [3],[4]. Because of an order of size mismatch between the wavelength of light and nanoelectronic components, the optical interconnects are preferred in the case of the global interconnect level. In this paper delay of copper interconnects and optical interconnects is simulated and compared at different technology nodes.

This paper is divided into five sections. Section 2 describes copper interconnects. Section 3 describes optical interconnects. Section 4 includes result and discussion. Conclusions are made in section 5.

II COPPER INTERCONNECTS

In copper interconnects, repeater or buffer is basically implemented as CMOS inverter [5] as shown in fig. 1. In this paper, for the design of CMOS inverter PMOS is assumed as thrice as NMOS. A CMOS inverter is used to derive interconnect load as shown in fig. 1.

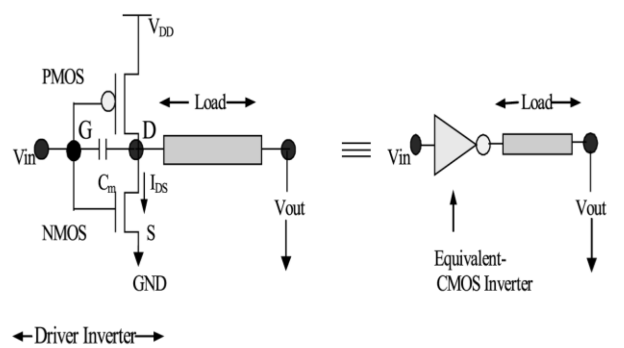

Fig. 1 CMOS buffer driving an interconnect load

Interconnect load can be represented as RLC lumped model as shown in fig. 2.

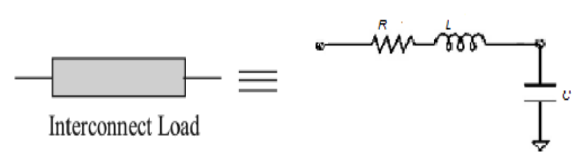

Fig. 2 RLC lumped model representations of an interconnect line

R, L and C parameters per unit length are determined from the physical geometries of interconnects. The space between adjacent interconnects is same as interconnect width. The RLC interconnect delay is simulated using SPICE simulation tool.

Repeaters are inserted in the copper interconnect circuit to reduce interconnect delay, transition times, and crosstalk

ISSN (Print) : 2319-5940
ISSN (Online) : 2278-1021

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 2, Issue 5, May 2013

noise as shown in the fig. 3. A lot of work has been done that describes copper interconnect design methodologies. The RLC interconnects with repeaters are examined at various technology nodes.[6],[7].

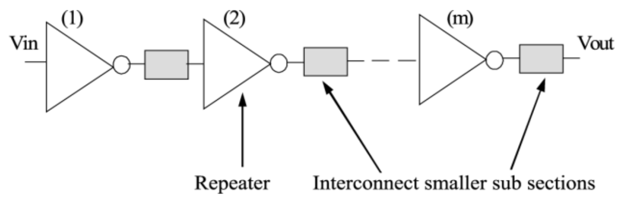

Fig. 3 Copper interconnect with repeaters

In this paper, copper is used as an interconnect material instead of aluminium. The most important benefit of using copper in integrated circuits is that copper offers low resistivity than aluminium which has historically has been the dominant interconnect material. Using a low resistivity material like copper decreases the interconnect delay, which, in turn, increases the IC speed.

III OPTICAL INTERCONNECTS

To solve the interconnects problem at the global interconnect level, optics emerges as a promising technology [8],[9]. Optical interconnects can have many advantages over conventional copper interconnects, thus making it easier to achieve and maintain good signal integrity. The latency of an optical signal depends on the speed of light in the medium, variations in transmission delay are very less, and so the timing of these optical signals can be modelled easily and predicted accurately. This is very useful in clock distribution network. Optical interconnects have larger bandwidth as compared to bandwidth of copper interconnects. There is no requirement of repeaters in optical interconnects as they have low attenuation.

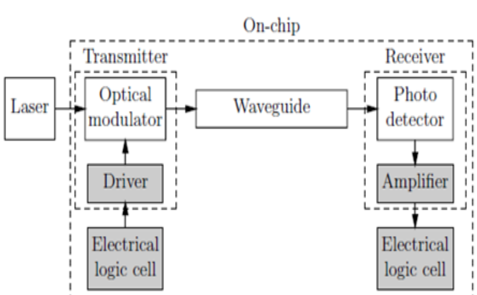

Fig.4 On-chip optical interconnect data path.

A diagram of optical interconnect system is shown in fig. 4. It contains off chip laser, an optical modulator, a polymer waveguide and a photo detector. Here external laser is used as a light source which introduces propagation and coupling losses. Conflict in the requirements of the optical material arises as the modulator and detector operate at the same wavelength. The modulator requires negligible optical loss, whereas the principle of detector operation depends on the absorption of light. Use of 1.5μm wavelength light source with a silicon modulator and a SiGe or Ge photo-detector is a good solution as it is compatible with CMOS technology also. Due to light wavelength constraint optical devices are not easily scalable [10]. A specific design is chosen to fulfil on chip requirements. Based on that design optical transmitter, waveguide and receiver are described in the following subsections.

A. Transmitter

A transmitter in an optical interconnects system contains two parts: an electro-optical modulator and a driver circuit as shown in fig. 5 [11]. In a modulator, first optical properties of the medium, e.g., the refractive index or absorption co-efficient are changed by the copper signals and then the optical signals are modulated either in amplitude or in phase, by varying the optical properties.

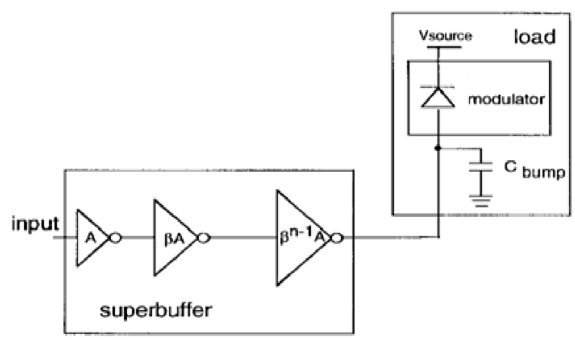

Fig.5 CMOS superbuffer driving the modulator.

Driver circuit is a CMOS superbuffer which is used to drive the modulator. The superbuffer is a set of cascaded inverters. In the superbuffer size of each inverter is larger than the previous one by a constant factor β. The value of β is taken between three and four to reduce the delay of the superbuffer. Its value is determined from the parameters of a minimum size transistor for a given CMOS technology [12].

B. Waveguide

Wavelength of the light signal and optical material limit the performance of waveguide. Although a novel waveguide like photonic crystal waveguide reduces the waveguide pitch but introduces optical losses.

There are two types of waveguide material for the operating wavelength of the signal. A silicon-on-insulator (SOI) structure is used for applications requiring dense and short waveguide arrays because of its smaller waveguide pitch. Low loss polymers are used for longer links as they provide smaller losses and optimized propagation delay [13]

ISSN (Print) : 2319-5940
ISSN (Online) : 2278-1021

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 2, Issue 5, May 2013

[14]. Area required by polymer waveguide for fabrication is more than the area required by SOI waveguides but polymer waveguides are fabricated on an additional layer, so they do not reduce the on-chip silicon resources. Here polymer waveguides with low refractive index are assumed. They have effective index of 1.4 [14].

C. Receiver

Here transimpedance type receivers are used because of their high bandwidth, low noise and ease of biasing [15],[16],[17]. A receiver contains a photo detector, a transimpedance amplifier and voltage amplifier as shown in fig. 6 [18]

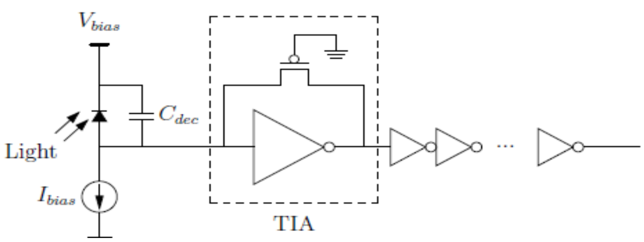

Fig. 6 Block diagram of a receiver circuit

Photo detector converts the light signal received from the transmitter through waveguide into current form. Here interdigitated SiGe p-i-n or metal semiconductor metal (MSM) detectors are considered as they have fast response and good quantum efficiency. Next stage in the receiver circuit is transimpedance amplifier. Transimpedance amplifiers are used to convert the signal from current to voltage. After transimpedance amplifier signal is further amplified by the cascaded voltage amplifier. Finally signal is provided to the decision circuit.

IV RESULTS and DISCUSSION

Delay of optical and copper interconnects is simulated using SPICE simulation. Delay of the waveguide is taken as the propagation delay of the signal through it which is same for all technology nodes. The delay of each individual part of the transmitter and receiver of optical interconnects is calculated. The results of delay of the transmitter for optical interconnects are shown in table1.

Table 1: Delay (ps) distribution of Transmitter in Optical interconnect system.

Technology node	90 nm	65 nm	32 nm	22 nm	14 nm
Modulator driver	68.3	54.9	42.5	36.1	23.6
Modulator	54.4	43.3	36.5	27.5	20.2
Total for Transmitter	122.7	98.2	79.0	63.6	43.8

Fig. 7 shows the performance of the transmitter of the optical interconnects at different technology nodes.

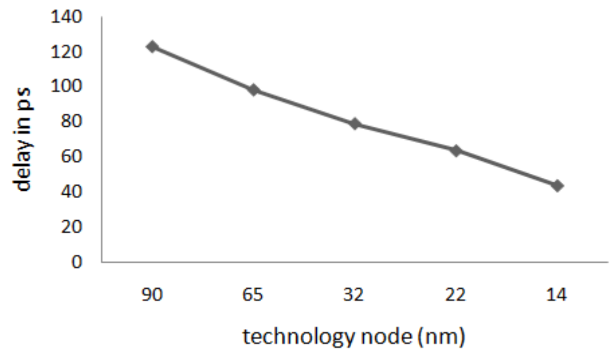

Fig. 7 Transmitter delay with respect to technology node.

The results of delay of the receiver of the optical interconnect for various technology nodes are shown in table2.

Table 2: Delay (ps) distribution of Receiver in Optical interconnect system.

Technology node	90 nm	65 nm	32 nm	22 nm	14 nm
Detector	8.2	6.9	4.2	3.1	1.9
Receiver amplifier	65.6	55.3	42.8	32.7	21.4
Total for Receiver	73.8	62.2	46.0	35.8	23.3

Delay of receiver of the optical interconnects also changes as technology is scaled. Fig. 8 shows the performance of the receiver of the optical interconnects at different technology nodes.

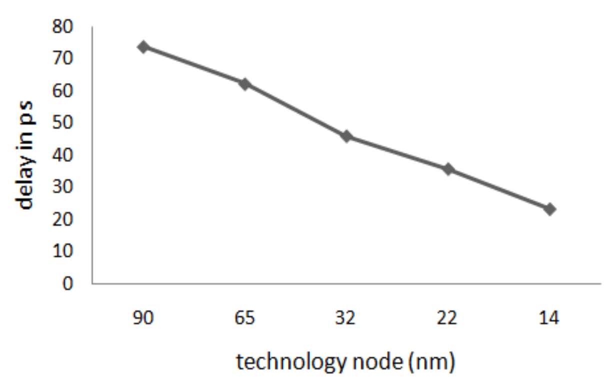

Fig. 8 Receiver delay with respect to technology node.

Performance of optical interconnects and copper
Performance of optical interconnects and copper
interconnects with respect to delay for different technology nodes is shown in table3.

ISSN (Print) : 2319-5940
ISSN (Online) : 2278-1021

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 2, Issue 5, May 2013

Table 3: Delay (ps) distribution in a 1 cm optical data path as compared with the copper interconnects delay.

Technology node	90 nm	65 nm	32 nm	22 nm	14 nm
Transmitter	122.7	98.2	79.0	63.6	43.8
Receiver	73.8	62.2	46.0	35.8	23.3
Waveguide	48.3	48.3	48.3	48.3	48.3
Total optical	244.8	208.7	173.3	147.7	115.4
Copper	980	1150	1430	1840	2050

Fig. 9 shows the performance comparison of optical interconnects and copper interconnects at different technology nodes.

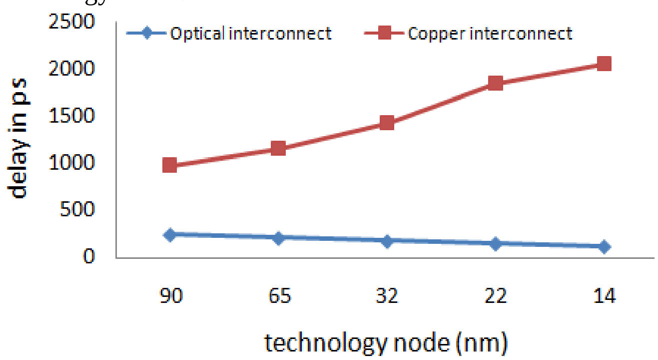

Fig. 9. Comparison between Optical interconnects and Copper interconnects.

V CONCLUSION

In this paper, we presented the simulation results for copper interconnects and global interconnects for one cm length at different technology nodes. Comparison of optical and copper interconnects is done in terms of delay at different technology nodes. It can be concluded from the results shown here that optical interconnects are better than the conventional copper interconnects at global interconnect level. As the technology level is decreasing, the overall delay of the system is also decreasing in optical interconnects. Optical interconnects give optimized result at 14nm technology as compared to others considered here.

REFERENCES

[1] D. B. Miller, "Rationale and challenges for optical interconnects," *Proceedings of the IEEE*, vol. 88, no. 6, June 2000.
[2] D. Miller, "Device requirements for optical interconnects to silicon chips," *Proceedings of the IEEE*, vol. 97, no. 7, pp. 1166 –1185, July 2009.
[3] J.H.Collet et.al, "Performance constraints for on chip optical interconnects," *IEEE Journal of Selected Topics in Quantum Electronics*, vol. 9, pp. 425–432, 2003.
[4] K. Ohashi et.al., *Proceedings of the IEEE*, vol. 97, no. 7, pp. 1186–1198, july 2009.
[5] Rajeevan Chandel et al., *Repeater insertion in global interconnects in VLSI circuits*, Emerald Group Publishing Limited, Microelectronics International 2005.
[6] *The International Technology Roadmap for Semiconductors*, Semiconductor Industry Association, California, 2003.
[7] Helmut Graeb "ITRS 2011 Analog EDA challenges and approaches"*Design, Automation and Test in Europe Conference*, March 2011.
[8] K.-H. Koo, H. Cho, P. Kapur, and K. Saraswat, "Performance comparisons between carbon nanotubes, optical, and cu for future highperformance on-chip interconnect applications," *Electron Devices, IEEE Transactions on*, vol. 54, no. 12, pp. 3206 –3215, dec. 2007.
[9] K.-H. Koo, P. Kapur, and K. Saraswat, "Compact performance models and comparisons for gigascale on-chip global interconnect technologies," *Electron Devices, IEEE Transactions on*, vol. 56, no. 9, pp. 1787 –1798, sept. 2009.
[10] G. P. Agrawal, *Fiber-Optic Communication Systems*, Wiley, New York, 1997.
[11] Osman Kibar, Daniel A. Van Blerkom, Chi Fan, and Sadik C. Esener, "Power Minimization and Technology Comparisons for Digital Free-Space Optoelectronic Interconnects," *Journal of Lightwave Technology*, vol. 17, no.4, pp. 546-554, Apr. 1999.
[12] N. C. Li, G. L. Haviland, and A. A. Tuszynski, "CMOS tapered buffer," *IEEE J. Solid-State Circuits*, vol. 25, pp. 1005–1008, Aug. 1990.
[13] Y. A. Vlasov and S. J. McNab, "Losses in Single Mode Silicon-On-Insulator Strip Waveguides andBends," *Optical Express*, Vol. 12, No. 8, pp. 1622-1631, April 2004.
[14] L. Eldada and L. W. Shacklette, "Advances in Polymer Integrated Optics," *IEEE Journal of Se-lected Topics in Quantum Electronics*, Vol. 6, No.1, pp. 54{68, January/February 2000.
[15] A. A. Abidi, "Gigahertz transresistance amplifiers in fine line NMOS," *IEEE J. Solid-State Circuits*, vol. 19, pp. 986–994, Dec. 1984.
[16] M. Ingels, G. Van der Plas, J. Crols, and M. Steyaert, "A CMOS 18THz 240 Mb/s transimpedance amplifier and 155 Mb/s LED driver for low cost optical fiber links," *IEEE J. Solid-State Circuits*, vol. 29, pp. 1552–1559, Dec. 1994.
[17] G. F. Williams, "Lightwave receivers," in *Topics in Lightwave Transmission Systems*, T. Li, Ed. San Diego, CA: Academic, 1991.
[18] G. Chen *et al.*, "Predictions of CMOS Compatible On-Chip Optical Interconnect," *Proceedings of the ACM International Workshop on System Level Interconnect Prediction*, pp. 13–20, April 2005.