1998

Technical

Digest Series

Volume 4

Integrated Photonics Research

Technical Digest

March 30–April 1, 1998

Victoria Conference Centre
Victoria, British Columbia, Canada

Conference Edition

Sponsored by
Optical Society of America
In cooperation with
European Conference on Integrated Optics (ECIO)
Technical Cosponsor
IEEE/Lasers and Electro-Optics Society

OSA
Optical Society of America

Fabrication and characterization of a 1-to-48 fanout H-tree structure for clock signal distribution system

Linghui Wu, Bipin Bihari, Jianhua Gan, and Ray T. Chen
Microelectronics Research Center, Department of Electrical and Computer Engineering
The University of Texas at Austin, Austin, TX 78758
Phone: (512) 471-7035 FAX: (512) 471-8575

Suning Tang
Radiant Research, Inc., 9450 Research Blvd., Suite IV305, Austin, TX 78759
Phone: (512) 338-4670 FAX: (512) 338-4645

Randy Wickman
Cray Research, Inc., 655 Lone Oak Dr., Eagan, MN 55121

Summary

The clock rate is one of the important parameters determining system performance in the high-speed computing environments. The state-of-the-art VLSI circuits are capable of operating and generating ultra-high clock rates (> 1 GHz). However, clock signal distribution systems based on electrical interconnect technologies fail to keep up with the cycle times and pulse widths needed to synchronize the operation of logic devices over long distances. This timing bottleneck is a consequence of the variations in the transmission line propagation losses and dispersion, different packaging environments, and impedance discontinuities at the interfaces of the chips and boards. Further, capacitive loading, switching noise and signal cross-talk alter the clock signal waveform and become critical at high clock rates and large system lengths. These bottlenecks manifest themselves as clock skew and timing jitter in synchronous clock signal distribution systems. An array of novel optical interconnect architecture has been proposed to circumvent these bottlenecks [1-3]. For example, the latest T-90 microprocessor machines from Cray Research incorporate up to 36 processor-boards with a system clock speed of 500 MHz. All the boards in this system are synchronized to a central clock using an optical clock signal distribution system utilizing a high power semiconductor laser operating in conjunction with single-mode optical fiber array at 1.3 μm. Within the each board the clock signal distribution is still all electrical which puts a limitation on the further improvements in the overall system speed. The guided wave optical clock distribution system can effectively resolve this bottleneck at board-level applications.

A novel board-level optical clock signal distribution system based on polymeric channel waveguides in conjunction with waveguide output couplers and fast photodetectors will be discussed in this presentation. The guided wave optoelectronic interconnect network under development will be inserted into the Cray supercomputer boards to become an additional interconnection layer along with the electrical interconnection layers. The Cray T-90 supercomputer board consists of 52 vertical electrical interconnection layers with the board size of 14.48 x 26.67 cm^2 [4], and in order to implement an additional optoelectronic interconnection layer (OIL) for high-speed clock signal distribution, the Si-CMOS process compatibility and planarization of the OIL are the two major concerns required to be addressed. These two issues could be effectively handled by application of polyimide based waveguide structures. Our approach utilizes low-loss polyimides for optical channel waveguides which are Si-CMOS process compatible and all associated components including waveguides, waveguide grating couplers and waveguide splitters can be easily planarized.

In the OIL all the optical paths have to be of equal lengths to minimize the clock skew problems. A waveguide H-tree structure can provide the equal path lengths for 1-to-many fanouts. The optical components required for constructing such a H-tree system include low loss polymer-based channel waveguides, waveguide output coupler, and 3 dB 1-to-2 waveguide splitters. We have constructed a 1-to-48 fanout H-tree waveguide structure using polyimide planarization and photolithographic technique. Fig. 1 shows a photograph of the waveguide H-tree system constructed using Ultradel 9120 polyimide. The optical clock signal delivered by an optic fiber will be coupled into the input end of the OIL. At the output end the optical signal will be coupled-out by surface-normal grating coupler and will be converted into the electrical signal by a fast-photo detector.

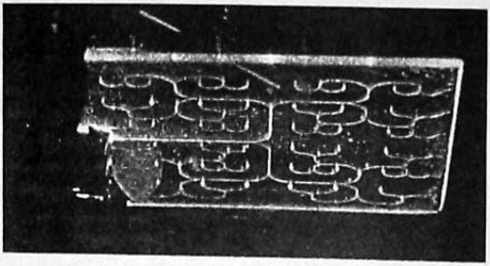

Fig.1 Photograph of the 1-to-48 fanout H-tree on quartz substrate using Ultradel 9120 polyimide. He-Ne laser beam at λ=633 nm was coupled into the input end using a prism coupler.

High-speed operation and massive fanout requirements impose stringent conditions on the material selection, minimization of waveguide propagation loss, and optimization of output coupling efficiencies. Ensuring enough optical power at the end of photodetectors for high-speed operation is essential. For example, the total optical splitting power budget is 18 dB (3x6) in an optical H-tree system (capable of providing 64 fanouts), which consists of six stages of 1-to-2 (3 dB) optical fanout. If the optical power at the input end is 10 dBm, and a 1.3 GHz optical receiver (having a sensitivity of -18 dBm at 1 GHz), [5] is used at output end for signal detection, the total insertion loss (output coupling loss plus waveguide propagation loss) should be less than 10 dB. Experimentally estimated loss at each fanout of the H-tree structure shown in Fig. 1 is 38.04 and 34.44 dB at operating wavelengths of 633 and 830 nm, respectively. These loss figures can be further improved by optimizing the feature size at the 1-to-2 waveguide splitters and purifying the polyimide.

To ensure the desired electrical and mechanical properties imposed by the Cray supercomputer board, and to meet the required optical properties for the low-loss waveguide formation, Ultra-9000 series photosensitive polyimides (Amoco Chemicals) [6] are used for the waveguide fabrication. Fully cross-linked polyimides have an excellent thermal stability (Tg = 400 °C) and optical transparency. The high Tg is critical for it to survive wire-bonding and metal deposition process, which makes it compatible with silicon CMOS processing. To fabricate the channel waveguides, the photosensitive polyimide was first spin-coated on the substrate, followed by a soft-curing process to remove the solvent. After the UV exposure, a post-exposure bake at 175 °C was made following a process to form the H-tree waveguides. Finally, the fabricated H-tree was post-baked at 260 °C to remove residual solvent and to improve its solvent resistance.

Efficient output coupling is another important factor to be addressed for reasonable performance from the OIL. We are investigating polymer-based tilted waveguide gratings as potential approach. Note that a 45° waveguide end mirror is not suitable in this case because of the requirement of planarization imposed by the vertical integration of the other electrical interconnection layers. The tilted grating waveguide couplers can surface-normally couple the optical signal into and out of a channel waveguide. The surface-normal feature of fanout beams and the planar compact device structure convert the most difficult three spatial and three angular multiple alignment problem into a single step 2-D planar one. Fig. 2 shows a photograph of such an input-grating coupler on glass substrate. Because of the reciprocity of the tilted grating coupler same structure can be used for output coupling as well. We have experimentally estimated an output efficiency of ~ 35%, which has potential for further improvements. Our theoretical prediction indicate that an efficiency as high as 70% is achievable by using high index polyimides and fine tuning the grating parameters such as grating period, depth, and tilt angles [7].

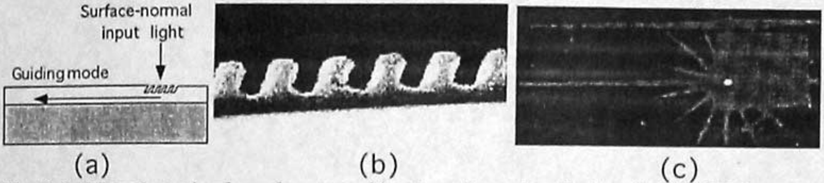

Fig. 2. (a) The schematic of a surface-normal input coupling using tilted grating. (b) SEM micrograph of polyimide tilted-grating with tilt angle of ~32°. (c) The photograph of coupling a surface-normal input laser into the 9120D polyimide waveguide.

Experiments are underway to verify the bandwidth of H-tree structure in conjunction with waveguide grating coupler, and results will be discussed in detail in the presentation. Preliminary measurements were performed on a straight channel waveguide launching an 1-GHz optical signal generated by a laser diode at 1.3 μm and a high-speed transmitter (2556T, Force Inc.), and detecting by a high-speed receiver (2556R, Force Inc.) and a Tektronics 11403 Digitizing Oscilloscope. The sinuous 1-GHz modulation applied on the transmitter was provided by a HP 8656B signal generator. Initial observations indicate that the speed of the optical signal was limited by the transmitter bandwidth (1.3-GHz) and the speed of the (HP 8656B) signal generator (1-GHz), rather than the channel waveguide length.

In conclusion, we present results and progress towards our effort to construct an optoelectronic interconnection layer for the high-speed massive clock signal distribution for the Cray T-90 supercomputer board. The optical interconnection layer under development employs optical multimode channel waveguides in conjunction with surface-normal waveguide grating couplers. Equalized optical paths are realized using an optical H-tree structure having 48 optical fanouts which could be increased to 64 without any additional complication introduced.

5. References

1. Ray. T. Chen, H. Lu, D. Robinson, Michael Wang, Gajendra Savant, and Tomasz Jannson, "Guided-wave planar optical interconnects using highly multiplexed polymer waveguide holograms," IEEE J. Light. Technol., vol. 10, pp. 888-897, 1992.
2. Bradley D. Clymer and Joseph W. Goodman, "Optical clock distribution to silicon chips," Opt. Eng., vol. 25, pp. 1103-1108, 1986.
3. R. W. Wickman, "Implementation of optical interconnects in GibaRing supercomputer channel", Proc. SPIE, vol. CR62, pp. 343-356, 1996.
4. Suning Tang and Ray T. Chen, "1-to-42 optoelectronic interconnection for intra-multichip-module clock signal distribution," Appl. Phys. Lett., vol. 64, pp. 2931-2933, 1994.
5. Data Sheet of VSC7810, Vitesse Semiconductor Corporation.
6. T. C. Kowalczyk, T. Kosc, and K. D. Singer, P.A. Chhill, C. H. Seager, and M. B. Meinhardt, A. J. Beuhler and D. A. Wargowski, "Loss mechanism in polyimide waveguides," J. of Appl. Phys., vol. 76, no. 4, pp. 2505-2508, 1994.
7. Feiming Li, Linghui Wu, Bipin Bihari, Suning Tang and Ray T. Chen," Unidirectional surface-normal wave-guide grating couplers for wafer-scale MCM interconnect," to be submitted to IEEE Photonics Tech. Lett.