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Optoelectronic Device and Material Technologies for Photo-Electronic Integrated Systems

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The future direction of optoelectronic technologies will be presented while emphasizing what is needed to establish collaboration between photons and electrons in a single system. Drastic improvements, or even new functions, will be obtained with systems that combine the best features of both electronics and photonics. Optical interconnections in computers are just the first indication of Photo-Electronic Integrated Systems A variety of "optical systems" should become feasible upon introducing "electronic circuits" in many important parts of such systems, where logical operations are required.

1. Optical Interconnections in Microprocessors

"Optical interconnections" in computers are giving the first indications of high-density electronic systems which are incapable of signal interconnections, even over short distances.[1)]

Although this problem started at the inter-equipment level within computers, it will be proven to exist at even deeper levels in such systems. In the early 21st century, optical interconnections at the chip level will be very necessary for large-scale microprocessors (Fig.2). By employing optical interconnections, the global interconnections of microprocessors will become much faster (~0.1ns/cm).[2)] Low-power consumption is also expected. It could possibly be about 1 μ-watt at 1 GHz per line, independent of distance.[3)] This would be particularly attractive for clock distribution and bus lines, in which many fan out or fan in are required (Fig.3).

A variety of new device and material technologies in optoelectronics must therefore be developed in order to produce such optical interconnections. Micron-size optoelectronic devices must be integrated onto LSIs, silicon-based transistor circuits, in order to meet the requirements for optical interconnections.

Hundreds, or even thousands, of micron-size lasers operating at low threshold levels must be installed at any designated locations in the sea of IC transistors. Highly sensitive photo-detectors of micron-size will also be needed (Fig.3,4,5).

New device technologies, such as highly reflective mirror cavities, and thresholdless microcavity structures, will be useful for these micro-lasers.

New material technologies must be developed for these optical interconnections, including lattice-mismatched hetero-epitaxies, which combine Si and (III-V)s, atomically controlled processings, clean surfaces and interface in-situ processings.[4)]

Interconnecting optical circuits must be designed in such a way that it will be possible to distribute light signals between any designated points in the system. In order to solve "positioning" problems among hundreds of optical passways and the corresponding optoelectronic devices, the "optical plate" structure is promising, since it can be constructed separately from optoelectronic devices on a microprocessor substrate.[5)]

2. The Development of Photo-Electronic Integrated Systems

Optical interconnections in a microprocessor represent the first example of a Photo-Electronic system. Once these technologies, which combine photonics and electronics have been established, a wide variety of applications will certainly be devised.

A new class of parallel-processing systems will thus become feasible, which will utilize "vertical optical interconnections" between multi-layered processor circuits. A prototype of such a system has been under construction.[6] These three-dimensional interconnecting systems will become practical only after replacing electronic interconnections by optical interconnections: thus, each layered circuit will become free to be constructed individually (Fig.5). Super parallel-processor systems can be constructed by using a multilayer common-memory type hypercube structure.[7]

"Optical System" can be constructed using the Photo-Electronic scheme. A large two-dimensional array of 4000 photo-detectors has been connected individually to small processor elements. A group of processors connected with each other's nearest neighbors is capable of processing incoming pictures.[8] Although today's system is a phototype of large dimension, it is possible to greatly reduce the size to that of the LSI level. Sophisticated image-recognition systems could be built based on an extension of this system. Neural network systems, or many other applications, will certainly appear based on the Photo-Electronic Integrated System concept.

References

1) J.W. Goodman, F.I. Leonberger, S.Y. Kung and R.A. Athale, Proc. IEEE 72, pp850-866 (1984)

2) a) U-OEIC Research Group Report 1992 (In Japanese), pp42-50
Optoelectronic Industry and Technology Development Association, Toranomon 1-chome Bldg. 19-5, Toranomon 1-chome, Minato-ku, Tokyo 105, Japan
Phone:+81-3-3508-2091, Fax:+81-3-5511-8218
(U-OEIC 研究会報告書、光産業技術振興協会)

b) A part of the Report (Round Table Talk of U-OEIC Research Group) is published in OITDA ACTIVITY REPORT Vol. 5, pp58-64 (1992)

3) Ref. 2) a) pp70-76

4) Y. Katayama, K. Akita, Y. Ohki, Y. Sugimoto, Y. Hiratani and H. Kawanishi, Ext. Abs. 1991 Int. Conf. Solid State Devices and Materials, Yokohama, PP281-283 (1991)

5) Ref.2) a) pp.114

6) M. Koyanagi, H. Takata, H. Mori and J. Iba, IEEE J. of Solid-State Circuits, 25, 1, pp109-116 (1990)

7) Tadashi AE, Professor of Hiroshima Univ. Private Communication

8) M. Ishikawa, A. Morita and N. Takayanagi "光入出力を有する超並列演算処理機構(SPK-4)" 並列処理シンポジウム JSPP'92,pp353-358, June 1992

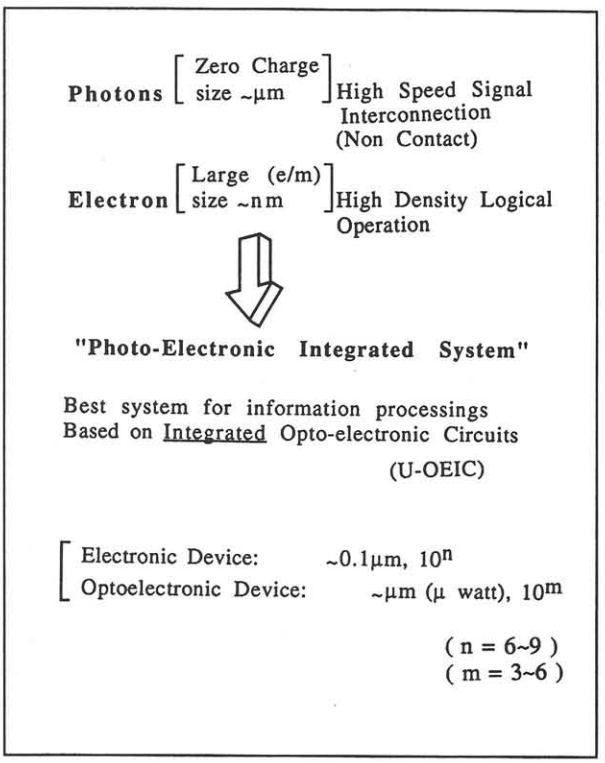


Fig. 1
Direction of Future Photo-Electronic Systems

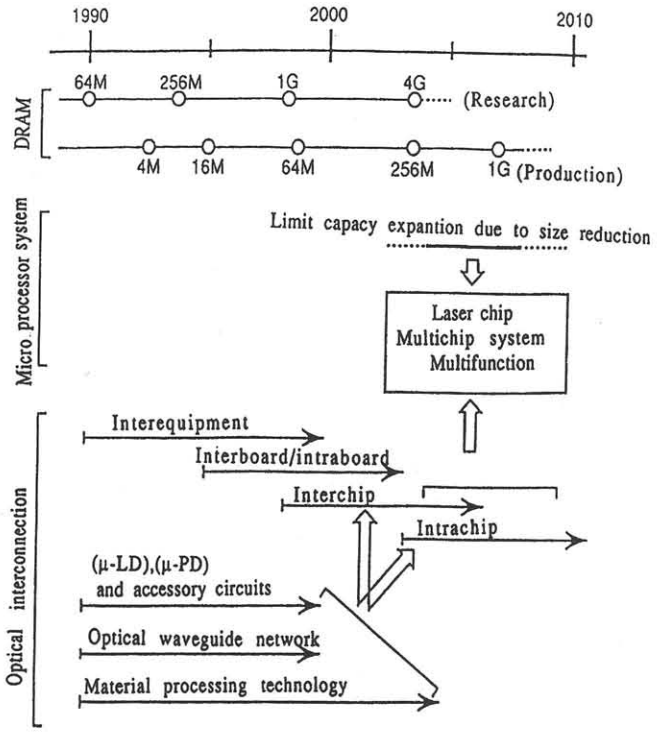
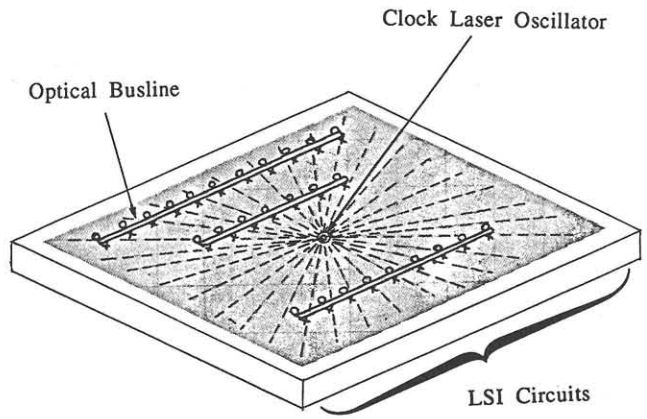


Figure 2
Time Schedule of Introduction of Optical Interconnections to LSI



∘ Laser

× Detector

Fig. 3
A schematic drawing of an optically interconnected micro-processor

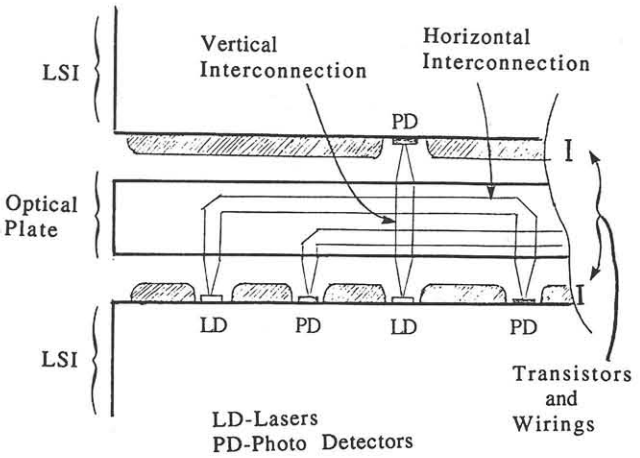
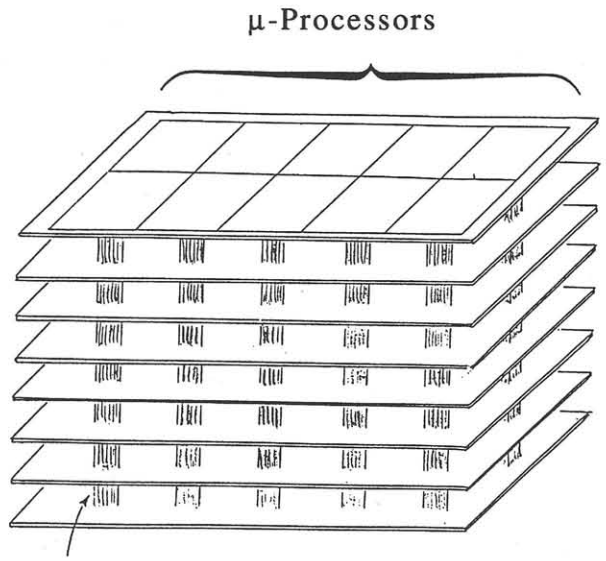


Fig. 4
Optical wirings inside an LSI: "Horizontal" Interconnection between two LSIs: "Vertical" Interconnection

All optical wave-guides and associated optics are accommodated inside an "Optical Plate"



Horizontal Optical Interconnections are omitted

Fig. 5
A Three Dimensional Photo-Electronic Integrated System, constructed by Vertical and Horizontal Optical Interconnections