

Recent Advances in Board-Level Optical Interconnection

Osamu Mikami

School of Engineering,

Tokai University

1117 Kitakaname, Hiratsuka-shi, Kanagawa 259-1292, Japan

mikami@tokai.ac.jp

Abstract

The potential of optical interconnection technology is discussed. Particular attention is paid to the introduction of "optical wiring" at the printed wiring board level ("last 1 meter area") to overcome conventional electrical copper-based bandwidth limitations. The R&D status of optoelectronics system integration in Japan is also briefly introduced, and is followed by a review of optical surface mount technology (O-SMT), one of the possible solutions in this field. The development of sophisticated technology enabling high efficiency and alignment-free coupling between optical wirings and optical devices is found to be key to the practical use of optical wiring. A novel interface using an "optical pin" and a "self-written waveguide" is shown to be very promising for the achievement of optical interconnection technology.

Key words:

Optical wiring, Optical surface mount technology, Optical pin, Self-written waveguide

1. Introduction

In the future information technology (IT) society, smooth, fast and intelligent transmission and processing of huge amounts of information data will be necessary. One of the expectations for the future is that total data rates inside boxes such as high-end routers, servers, and some IT equipment, i.e., next-generation games and computer graphics devices, will reach over 10 Tbps by 2010. Electric signal transmission by conventional "copper metallic wiring" will be the bottleneck in system performance improvement. To cope with these high-capacity throughputs, the use of "optics" will play an important role in solving the existing I/O bottleneck of copper metal wiring around high-capacity switching LSIs of IT equipment and servers, and around electrical connectors between interface boards and backplanes, as shown in Fig. 1. However, such an approach is very complicated, because it will require new sophisticated technologies of cost-effective optoelectronics packaging.

In this paper, the R&D status of optoelectronic (OE) system integration in Japan is briefly described. Then, optical surface mount technology

(O-SMT) including the new architecture of the optical interface of "optical pins" and "self-written waveguides (SWWs)" is introduced.

2. Optical Interconnection and Promising Applications

Optical fiber communication has exhibited great success in high-end telecommunication networks over the past 25 years. Signal transmission by means of photons has reasonably

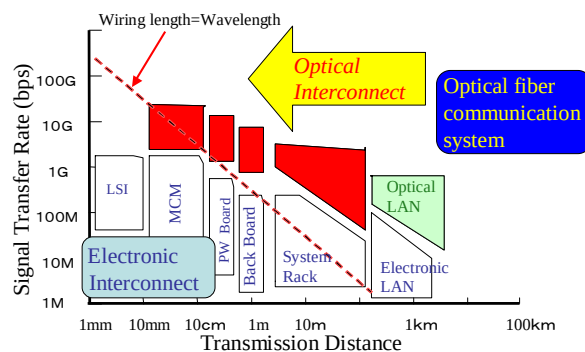


Fig. 1 Metallic wiring vs. optical wiring.

high transmission speed characteristics. Moreover, the noise problem of electromagnetic interference (EMI) and electromagnetic compatibility (EMC) can be minimized. New signal-carrying materials of polymeric waveguides with low propagation loss have been developed as replacements for silica fibers. These materials have considerably high flexibility and can be combined well with conventional metallic printed wiring boards (PWBs). These characteristics make them appealing for use in handy phones in low-end applications. In addition, a lightweight polymeric wiring has great advantage over conventional copper harness used in motor vehicles from the energy conservation standpoint. Particular attention has also been paid to optical interconnection from the viewpoint of the highly efficient use of energy. Some prospects indicate that the energy required for transmitting a one-bit signal by means of photons can be reduced compared with that required for transmitting a one-bit signal by means of electrons. In addition, it is expected that the small space occupied by optical wiring will enable a highly efficient cooling system for high-end servers and routers.

However, several difficulties are encountered in terms of the device and circuit packaging/assembly in the "last 1 meter area" owing to the use of a photon as the signal carrier. This is because the assembly of optical devices, which is very unlike that of electronic devices, requires high-precision positioning and high man-hour cost. Thus, although the technology itself is quite sophisticated and highly intellectual, the inherent cost problem should be solved in order to realize wider application to consumer markets.

3. Optoelectronic System Integration R&D in Japan

In 1999, the Association of Super-Advanced Electronics Technologies (ASET) started its 5-year National Consortium Project of Opto-Electronic R&D. The project had three main research themes, one being opto-electronics packaging technology for the backplane of high-end servers and routers. However, a new scheme called the Opto-Electronic System Integration Collaboration Research Project has replaced the project. The key objective of the new project is the R&D of optoelectronic packaging technology focusing mainly on optical modules and related component technologies [1,2]. The organization of this project is summarized in Fig. 2. The National Institute of Advanced Industrial Science and Technology (AIST) conducted the research in collaboration with eight leading companies. The

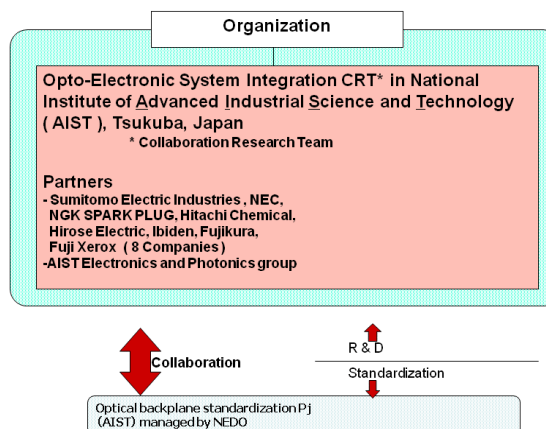


Fig. 2 Opto-Electronic System Integration Collaboration Research Project.

project ended in March of this year, and its continuation is still under consideration.

The project resulted in the development of optoelectronic packaging technologies such as optical backplanes utilizing 300 high-index fine-diameter multimode fibers and low-cost and high-density OE-conversion parallel-link modules operating at 10 Gbps/ch for less than 1 m regime applications. The successful combination of such developed backplanes and modules implies the potential of 3 Tbps aggregate throughputs for optical interconnections at the board-to-board level. Furthermore, novel component technologies were developed for low-cost and high-density optical coupling between optical devices. These technologies include monolithic two-wavelength twin vertical-cavity surface-emitting lasers (VCSELs), and an easy self-alignment coupling technology capable of alleviating difficulties in optics penetration inside boxes.

On the other hand, standardization activities for optical wiring boards, optoelectronic modules, and other devices have been extensively promoted and several standardization documents have already been published by the Japan Printed

Standardization target of opto-electronic assembly system

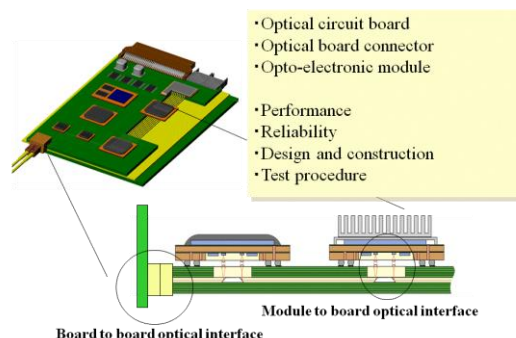


Fig. 3 Standardization target

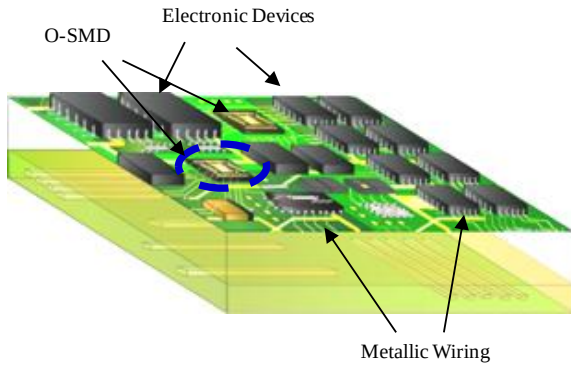


Fig. 4 Principal configuration of optical surface mount technology

Circuit Association (JPCA). These documents have also been mentioned and discussed internationally at IEC, TC86/JW9 [3]. The standardization target is summarized in Fig. 3.

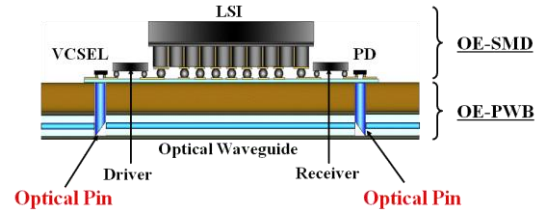
4. Optical Surface Mount Technology

O-SMT, which was proposed by Professor Teiji Uchida in 1992, is an optical device-mount technology at the board level corresponding to the surface mount technology (SMT) widely employed in electronic circuits [4,5]. Its principal configuration is schematically shown in Fig. 4. To meet the requirements for the expansion of optoelectronic productions in the near future, we must take into account that the low-cost mass production of electronic products has been successful under the concept of "device + interconnection". The concept of O-SMT is also "optoelectronic device + interconnection". An optoelectronic surface mount device (OE-SMD) is mounted on an optoelectronic printed wiring board (OE-PWB). These OE-SMD and OE-PWB have a standard interface so that both optical coupling and electrical linking between them can be achieved efficiently and easily. In the OE-PWB, low-loss polymeric optical waveguides are utilized as the optical wiring. O-SMT requires a method of changing the beam direction from the horizontal to the vertical and vice versa in order to couple the optical waveguide and the OE-SMD mounted on the board.

5. Optical Pin Interface

5.1 Concept

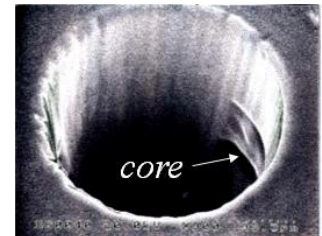
To achieve a 90° optical path conversion, a novel scheme using an optical pin was proposed and investigated [6-8]. Its fundamental concept is schematically shown in Fig. 5 (a). A photograph of the fabricated optical pin using an MMF is shown in Fig. 5 (b), and a via-hole with a diameter of 200 μm



(a) Basic concept



(b) Optical pin



(c) Optical Via-hole

Fig. 5 New optical interface using an optical pin.

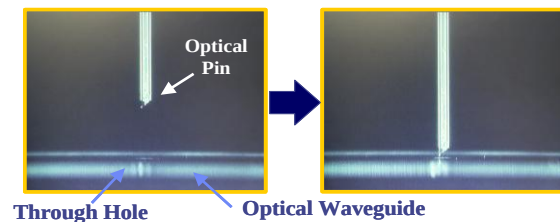


Fig. 6 Inserting the optical pin into a via-hole

was fabricated on a polymeric waveguide by laser ablation, as shown in Fig. 5 (c). This method enables the alignment-free coupling between optical wirings and optical devices.

Optical pins were actually inserted into via-holes, as shown in Fig. 6. A very high coupling efficiency of -1.0 dB was achieved. Very large positional tolerances were also confirmed both theoretically and experimentally. These results suggest that the optical pin coupling scheme is feasible with passive alignment.

5.2 Polymer Optical Pin

Minute optical pins required in packaging are fabricated by the mask transfer method. This method utilizing SWW technology will be introduced in the next section. The experimental setup is schematically shown in Fig. 7. In the fabrication experiment, a photomask with oval apertures was used. In addition, a prism was applied on the photomask to minimize light refraction. An example of the fabricated SWW pins shown in Fig. 8 indicates that a 45° end-face was successfully formed [9]. Recently, we succeeded in fabricating SWW pins on the emission window of a VCSEL

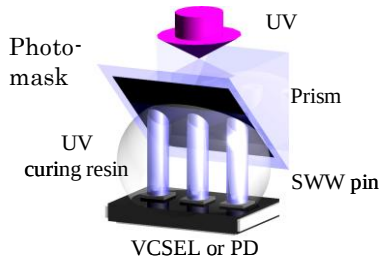


Fig. 7 Experimental setup for the new SWW optical pin

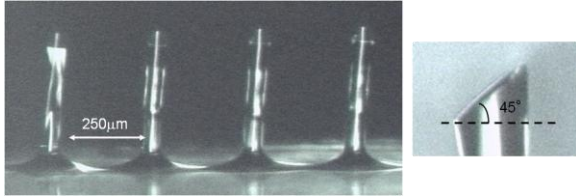


Fig. 8 Fabricated SWW optical pins

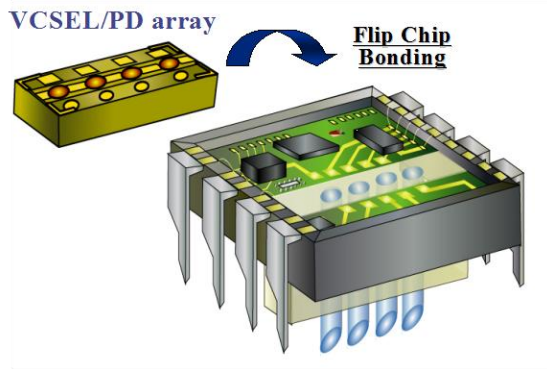


Fig. 9 Image of a future opto-electronic module

[10]. We also confirmed that such SWW pins are very promising as a 90° path conversion device and an optical interconnection in OE-PWBs. An image of future optical packaging with optical pin inlets/outlets is shown in Fig. 9.

6. Self-Written Waveguide Interface

6.1 Concept

An optical coupling method using a SWW has been studied. We called this method “optical soldering” because of its self-alignment effect, which is similar to that of metal soldering in electronics assembly. Optical soldering has attracted much attention owing to its simple and cost-effective optical coupling between optical components [11-14]. Moreover, it requires no alignment between waveguide and fiber because the waveguide is directly grown on the core of fiber. The formation mechanism of a self-written

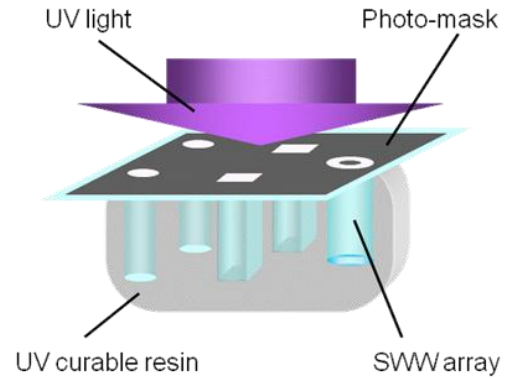


Fig. 10 Principle of the mask transfer method waveguide is based on the very fundamental principle of photopolymerization.

6.2 Mask-Transfer Method

We have proposed a novel SWW array fabrication method using a photomask transfer method [15]. An outline of the fabrication method is schematically shown in Fig. 10. UV curable resin is used to fill a space underneath a photomask, after which UV light is irradiated onto the photomask. After a few seconds exposure, an SWW array can be formed along the mask apertures. The formation of an SWW array with round and square cross sections of 50-100 μm and 1.0 mm length was confirmed, as shown in Figs. 11(a) and (b), respectively.

The above mask transfer method seems very suitable for SWW array connections when $M \times N$ channels optical wirings are introduced into an OE-PWB. We have already shown some applications of the mask transfer method to O-SMT. We have also succeeded in forming an SWW with a down taper using a microlens mask method, as shown in Fig. 12. This funnel-type SWW is very useful for high-speed receiver application since positional tolerance can be increased against the small photodiode aperture [16,17].

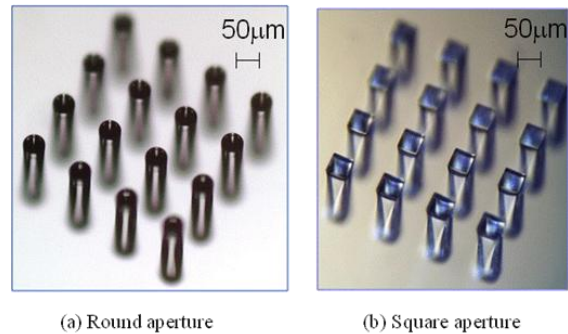


Fig. 11 Fabricated SWW array

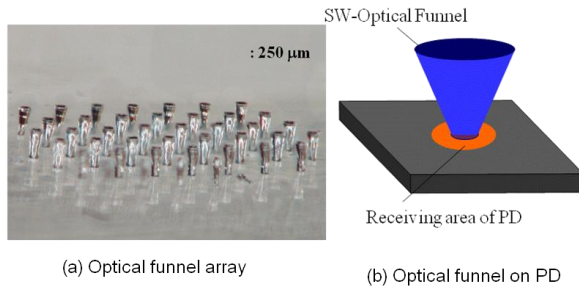


Fig.12 Fabrication of a SWW funnel

6.3 Chip VCSEL with Polymer Optical Outlet

We previously proposed the novel concept of the chip VCSEL which will enable passive alignment in OE-PWBs [18-20]. As shown in Fig. 13, the proposed chip VCSEL consists of a substrate, a VCSEL, polymer cladding and a built-in outlet rod as a core. This optical outlet is precisely positioned on a face of the chip VCSEL. The outlet is directly connected to the emission spot of VCSEL. The chip VCSEL can be directly mounted onto a PWB. A high optical coupling efficiency is expected between the chip VCSEL and an optical waveguide. Moreover, passive optical alignment is feasible because the position of the optical outlet is precisely controlled. In addition, all bonding wires for the VCSEL are protected by the polymer cladding. Therefore, no careful handling is necessary because all the delicate parts, such as bonding wires and emission spots, are covered by the polymer material and mechanical strength is thereby reinforced. Furthermore, the chip VCSEL can be extended to a two-dimensional array, and the concept can be applied to receiving devices such as photodiodes.

Fig. 14(a) shows a core formed on a VCSEL emission spot. Its diameter is 50 μm and its height from the substrate surface is 700 μm . Fig. 14(b) shows the finished chip VCSEL after forming the cladding. The external dimensions are 2 mm x 1 mm x 700 μm . The core part and bonding wires are

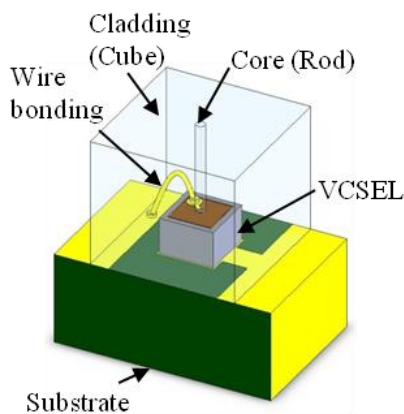


Fig. 13 New chip VCSEL for optical interconnect applications

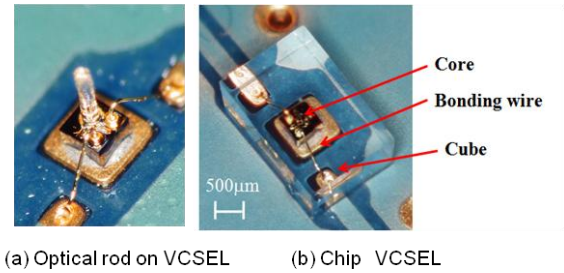


Fig. 14 Fabricated chip VCSEL.

completely covered with polymer cladding. The chip VCSEL is very effective in mechanical reinforcement.

7. Summary

The R&D status of the Opto-Electronic System Integration Project in Japan whose goal was overcoming conventional electrical copper-based bandwidth limitations was briefly introduced, and then followed by a review of O-SMT, one of the possible solutions for promoting optical interconnection technology in this field. Several experimental studies to verify the feasibility of actual use have suggested that a new interface based on optical pin and self-written waveguide technologies has a high potential for markedly reducing man-hours for optical device mounting on OE-PWBs. Electronic and optical wirings are likely to coexist on boards of IT equipment in the near future. Hence, the organic sharing of these two is important in achieving the final goal of marked improvement in IT equipment performance.

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Osamu Mikami received his B.E, M.E and Dr. Eng. degrees from Osaka University in 1969, 1971, and 1978, respectively. In 1971, he joined NTT Laboratories where he worked in the field of guided-wave optoelectronics. From 1985 to 1986, he was a visiting research fellow at the Department of Electronics and Electrical Engineering, University of Glasgow, Scotland. From 1991-1992, he was a visiting associate professor at University of Tokyo. In 1994, he moved from NTT to Tokai University as a professor. In 2006, he spent four months at Kassel University, Germany as a visiting professor. Currently, he is a professor of the School of Engineering, Tokai University. He is also an auditor of the Japanese Institute of Electronics Packaging (JIEP), and a Fellow of the Institute of Electronics Information and Communication Engineers (IEICE).