A New Architecture for Board-level Optical Wirings applying Optical Pin and Self-Written Waveguide

Osamu MIKAMI ,

School of Information Technology and Electronics, Tokai University
1117 Kitakaname, Hiratsuka, Kanagawa 259-1292, Japan
e-mail:mikami@keyaki.cc.u-tokai.ac.jp

Abstract

The potential of the optical circuit packaging technology is discussed. Special attention has been paid to introduction of "Optical wiring" into the Printed Wiring Board level ("last 1 meter area") to overcome conventional electrical copper-based bandwidth limitations. Optical Surface Mount Technology (O-SMT) can be one of possible solutions in this field is reviewed. High efficiency and alignment-free coupling between optical wirings and optical devices is a key. O-SMT requires a method to change the beam direction from the horizontal to the vertical and vice verse in order to couple between optical wirings in an OE-board and OE-devices mounted on the board. A novel method using an "Optical Pin" has been proposed and investigated. Furthermore, an optical coupling method using a Self-Written Waveguide called "Optical Solder" has been investigated. Several applications of self-written waveguides using a green-laser and a photo-mask are demonstrated.

Keywords : Optical wiring, Optical surface mount technology, Optical pin, Optical solder, Self-written waveguide

1. INTRODUCTION

In realizing a new seamless, value-added and multi-media tele-communication society, smooth, fast and intelligent transmission and processing of huge information data is required. The electric signal transmission by conventional "Metallic wiring" has become a bottleneck of the system performance improvement. For this solution, introduction of "linking with optics" in place of metallic wiring is the best way, as shown in Fig. 1. However, this approach is not simple and easy. New sophisticated technologies of cost effective opto-electronics packaging are required.
In this paper, the R&D status of Optical Surface Mount Technology (O-SMT) is described, including a new architecture of optical interface of "Optical Pins" and "Optical Solder" technique of Self-Written Waveguides (SWWs).

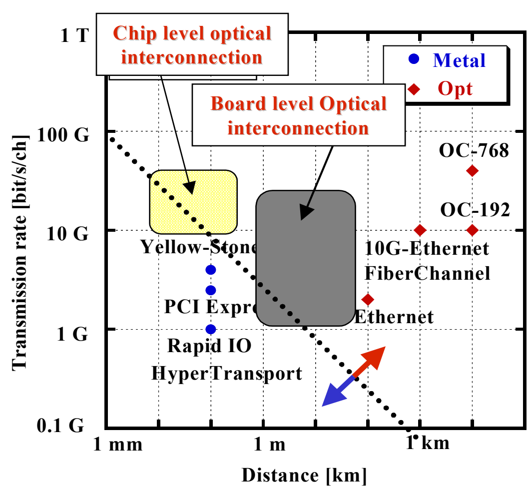

Fig. 1 Metallic Wiring vs. Optical Wiring

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2. LINKING WITH OPTICS

It is well known that optical fiber communications have exhibited a great success in the high-end tele-communication network for this quarter century. The signal transmission by photons has quite high transmission speed characteristics. The noise problem of EMI (Electro Magnetic Interference) and EMC (Electro Magnetic Compatibility) can be also minimized. However, several difficulties have been induced because the signal carrier is photon, in respect of the device and circuit packaging/assembling in the "last 1 meter area". It is because the assembling of optical devices, which is very unlike that of electronics, requires high precision positioning and high man-hour cost. Though the technology itself is quite sophisticated and highly intellectual, it has a cost problem for the application to consumer markets.

In Japan, a 5-year national consortium project on the Electronic System Integration was proceeded for 1999-2004 [1]. In this project, several key technologies of opto-electronics packaging were developed especially focusing on the "last 1 meter area", which includes the OE multi-chip module (OE-MCM), OE-conversion module termed "active interposer" for chip level optical interconnects between LSIs, OE-board and backplane associated with multi-channel optical connectors [2]. These OE-MCM and other devices are installed on OE-boards and then assembled into OE-sub-racks and server system cabinets which will reach more than Tbit/sec transmission rate performance. This project was followed by a new project of Hyper SI (System Integration). The Hyper SI started in 2004 for two-year, where development of high speed Tbps class optical backplane platform with multi-channel connectors is mainly focused. A new OE module named VGPAS (V-Grooved Passive Alignment Structure) has been proposed and investigated.

3. OPTICAL SURFACE MOUNT TECHNOLOGY (O-SMT)

O-SMT, which was proposed by Prof. T. Uchida in 1992 [3], is an optical device-mount technology of the board level corresponding to the surface mount technology (SMT) widely employed in electronics circuits. In order to meet the expansion of opto-electronics productions in the near future, we have to take into account that electronics products succeeded in low-cost and mass production with a concept of "Device + Interconnection". The concept of O-SMT is also "Opto- electronics device + Interconnection".

The principal configuration is shown in Fig. 2. Opto-Electronics Surface Mount Device (OE-SMD) is mounted on the Opto-Electronics Printed Wiring Board (OE-PWB). These OE-SMD and OE-PWB have standard interface so that both effective optical coupling and electrical linking between them can be easily achieved. In the OE-PWB, optical channel waveguides are utilized as the optical wiring. Among several waveguide materials, polymeric ones are considered to be most promising. O-SMT requires a method to change the beam direction from the horizontal to the vertical and vice verse in order to couple between the optical waveguide and OE-SMD mounted on the board [4-5].

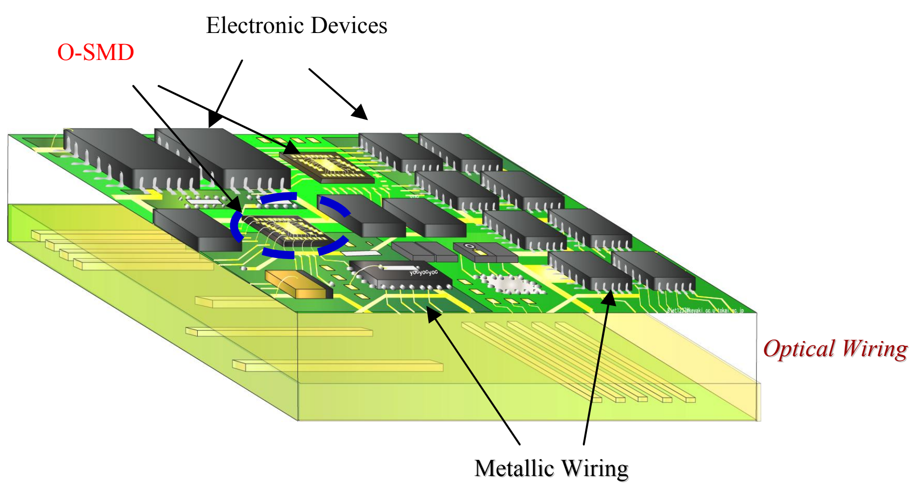
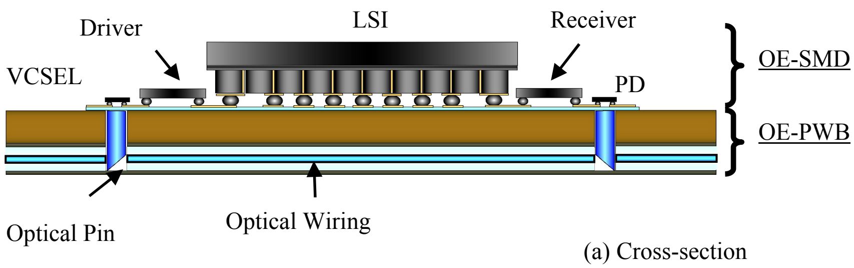


Fig. 2 Principal configuration of Optical Surface Mount Technology

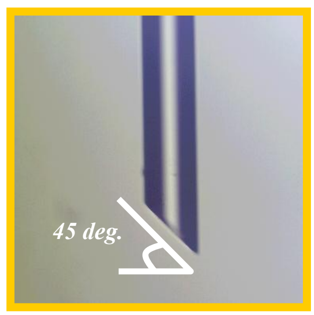
4. "OPTICAL PIN" INTERFACE

4.1 Concept

To achieve a 90 degree optical path conversion, the use of a micro mirror trench with 45 degrees has been studied so far. However, the conventional mirror trench method has the following problems. First, it is difficult to form micro mirrors in arbitrary places of the OE-PWB locally. Second, there is risk to disconnect other optical wirings in the vicinity. Third, the direction of the mirrors is limited.



(a) Cross-section



(b) Optical pin

Fig. 3 New optical interface using optical pins

A novel method using an "Optical pin" has been proposed and investigated [6]. Fundamental concept is schematically shown in Fig.3 (a). This method enables alignment free coupling between optical wirings and optical devices. Use of the optical pin is as follows. First a number of "through-holes" are processed beforehand at positions designed in advance on the OE-PWB by dry etching and laser ablation etc. Next, the optical pin having a 45-degree micro mirror at the end point will be inserted into the through-hole. Then, these optical pins are fixed with an optical adhesive. In the present electronics field, a connecting pin has been conventionally applied, and this is its optical version.

4.2 Preparation of Optical Pin

The optical pin with a 45 degree micro mirror at the end point can be processed by using a MMF (multi-mode fiber). A photograph of fabricated optical pin is shown in Fig. 3 (b). Through-holes are fabricated on polymeric waveguides using Excimer laser ablation, as shown in Fig.4. The core and clad materials of polymeric waveguide are d-PMMA and UV-cured epoxy, respectively. Photograph of a fabricated hole with about 200 μm diameter is shown also in Fig. 4.
Optical pins were actually inserted into holes on polymeric waveguides and coupling efficiency was measured. Photographs when the optical pin was being inserted into the hole are shown in Fig. 5. Coupling efficiencies of Au-film coated pin were measured to be about -2.84 dB and -2.76 dB for transmission and reception, respectively. These values were remarkably improved to be -1.0 dB when matching oil was immersed into the hole. The positional tolerances were measured using an experimental setup shown in Fig. 6. The measured results are summarized in Fig. 7. Along the optical axis (Z-axis), the tolerance for 1-dB down was measured to be nearly 100 μm. Along X- and Y-axes (vertical along the optical axis), it is about 20 to 30 μm. The rotational tolerances are much different for transmission and reception, and 15 degrees and 25 degrees, respectively. So, these results of maximum coupling efficiencies and positional tolerances have shown that a 90 degree optical path converter using an optical pin will be quite feasible with passive alignment.

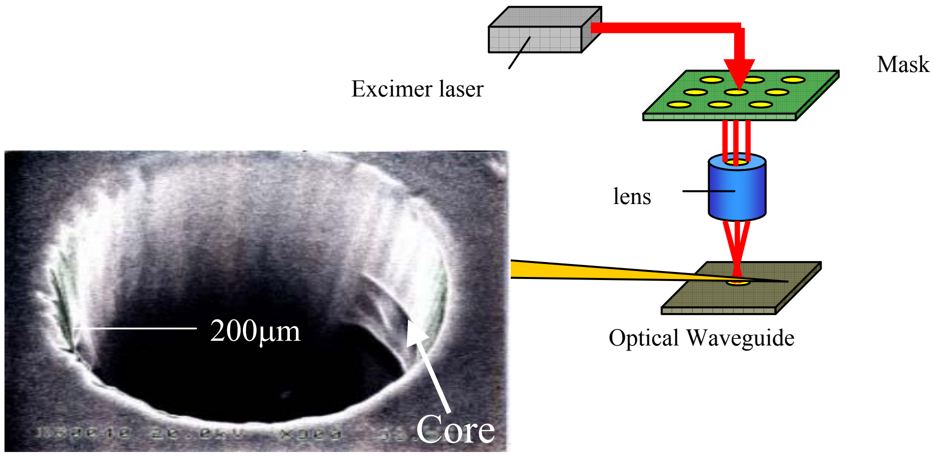


Fig. 4 Fabrication of through-hole for Optical Pin using Excimer laser ablation

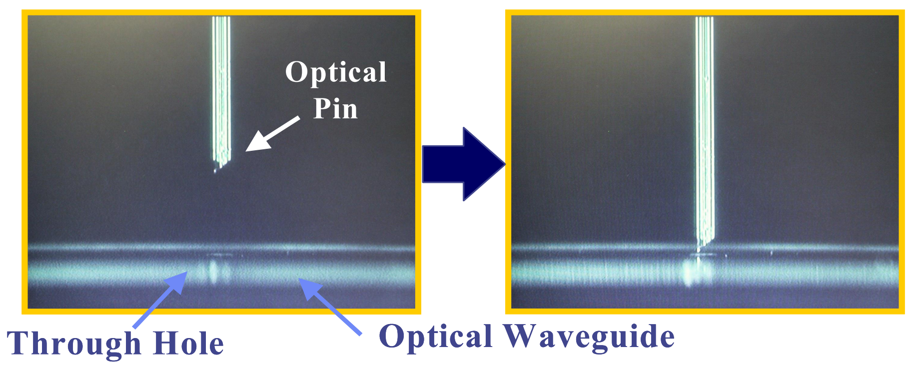


Fig. 5 Photographs when an optical pin is being inserted into a hole.

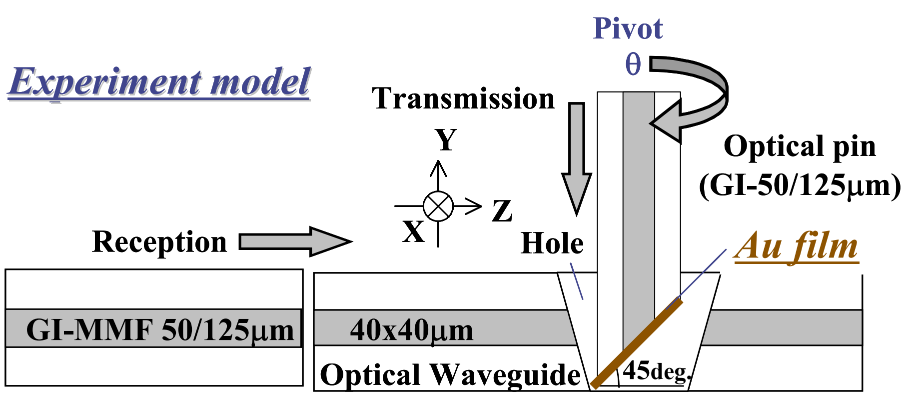


Fig. 6 Experimental setup for measurement of alignment tolerances.

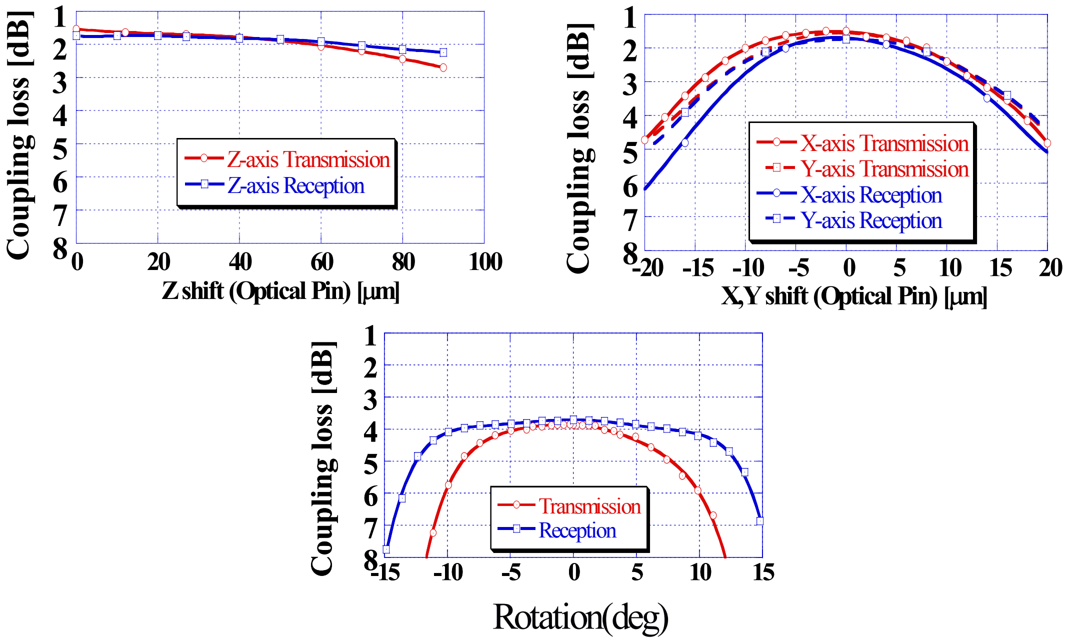
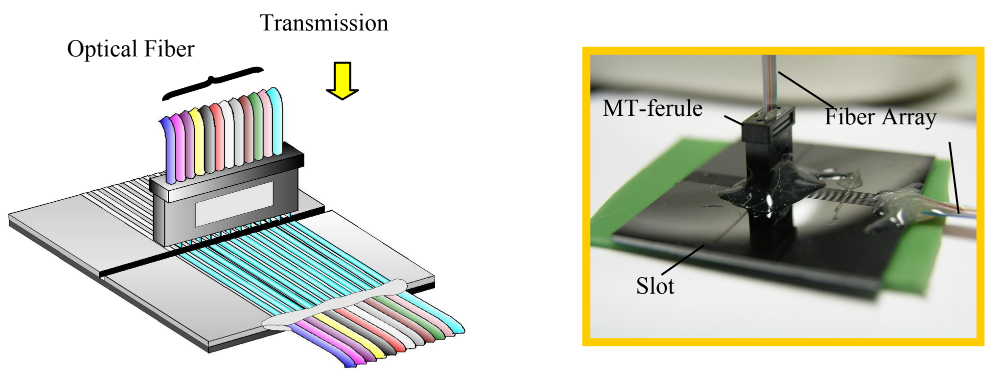


Fig. 7 Observed alignment tolerances for X-, Y-, Z-axes and rotation.

4.3 MULTI-CHANNEL CONNECTOR FOR OPTICAL PIN

So far, optical coupling characteristics of a single optical pin have been described. High coupling efficiency and high alignment tolerance can be clarified. Next, we have studied feasibility of multi-channel connector using optical pins [7]. Applying an MT connector and a tape fiber, a 12 channel optical connector was processed. The connector has 125 μm long chips having 45-degree mirrors at the end points. As an optical wiring board, a 12 channel tape fiber was buried into 130 μm wide grooves fabricated on a silicon substrate. The silicon substrate has also a 130 μm wide slot right angle to the array of optical wiring. Then the connector was inserted into the slot, adjusting the position only along parallel to the slot, as shown in Fig. 8. That is, passive alignment for two axes, and active alignment for only one axis were adopted. Coupling efficiencies were measured and average of about 3 dB was obtained.

We have refined this technology and realized excellent characteristics recently. We applied an MT connector for 4 channel optical pin coated with Au film on the end point of fiber. With polymeric waveguides having a core size 50 x 50 μm, coupling efficiency of about 1.0 dB was achieved. These experimental results may indicate a high possibility of passive alignment using optical pins. An image of future optical packaging is illustrated in Fig. 9.



(a) Basic structure of multi-channel optical pin connector (b) Multi-channel optical pin connector

Fig. 8 Multi-channel connector using optical pin

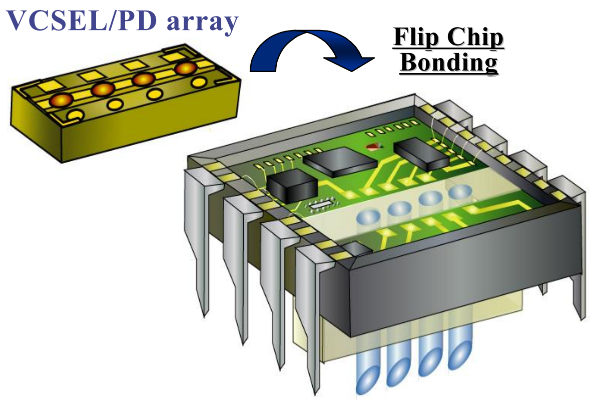
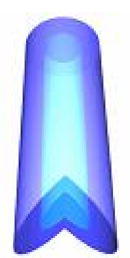


Fig.9 Future image of optical packaging having optical pins

4.4 NEW OPTICAL PIN FOR 1 VS. N SPLITTING

As mentioned above, an optical pin has a 45-degree micro mirror at the end point of the fiber. This means that a signal light beam coming from the top of the optical pin reflects to one direction right angle to the optical pin. In other word, optical splitting of one vs. one is obtained. In future, optical wiring will be applied into a lot of fields, not only replacement of metallic wirings. In this case, splitting of 1 vs. N will be required. We have investigated new optical pins which has unique structures of the end point [8]. The structures of the proposed optical pin is shown in Fig. 10. Among them, a V-shape optical pin enables 1 vs. 2 splitting. Ray tracing simulation was tried when a V-shape optical pin was inserted into the optical wiring board, as shown in Fig. 11. Using a Plastic Optical Fiber (POF) with a diameter of 980 μm, a V-shape was formed and a laser beam of 632 nm wavelength was launched into the optical pin. Fig. 12 (a) and (b) are pictures of the fabricated POF pin and experimental result, respectively. A splitting ratio of 1:1 was clearly obtained.



(a) V-shape optical pin

(b) Pyramidal-cut pin

(c) Cross-cut pin

(d) Condical-cut pin

Fig.10 New optical pins

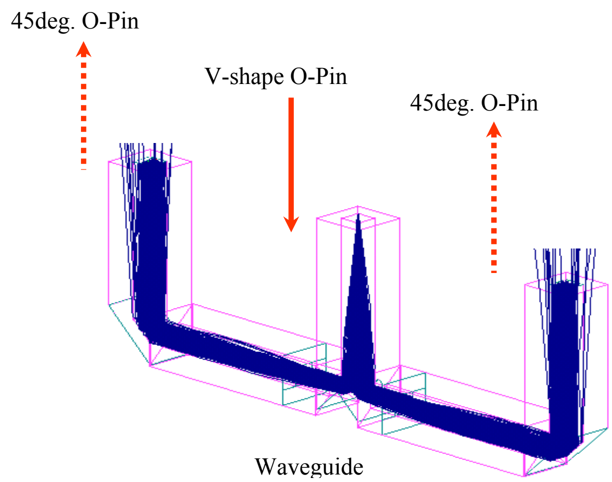
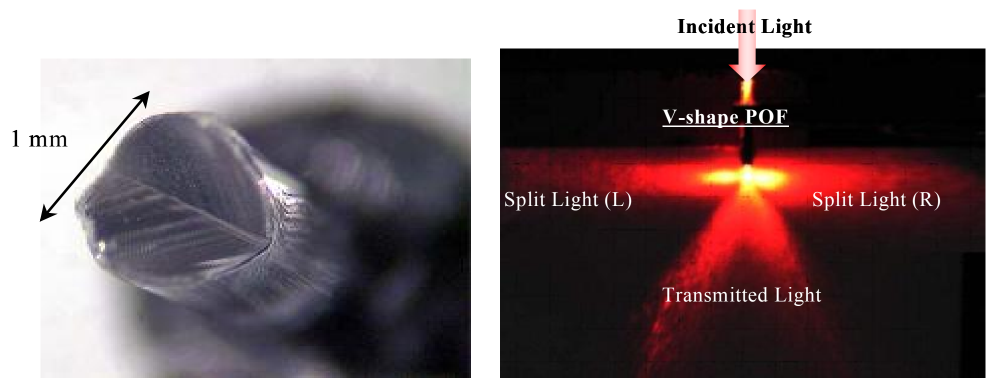


Fig. 11 Ray-tracing for1 vs. 2 connecting



(a) Fabricated V-cut optical pin

(b) Experimental result of 1 vs. 2 splitting

Fig. 12 V-shaped optical pin using POF

5. OPTICAL SOLDER OF SELF-WRITTEN WAVEGUIDE BY GREEN LASER

5.1 SWW

An optical coupling method using a self-written waveguide has been studied. We called this technique “optical solder”, because of its self-alignment effect, as similar to that of a metal solder in the electronics assembly. Thus the “optical solder” has attracted much attention for simple and cost-effective optical coupling between optical components. The alignment between a waveguide and a fiber is unnecessary, because the waveguide is directly grown from the core of fiber. The formation mechanism of a self-written waveguide is based on very fundamental principle of photo-polymerization.

So far, most SWWs were formed using UV irradiation through a silica optical fiber. A polymeric waveguide, which is one of promising candidates as optical wirings, has strong optical UV absorption. The high optical power irradiation to a polymeric waveguide may degrade the optical loss and further the mechanical properties of the waveguide. So, “optical solder” by using the laser light with a small optical power and a longer wavelength is required between polymeric waveguides and optical components [9].

We used a commercialized radical type (acryl-based) UV curable resin [10]. The refractive indices of the UV curable resin before and after curing were 1.497 and 1.531, respectively at the wavelength of 589 nm. The 0.01wt% Rhodamine 6G dye having the optical absorption peak at the wavelength of 540nm was dispersed in the resin. The resin was colored red by this slight dye, as shown in Fig. 13.

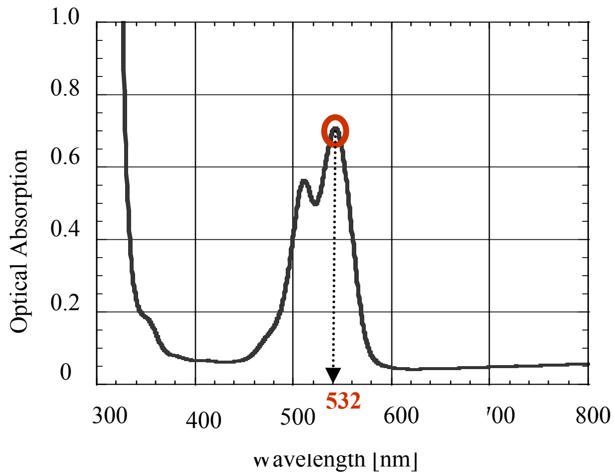


Fig. 13 Optical absorption of dye-mixed UV curable resin

Using this dye-mixed UV curable resin, high efficient optical coupling between MMFs, and between a MMF and a VCSEL have been achieved [10]. In some configuration of optical interconnection between fibers and an electric PWB, optical coupling between fiber having a 45-degree mirror with the end of fiber and a VCSEL is quite useful [11]. The gap of a few 100 μm is needed between a fiber and VCSEL, because the VCSEL typically has a bonding wiring on the top of an anode electrode and as a result the air spacing-gap between a fiber and a VCSEL is induced. Experimental setup is shown in Fig. 14. Fabrication process is summarized as follows.

1. The spacing-gap between a fiber and a VCSEL is set to be 500 μm.
2. The spacing-gap was filled up with the dye-added resin.
3. A green-laser beam was launched into a fiber.
4. The SWW grew from the fiber end face and reached to the VCSEL.

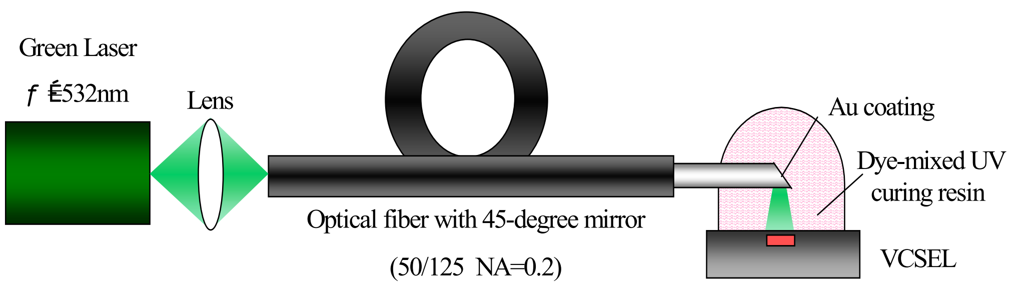


Fig. 14 Experimental setup for SWW connection

A picture of fabricated SWW is shown in Fig. 15. The optical coupling loss with the gap between the fiber and the VCSEL was 18dB. When a SWW was fabricated by introducing the green-laser beam into the gap through the MMF, the optical coupling loss was significantly improved to be 1.8 dB. We confirmed the “optical solder” effect of the SWW using a green-laser.

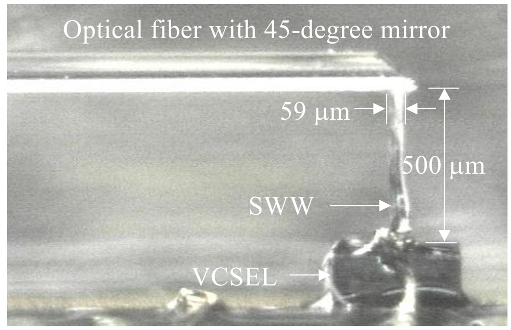


Fig. 15 Fabricated SWW between optical fiber with 45-degree mirror and VCSEL

5.2 Optical Connection with Larger Tolerance using Tapered Self-Written Waveguide

We have proposed "tapered self-written waveguide" for coupling of optical components in the board level optical interconnection [12]. Tapered waveguides have a possibility of having larger tolerance for optical coupling. We developed fabrication conditions of tapered SWW by adjusting the optical power and irradiation time of curing resin, and measured the optical tolerance. Experimental setup is shown in Fig. 16.

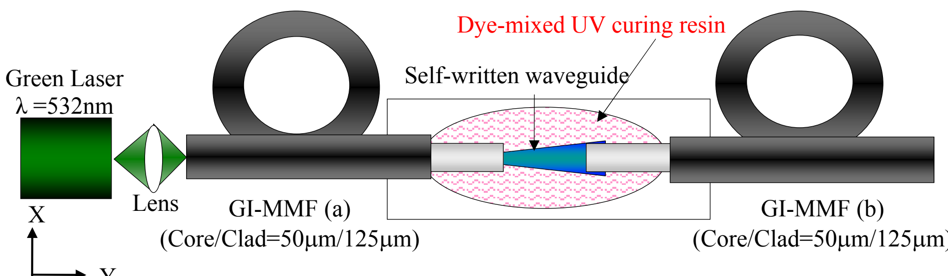
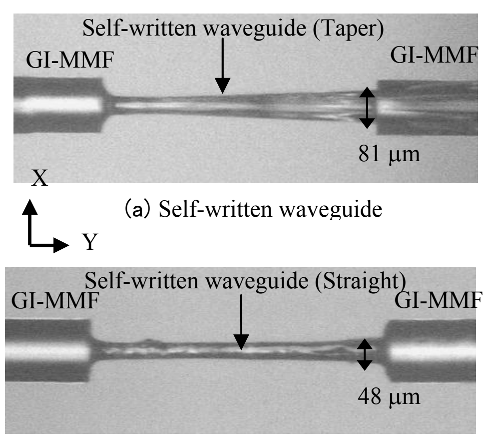


Fig.16 Experimental setup

Tapered SWW was fabricated into a gap of typical length 500 μm between MMFS of core diameter 50 μm. As shown in Fig. 17, the diameters of two faces of fabricated tapered SWW were about 43 μm (A) and 81 μm (B). Observed tolerances for tapered and straight form SWWs are shown in Fig.18. The 1 dB-down tolerance of B face of SWW to a MMF was measured to be 33 μm, whereas that of conventional straight SWW was 15 μm. We could show the usefulness of tapered SWW. By using this method, passive alignment of optical coupling will be feasible.



(a) Self-written waveguide

(b) Self-written waveguide

Fig.17 Photograph of self-written waveguides

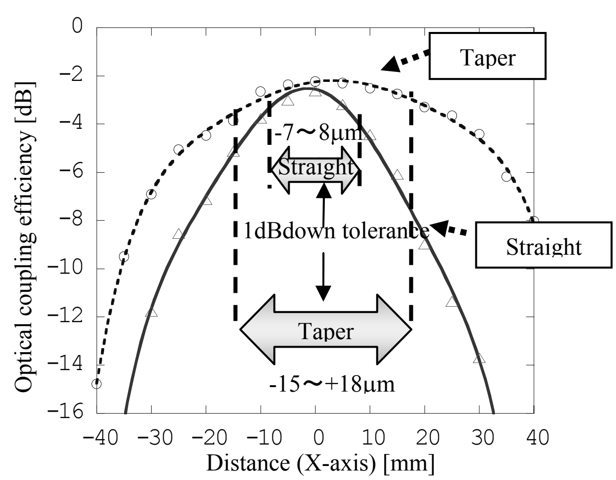


Fig. 18 Observed tolerances

5.3 Self-Written Connection between Optical Waveguides having V-slot

In the optical interconnection of board level, 45-degree micro mirrors are used to achieve 90-degree optical path change. These mirrors are often fabricated by using a rotating blade and this method has a serious problem of cutting other waveguides in the vicinity.

We have proposed SWW (Self-Written Waveguide) connection between 45-degree mirrors of waveguides, as shown in Fig. 19 [13]. The spacing gap between 45-degree mirrors is connected by SWW. SWW is fabricated by the same method as conventional SWW connection between flat face optical wirings. First, the spacing gap is filled up with curing resin having refractive index similar to that of the optical waveguide. Then, a laser beam is irradiated from the 45-degree face of waveguide. As a result, high efficient optical connection will recover even if waveguides are cut by a rotating blade. Therefore micro mirrors can be fabricated at specific points.

As an example, we performed SWW connection between V-slot polymeric waveguides. The structure of sample is shown in Fig. 20. The spacing gap between V-slot waveguide was set to be 60-140 μm and SWW was fabricated using a green laser and dye-mixed UV curing resin which had an absorption peak around 532nm. The picture of fabricated SWW part is shown in Fig. 21. The optical coupling efficiency of SWW connection was improved dramatically. We confirmed high efficient optical coupling between V-slot waveguides is possible by this proposed method.

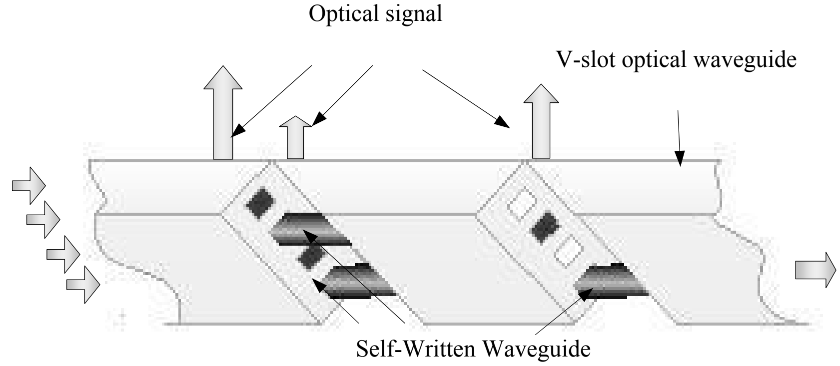


Fig.19 V-slot optical waveguide using Self-written waveguide

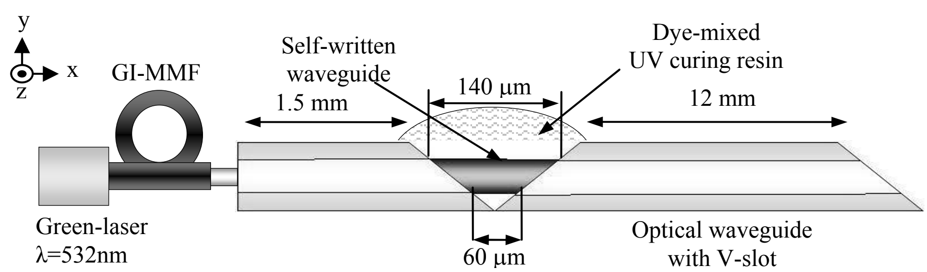


Fig.20 Experimental setup

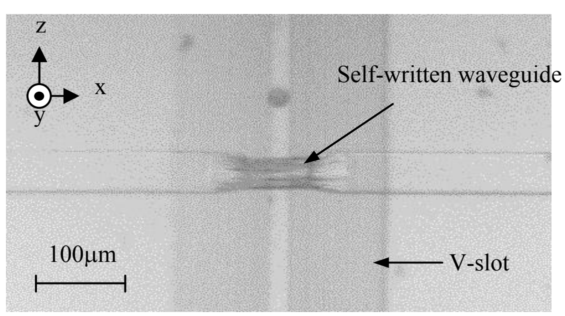


Fig. 21 SWW Connection point（Camera1）

5.4 Multi-array Self-Written Waveguides using Mask-Tranfer Method

Conventionally, SWWs have been fabricated by irradiating UV light from fibers and/or waveguides. In the case of optical connection between multi-array wirings and devices in OE-boards, it seems difficult to fabricate multi-array SWWs only by irradiating UV light from a single fiber. We have proposed a novel fabrication method of multi-array SWW using a photo-mask (named Mask-transfer Method) [14,15]. UV light is irradiated onto the photo-mask and multi-array SWWs can be formed at the same time all together. SWW has a cross- section very close to the used apertures. An outline of the fabrication method is schematically shown in Fig.22. One dimensional as well as two dimensional array can be easily fabricated.

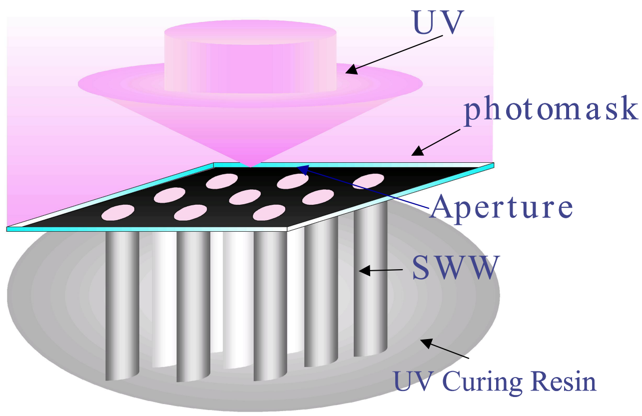


Fig. 22 Fabrication method of Mask-transfer SWW

The used masks were a thin aluminum plate and a glass plate coated with a chromium film. Their thickness was 1mm. The aluminum plate had hole-arrays with a diameter of 1mm. The chromium mask had disk patterns (diameter: 50 and 100 μm) and square patterns (50×50 μm and 100×100 μm), with a period of 250 μm. Commercialized radical-type UV curable resin was applied as a photo- polymerization resin. UV light, having a main wavelength of 365 nm and optical power of 465 mW/cm^2, was irradiated. In the experiment, the photo-polymerization resin was inserted into a spacing gap between the mask and a glass plate so that the length of SWW was controlled by the spacer thickness of 0.2, 0.5 and 1.0mm. The glass plate has a role of acting as an end face of optical wiring in SWW forming process. Two examples of fabricated MA-SWWs using a 0.5 mm spacer and a chromium mask (squares; 100×100 μm and disks of a diameter; 100 μm) are shown in Fig.23.

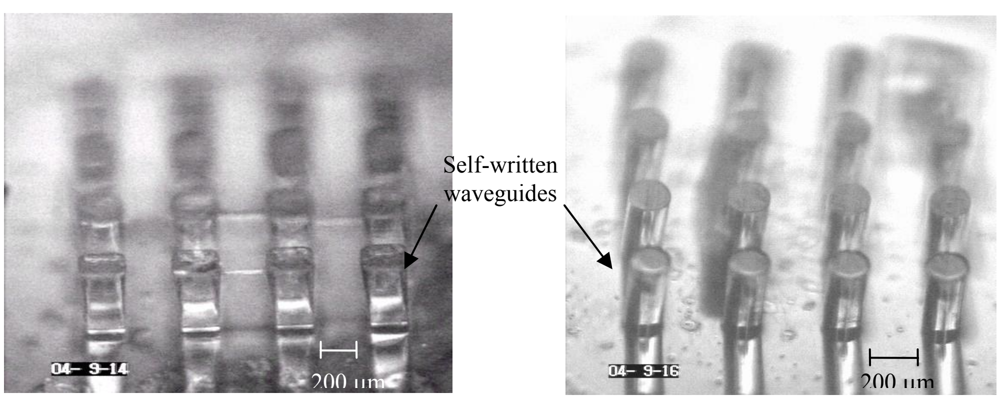


Fig. 23 Fabricated SWW by mask-transfer using disk patterns

Application of multi-array SWWs to 3-D optical wirings has been proposed, as shown in Fig.24. Here M channel optical wirings are formed in N layers. That is, MxN channels are included in the substrate. By mask-transfer method, UV light is irradiated onto the mask placed on the substrate so that the air gap between optical wirings and the substrate surface are can be connected all together by SWWs. Filling air gaps with another curable resin is effective to mechanically stabilize the connection. By connecting between devices on the substrate and wirings by SWW, it will be not necessary to consider the beam divergence even if the optical path length becomes long.

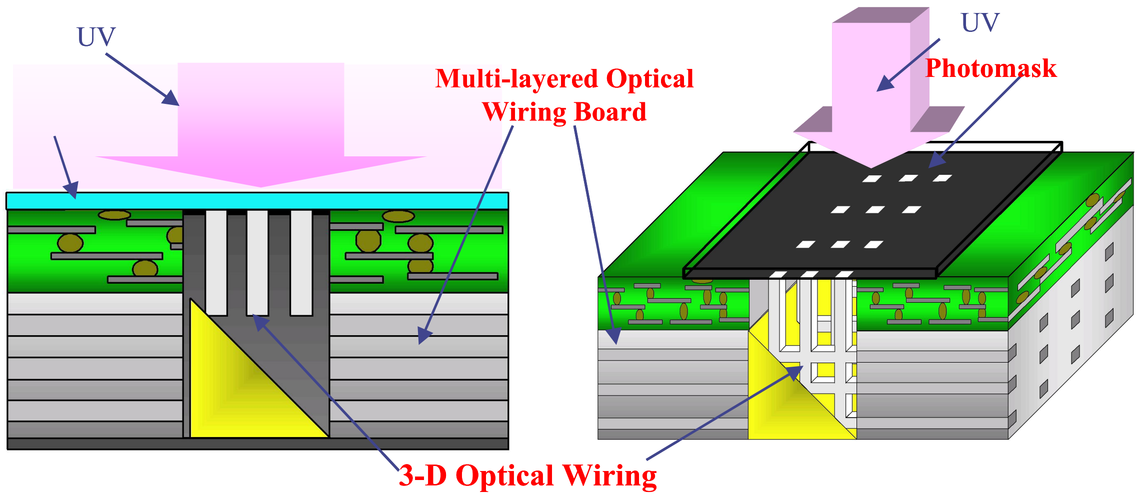


Fig.24 Proposed model by mask-transfer SWW to 3-D optical wiring

6. CONCLUSION

Introduction of "Optical wiring" into the Printed Wiring Board (PWB) level ("last 1 meter area") was investigated to overcome conventional electrical copper-based bandwidth limitations. Optical Surface Mount Technology (O-SMT) which can be one of possible solutions in this field is reviewed. Several experimental trials to verify the feasibility have suggested that a new interface based on optical pin has a high potentiality for drastically reducing man-hours for optical device mounting on OE-PWBs. Furthermore, it is demonstrated that optical soldering technology using Self-written waveguides is great promising to reduce the alignment difficulties. Mask-transfer method of Self-written waveguide has a further possibility of unique applications. The electronic wirings and optical ones are likely to co-exist on boards of the IT (Information Technology) equipments in the near future. Organic sharing these two is important in achieving the final goal.

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