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Investigations on Optical Coupler by Embedded Micro-Mirrors on Optical Wiring Boards

Toru Nakashiba, Hiroyuki Yagyu, Shinji Hashimoto, Tomoaki Matsushima and Kouhei Kotera
Matsushita Electric Works, Ltd.
Osaka, Japan

Abstract

In order to cope with a rapid increase in information processing speed, additional technical developments of an optical-electrical composite board are required. Generally speaking, it is more difficult to interconnect between optical devises and optical lines than between electrical devises and electrical lines, and this fact is one of the reasons why it is big challenges to put these boards to practical use. In this paper, we have investigated on this problem using an Optical Wiring Board (OWB) prototype with embedded micro-mirrors. The OWB prototype is consisted of polymeric multimode optical waveguides layer in conventional PWB and micro-mirrors that is embedded at the both ends of the optical waveguides. The height of the mirrors is the same as that of optical waveguides, and optical signal pass between optical waveguides and the board surface vertically through an upper cladding layer. We first calculated coupling efficiency of mirror by ray tracing method, and we found that mounting tolerance on optical misalignment for 1dB loss is plus or minus 10 microns. The calculated results were also supported by measurement using OWB prototype. We concluded that the OWB with the embedded micro-mirrors as the optical coupler is promising for a future practical application.

Introduction

In a recent advanced information-oriented society, a large amount of digital data such as a stream for motion pictures is often exchanged even in personal use. In order to cope with the situation, the equipments for information processing like personal computers and communicating routers are required to have higher performances and larger data capacity, on the other hand, the problem of EMI (Electro Magnetic Interference) or cross talk of the signals on the PWB inside become non-negligible. As one of the solutions of these problems, an optical wiring technique in the PWB has been widely investigated recently. An optical wiring board is anticipated to be a substitute for PWB in the future because it has very wide transmission bands and non-inductiveness, but higher costs make it big challenges to put the technique to practical use. One of the cost factors is difficulty of an optical coupling that is an interconnection between optical devices and lines. Generally speaking, the optical coupling is more difficult to achieve than an electrical coupling interconnection between electrical devices and lines, because optical waves see loss by scattering and do not have easy connecting methods like the soldering techniques for the electrical coupling. With these points as backgrounds, a variety of optical coupling methods are investigated, e.g. grating couplers,[1] micro-mirrors,[2, 3] butt-couplings, etc. Each has its own merits and demerits.

We take aim at developing a low cost optical-electrical composite board that is characterized by using a conventional PWB process like a lamination molding, surface mounting, etc. And we have determined that an optical layer consisting of multimode waveguides as signal lines and micro-mirrors as optical couplers is the best selection for this purpose.

Investigations on a Fabrication Process of Micro-Mirrors

Firstly we investigated the fabrication process of micro-mirrors. We have tried two methods for fabricating micro-mirrors for OWB: a fine molding method using a metal mold with V grooves and an etching method by a laser ablation or a cutting with 45-degree V shaped blade. The outlines of each method are shown in Figure 1. Our final goal is to put the Etching method into practical use because this method is easy to integrate into a PWB process. But, on the other hand, for a small size application like packages, the molding method has an advantage because of its high reproducibility. Each method has its own merits and demerits.

We tried fabricating micro-mirrors embedded in optical waveguides by these methods, and evaluating the mirrors by observation with a scanning electron microscope and measurement of a mirror surface roughness. We used a very fine metal mold manufactured by novel micro-nano machining for the molding method. The electron micrographs of the fabricated mirrors are shown in Figure 2. The data orf surface roughness measurements is 50 nm [RMS] for the fine mold method and 120 nm [RMS] for the etching method. These data show that the surface of the mirror made by fine molding was smoother than that by etching method that which produces lots of microscopic roughness on the surface. This etching roughness is from tool marks of the cutting blade. In case of a laser ablation process, it is well known that the microscopic structures peculiar to laser ablation for polymeric material will also be present.[4] So it is more difficult to fabricate a smooth surface by the etching process than the molding process.

Based on this we decided to evaluate micro-mirrors, embedded in OWB, fabricated by the molding method.

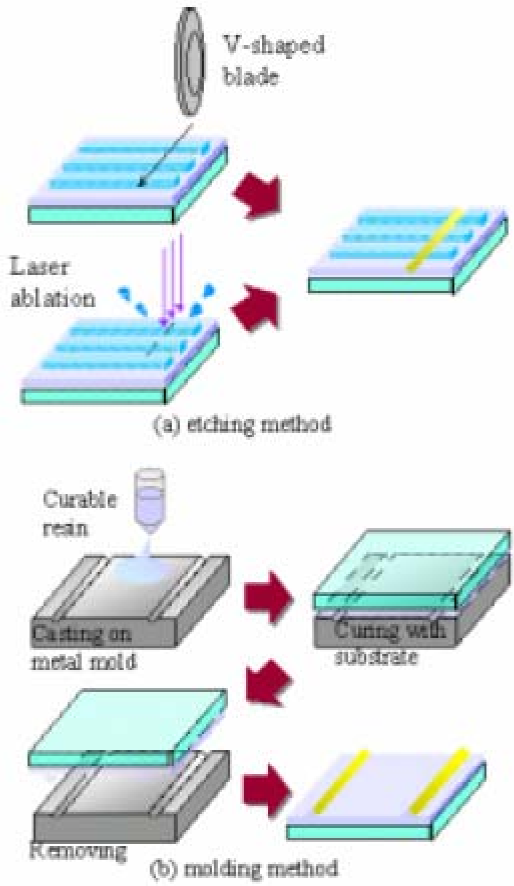

Figure 1 - Outlines of Mirror Fabrication Processes

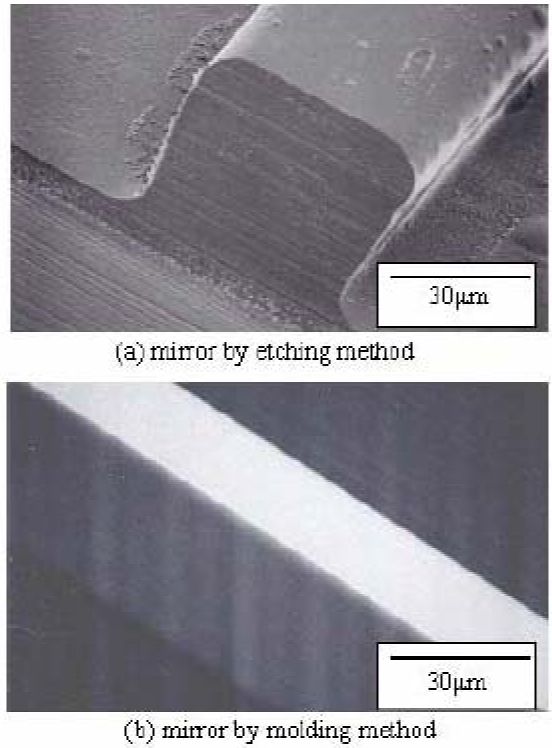

Figure 2 - Electron Micrographs of the Mirrors

Numerical Simulations of Mounting Tolerance

Before the fabrication of the OWB, we calculated the coupling efficiency of waveguide mirrors by a ray tracing method, and predicted a tolerance on optical misalignment for 1 dB coupling loss. The larger the cross section of a waveguide core is, the wider the mounting tolerance is. But too large of a cross section narrows a transmission bandwidth and makes it difficult to select the proper PD chip. We determined the size of core to be 40 by 40 microns, and upper cladding layer's thickness to be 20 microns which should be thick enough to confine a guiding mode. We determined the difference of refractive indices between the core and the cladding layer to be 1.3 %, which corresponds to about 8 GHz in a transmission bandwidth. The drawing of simulation model is shown in Figure 3. The incident beam was 14 microns in initial diameter and radiated toward the mirror with divergent angles of 25 degrees (Full width, 1/e2). The gap between the radiant plane and the surface of the upper cladding layer was 40 to 100 microns. These conditions were set in consideration of flip-chip mounting of VCSEL with solder bumping. The reflectance of the mirror was 100% and all the other loss factors were neglected for simplification. The calculation results are shown in Figure 4. The graph shows that the tolerance on optical misalignment for 1dB loss is about 10 microns or more with all tested gaps along both X and Y axis.

Recently even general flip-chip bonder can mounts circuit elements on PWB with misalignments by lower than 10 microns. The calculation result shows that the designed structures are possible with conventional PWB processes.

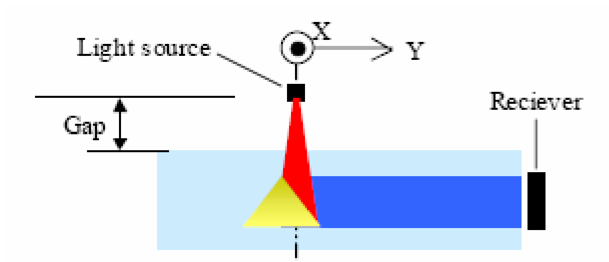

Figure 3 - Drawing of Simulation model

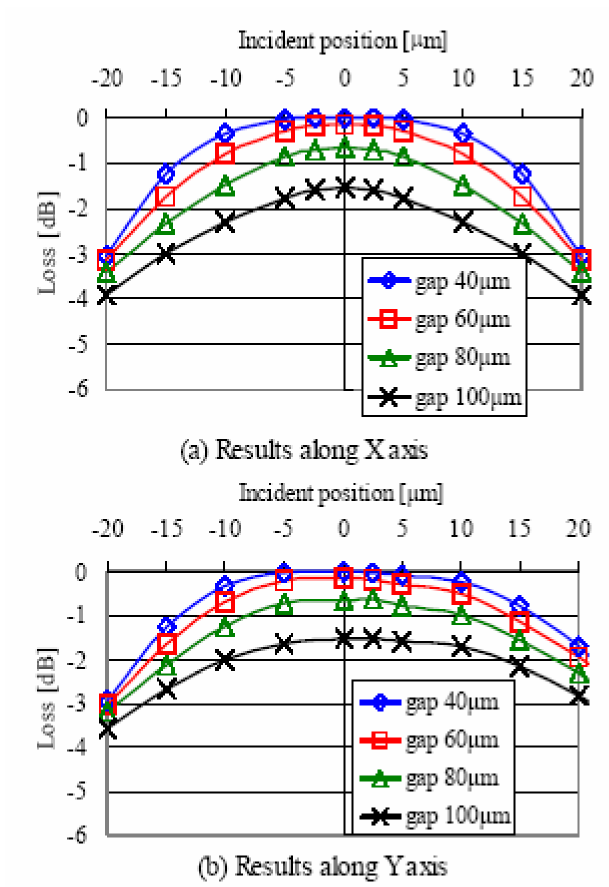

Figure 4 - Result Charts of Calculation

Fabrication of OWB Prototype

We tried fabricating the OWB prototype with embedded micro-mirrors using the fine molding method. The layer structure of the produced OWB prototype is shown in Figure 5. An optical wiring layer is embedded in a conventional PWB. The optical layer was consists of 50 to 100 millimeter length optical waveguides and micro-mirrors embedded at the both ends of the waveguides. The other dimensions of optical layer and the difference of the refractive indices were controlled for the same conditions as the simulation model. In order to improve reflectance, Au coating was formed on a reflecting surface of the mirrors. The process flow chart of the prototype is shown in Figure 6, and a brief description will be given in due order below.

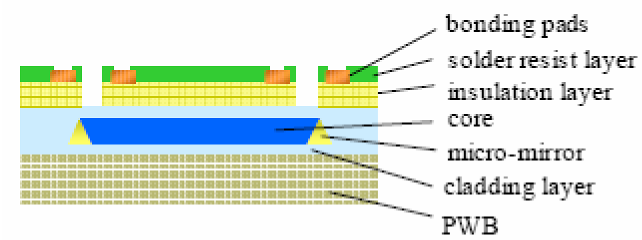

Figure 5 - Schematic Diagram of Layer Structure

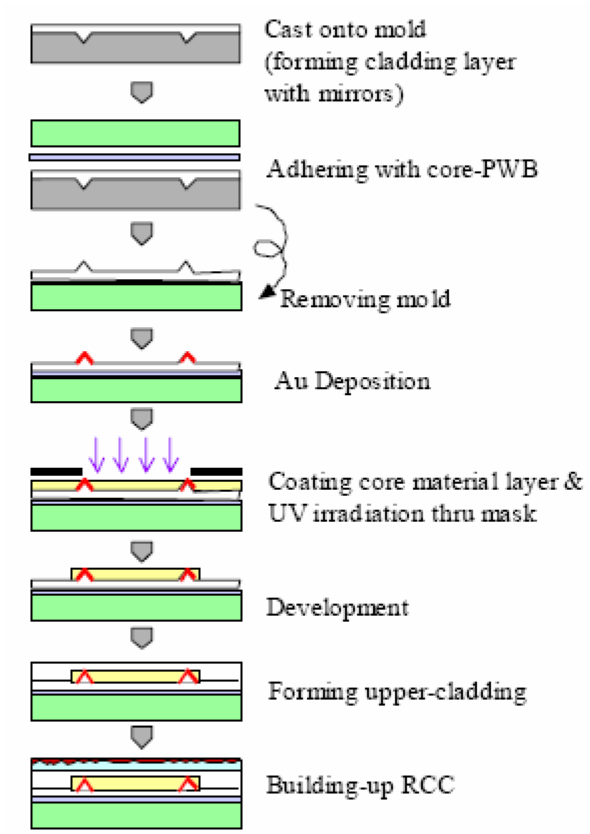

Figure 6 - Flow Chart of Fabrication Process

Firstly the photo-curing resin for an optical cladding layer was cast on the metal mold with V grooves and cured by UV irradiation. Next the cladding layer formed on the metal mold was transferred on the core-PWB. The both were attached with thermosetting epoxy resin. After that an Au coating of 0.17 microns thickness was formed on the reflecting surface of the micro-mirrors by electric beam evaporation. A core layer was patterned on the cladding layer by photolithography method and covered by another cladding layer. Finally a resin coated cupper (RCC) layer was laminated by lamination molding under a high temperature and pressure, and patterned by a conventional process.

The resin for the waveguide was our original transparent epoxy resin and its absorption loss was 0.06dB/cm at 850mn. The glass transition temperature (Tg) is about 160 degrees centigrade, which is supposed to be enough high to put the resin into thermo molding for PWBs.

The external appearance of the resulting OWB prototype, which includes 50 millimeters length waveguides, is shown in Figure 7. The cross section of the optical layer, the top view of optical I/O part and optical I/O part with light radiating are showed in Figure 8, Figure 9 and Figure 10, respectively.

Figure 7 - External Appearance of the Fabricated OWB [waveguide length: 50 mm]

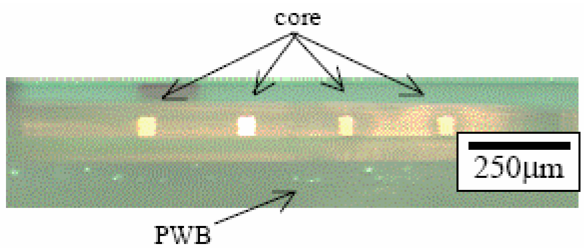

Figure 8 - Cross Section of Optical Layer

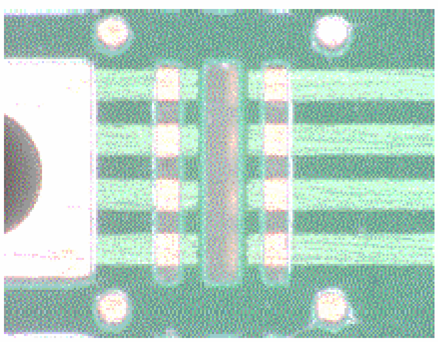

Figure 9 - Top View of Optical I/O Part

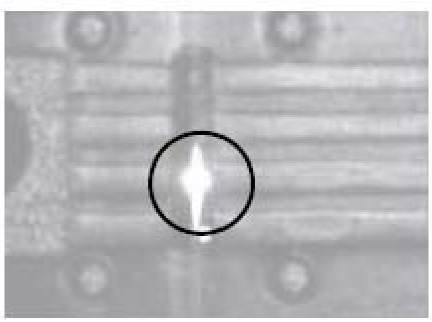

Figure 10 - Output Light from OWB

Evaluations by Optical Measurement

We evaluated the produced OWB prototype for optical performance. First, we carried out a transmission test for the embedded optical layer with an experimental setup shown in Figure 11. An 850nm LED was used as light source and incident vertically on the micro-mirror of the OWB through an optical fiber. The diameter of the core is seven micron and the numerical aperture is 0.22. The light source and fiber were selected in consideration of the optical characteristic of VCSEL. The incident light propagated through the embedded waveguide, and reflected again on the other micro-mirror vertically out of the OWB. We measured an insertion loss from the intensity of the output light. The core of the receiving fiber is 100 microns in diameter, and the numerical aperture of the fiber is 0.26. We also plotted a near field pattern and a far field pattern (NFP&FFP) from the intensity profile and the divergence angle profile of the output light.

Secondary, we evaluated the micro-mirrors as optical couplers for the possibility of mounting with flip-chip bonding technology by measuring misalignment tolerance for 1 dB loss. We used the same experimental setup as the transmission test. The measurement was carried out by plotting the intensity of output light against the incident position that is scanned horizontally with the input fiber. The incident position was scanned in the X and Y directions shown in Figure 11. The gap between the fiber edge and the OWB surface was varied from 40 to 100 microns by 20 micron increments.

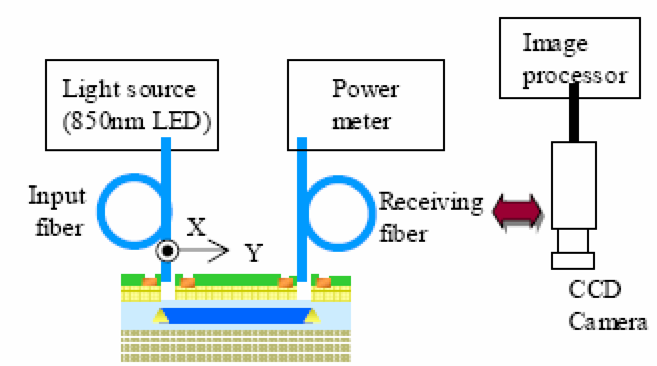

Figure 11 - Experimental Setup

The insertion loss obtained was 3.6 dB. This is a favorable result considering that the value includes other loss factors like a propagating loss. The diagrams of NFP and FFP are shown in Figure 12 and Figure 13. Full width $1/e^2$ is about 40 microns for NFP, which is well matched with designed the dimensions. Along the Y-axis, the intensity varied monotonously. This phenomenon probably relates that the distance between an observation point and a mirror surface is different along the axis. For FFP, full width $1/e^2$ is about 19 degrees. From the value, the difference of the refractive indices is calculated to be 0.07%. This value is smaller than designed value: 1.3 %. But, from the first, the definitions are different between measurement value and designed value, so we cannot simply compare the both. From these results it is no exaggeration to say that the optical layer keeps functioning proper after exposure to the high temperature and pressure of PWB fabrication process.

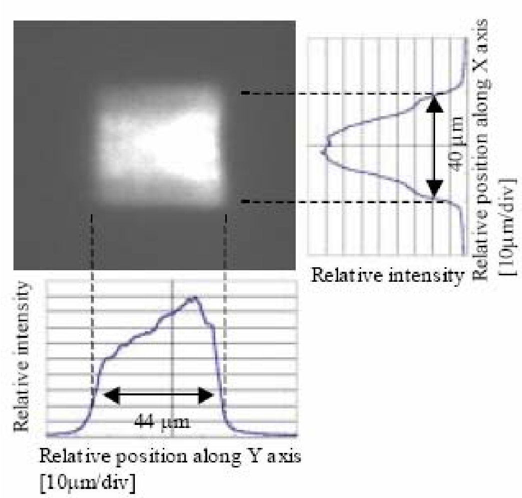

Figure 12 - NFP Diagram of Output Light from OWB

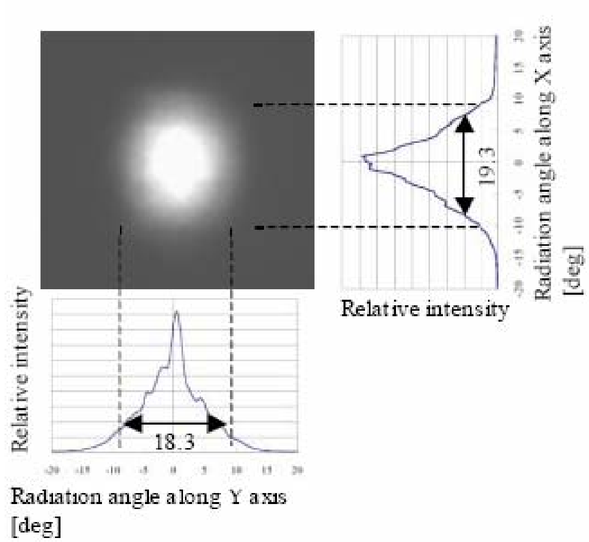

Figure 13 - FFP Diagram of Output Light from OWB

Figure 14 shows the results of mounting tolerance measurements. Let the loss at zero misalignments with 40 microns gap be zero dB for convenience. Although the tolerance for 1 dB loss became a little smaller than the calculation data, generally it is proved that there is at least plus or minus 8 microns for that value from the results along X-axis. A trend of the plot curve of the measurement results is almost same as the calculation data. The reason why the tolerance has got smaller is probably that the neglected loss factors in the calculation, for example, a propagating loss, an absorption loss of mirrors, etc. has increased the total loss. At any rate, it is readily achievable, with current flip-chip bonders, to mount devices with the misalignment kept within the value we have obtained here. This is very favorable for practical use of OWBs in the future.

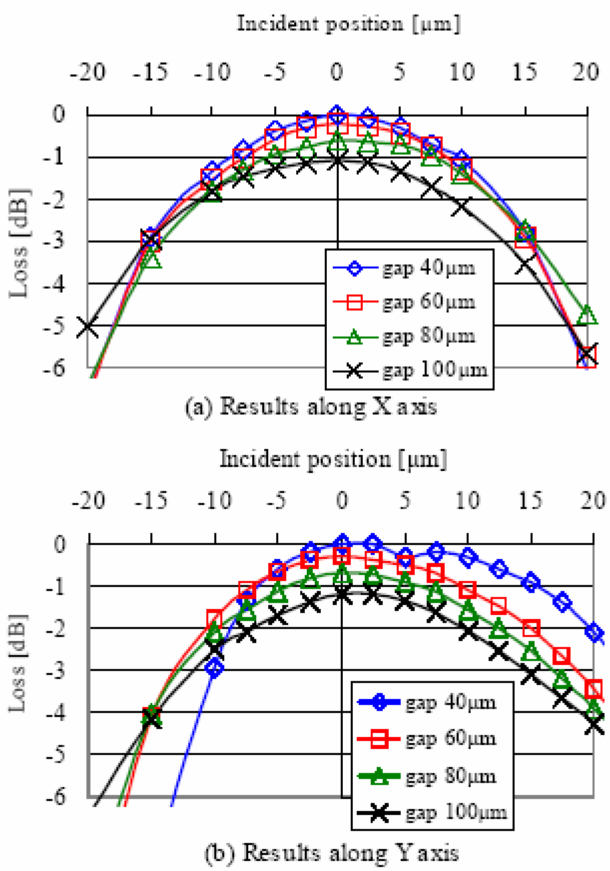

Figure14 - Result Charts of Mounting Tolerance Measurement

Summary
We concluded that the OWB with the embedded micro-mirrors as the optical coupler is promising for practical applications. We produced the OWB prototype, which was characterized by the polymeric multimode optical waveguides layer within a conventional PWB, by the method of fine molding process. We proved by a transmission test that the optical layer keeps proper functions after exposure to a high temperature and pressure of conventional PWB fabrication process. We further measured mounting tolerance on conditions of flip-chip VCSEL bonding, and proved that recent flip-chip mounting technology was adequate to realize a practical optical I/O.

We mentioned that our final goal is putting the Etching method to practical use because of easiness to integrate into a PWB process. We will carry out further investigation on a low cost process for OWB based on the etching method.

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