A Novel Packaging Method of Fully Passive Optical Alignment for Multi-Channels Optical Interconnection Module

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Abstract—In this paper, a novel packaging method of fully passive optical alignment and surface mounting for parallel optical interconnects modules has been developed for a high-capacity data transmission such as chip-to-chip and board-to-board interconnects within smart device and interconnects between devices.

Keywords—packaging method; passive alignment; optical interconnect; multi-channel

I. INTRODUCTION

The requirements for reducing the cost, volume and dissipated power consumption of the optical interconnection modules are also growing strongly according to increasing the required bandwidth. The effective ways to realize the reduction in cost, volume, and power consumption of an optical interconnection module are to increase the integration of optics, simplify the module structure, and reduce the number of parts. These methods can be an attractive and cost effective approach for satisfying these requirements. And the demand of more than 40-Gbps high capacity optical parallel interconnection modules continues to increase rapidly. In recent years, the research for very short reach optical interconnects for device-to-device, board-to-board, and chip-to-chip interconnects has been actively conducted.

There are two different approaches for manufacturing of optical interconnection modules. One is based on the monolithic integration of optical and electrical components such as laser diode (LD), photo diode (PD), waveguide, modulator, amplifier on Si wafer using complementary metal oxide semi-conductor (CMOS) and silicon photonics technologies [1-3], and the other is based on the hybrid integration using passive surface mounting technologies [4-6]. The monolithic integration approach is seems to be superior than the hybrid integration approach, but the developing cost based on the former is very high. The merits of the hybrid integration approach can use the latest commercial miniaturized components and can be realized in reduction of developing cost if all optical components as well as electrical components can be attached on a wafer using wafer-level fully passive surface mount techniques.

In this paper, a novel packaging method of fully passive optical alignment and surface mounting for parallel optical interconnects modules has been developed for a high-capacity data transmission such as chip-to-chip and board-to-board interconnects within smart device and interconnects between devices. The measured optical direct butt coupling efficiencies of each channel without any optics are more than 33% for transmitter and 95% for receiver respectively. This passive surfacemounting approach can be promised to realization in reduction of the size and developing cost of multi-channel optical interconnects modules and can be easily extended the number of channels for a sub-tera-bit per second optical system.

Fig. 1. Proposed multi-channel optical interconnection module

II. DESIGN OF MULTI-CHANNEL OPTICAL MODULE

A. Design of compact optical interconnection module

Typically multi-channel optical modules based on a VCSEL which is a kind of vertical emission laser diode use a micro-lens array for optical coupling between a VCSEL array and an optical fiber array after optical beam path conversion of 90 degree by using a mirror having a 45 degree inclined facet. In the case of using a micro-lens array for optical coupling between optical device such as VCSEL and PIN-PD and optical fiber, it is not easy to avoid an active optical alignment process to achieve the required fiber optical...
coupling efficiency and also not easy to reduce the number of parts and the unit price of optical interconnection module due to the expensive alignment processes as well as the material and manufacturing cost. And the structure of optical module is somewhat complicated.

The effective ways to solve these problems and achieve the reduction in cost, volume, and power consumption of an optical interconnection module are to simplify the module structure, use the passive optical alignment process, and reduce the number of parts. In order to satisfy these requirements for manufacturing a more than 40-Gbps multi-channel optical interconnection modules, we have designed the simple structure of parallel optical module and reduce the number of parts and manufacturing processes using fully passive optical alignment technique based on a direct butt coupling scheme without applying power to the modules and well-defined surface mounting techniques in the field of microelectronics packaging. A novel fully passive optical alignment packaging method using surface mounting techniques has been developed for a high-capacity data transmission such as chip-to-chip and board-to-board interconnects within smart device and interconnects between devices.

Figure 1 shows the conceptual structure design of the proposed axial type compact optical interconnection module. As shown in Fig. 1, the proposed optical interconnection module has a very simple structure based on the direct butt coupling scheme without any micro-lens array in order to reduce the packaging and material cost. This simple structure can realize the fully passive optical alignment compact optical module by using the passive surface mounting techniques and reduce the unit price of optical module. The volume of proposed compact optical module is 13.0 (L) x 8.4 (W) x 4.6 (H) mm$^3$.

### B. Design of the structure and fabrication processes

The considerations for the structural design of the optical module are low cost and high performances. The keywords we have to consider to realize a low cost and high performance optical module are mass production, easy to make, no lens array, passive optical alignment process, operation of data rate up to 25 Gbps, and easy to extended up to 12 channels for a future sub-tera-bit per second optical system.

We used the wet etch technique for implementation of the cavity of Si platform using a high resistivity silicon (HRS) wafer. The resistivity of the used HRS wafer is about 10 kΩ·cm. The size of the cavity can be adjustable with the number of channels and the shape of the FAB. The height of the cavity of Si platform is 300 µm. Due to the thickness of the VCSEL/PIN-PD array, the space between top of the array chip and the end of the FAB is 150 µm.

Figure 2 shows the fully passive optical alignment process between the cores of VCSEL/PIN-PD array and the cores of the MT ferrule using an UV epoxy without applying power to the VCSEL/PIN-PD array. Figure 3 shows the optical image of MT ferrule after attaching the Si platform. This passive surface mounting approach can be promised to realization in reduction of the size and developing cost of multi-channel optical interconnects modules and can be easily extended the number of channels for a future sub-tera-bit per second optical system.

**C. Design of a non-planar differential transmission lines**

Figure 4 shows the coupled differential transmission lines on the silicon platform and port setting for calculation of the electrical characteristics. We use the CST2006B 3D EM solver for analysis. The designed differential characteristic impedance is about 100 Ω. The designed transmission lines are non-planar shape according to the surface of the etched Si platform. As shown in Fig. 4, there are two bonded wires to interconnect between VCSEL/PIN-PD array and the TX/RX-IC respectively.

![Fig. 2. Fully passive optical alignment process between the cores of VCSEL/PIN-PD array and the cores of the MT ferrule using UV epoxy.](image)

![Fig. 3. Optical image of MT ferrule after attaching the Si platform.](image)

![Fig. 4. Shematic view of a non-planar coupled differential transmission line on Si platform.](image)
The measured optical direct butt coupling efficiencies of both transmitter and receiver modules are optimum fiber position with an alignment tolerance of about 60 µm for axial axis and 113 µm for lateral axis. We obtained the more than 8 dB of extinction ratio for transmitter module and less than -13 dBm at BER 10^{-12} of minimum sensitivity for receiver module.

### IV. Conclusion

A novel packaging method of fully passive optical alignment and surface mounting for parallel optical interconnection modules has been developed for a high-capacity data transmission such as chip-to-chip and board-to-board interconnects within smart device and interconnects between devices. The measured optical direct butt coupling efficiencies of each channel without any optics are more than 33 % for transmitter and 95 % for receiver respectively. We also obtained the more than 8 dB of extinction ratio for transmitter module and less than -13 dBm at BER 10^{-12} of minimum sensitivity for receiver module. This passive surface mounting approach can be promised to realization in reduction of the size and developing cost of multi-channel optical interconnects modules and can be easily extended the number of channels for a sub-tera-bit per second optical system.

### References


