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An Efficient Optical Coupling Method for Multilayer Optical Printed Circuit Boards

Y. Matsuoka, T. Ban, T. Shibata*, A. Takahashi*, and M. Shishikura

Central Research Laboratory, Hitachi, Ltd., 1-280 Higashi-koigakubo, Kokubunji-shi, Tokyo 185-8601, Japan

** Advanced Materials R&D Center, Hitachi Chemical Co., Ltd., 48 Wadai, Tsukuba-shi, Ibaragi 300-4247, Japan*

TEL:+81-42-323-1111, FAX:+81-42-327-7673, E-mail: yasunobu.matsuoka.av@hitachi.com

Abstract

An efficient optical coupling method has been developed for multilayer optical printed circuit boards. Excess coupling loss of less than 0.2 dB in a two-layer waveguide was achieved using the proposed cube-core optical confinement structure.

Introduction

The rapid increase in data processing in routers and servers requires higher speed and larger capacity interconnections. Optical interconnections are suitable for such a high bandwidth signal transmission because they have both a low propagation loss and a small inter-channel crosstalk even at a data rate of 10 Gbit/s or higher [1-3]. In particular, a large number of wirings more than a thousand will be needed to achieve Tbit/s-class interconnection; thus, a multilayer optical printed circuit board (OPCB) using a polymer waveguide is advantageous to such high-density inter-connection. With the multilayer OPCB, maintaining the high coupling efficiency between the optical device and the waveguide, especially the lower layer, is very difficult because the insertion loss increases due to the spread of the light beam. To solve this problem, an effective optical coupling structure using optical micro-lenses has been reported [4]. In this paper, we propose an efficient optical coupling method using a newly optical confinement structure called a cube core. The excess optical coupling loss of less than 0.2 dB in a two-layer waveguide has been demonstrated in the fabricated OPCB.

Structure and analysis

Figure 1 shows the structure of the multilayer OPCB. It consists of multilayer multimode polymer waveguides on an FR-4 substrate, 45-degree mirrors, and optical I/O packages that integrate a vertical cavity surface-emitting laser (VCSEL) or photo diode (PD) and an IC. A light beam from the VCSEL propagates in a vertical direction to the board, and is coupled to waveguides after being reflected by the 45-degree mirror.

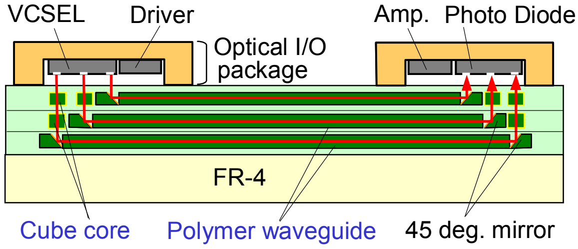
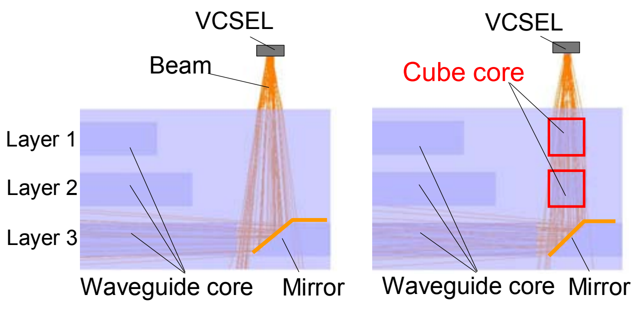


Fig. 1 Structure of the multilayer OPCB

In this structure, the insertion loss between the VCSEL (or PD) and the lower waveguide layer increases as the number of layers increases. To solve this issue, we proposed a cube-core structure made of the same material as the waveguide core. The proposed optical coupling system using the cube-core structure is illustrated in Fig. 2. As shown in Fig. 2 (a), with a conventional optical coupling system without the cube core, the spreading light beam from the VCSEL extends past the mirror that is mounted on layer 3; thus, excess loss increases. With the proposed cube core shown in Fig. 2 (b), the beam spread is confined in the high-refractive-index cube-core structure, which is formed just above the mirror. Therefore, the optical coupling efficiency in a multilayer OPCB can be improved with the proposed optical coupling method using the cube-core structure. Further, this cube core can be simultaneously formed in the same process as the upper-layer waveguide core. Thus, it also has the advantage of being less-costly to manufacture.



(a) Conventional optical coupling system

(b) Cube-core optical coupling system

Fig.2 Proposed optical coupling system

The effect of our proposed cube-core structure was confirmed in an optical simulation of the ray-tracing method. Figure 3 plots the simulated results of optical coupling efficiency between the VCSEL and the waveguide with and without the cube-core structure. These results show that the excess optical coupling loss that occurs when increasing the number of waveguide layers from one to two is very low, less than 0.2 dB, with the cube core, compared to 0.8 dB without the cube core. Furthermore, the excess loss at three layers is estimated to be less than 0.5 dB compared to 2.0 dB without the cube core. These results indicate that our proposed cube-core structure provides effective optical coupling for the multilayer OPCB.

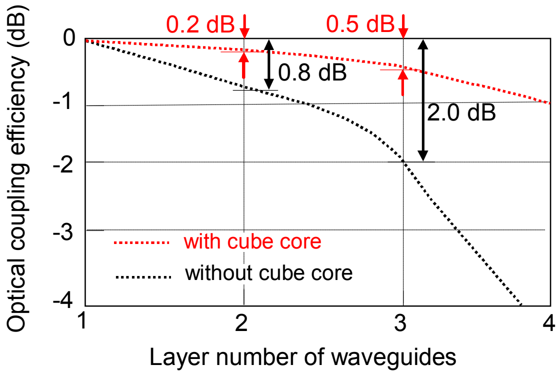


Fig. 3 Simulated results of optical coupling loss versus layer number of waveguides

Fabrication

To verify the effectiveness of this structure, we fabricated single or double-layer waveguides with the cube core on FR-4 substrates. A photo image of the fabricated OPCB is in Fig. 4. The waveguide core using photosensitive polymer material was fabricated on a FR-4 substrate by film lamination and UV photolithography, which are suitable for conventional PCB fabrication. The cube core was formed just above the mirror in the layer-1 waveguide.

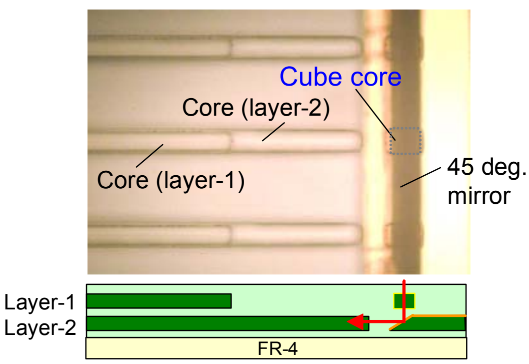


Fig. 4 Photo image of the fabricated OPCB

Experimental Results

Figure 5 plots the measurement results of the optical coupling efficiency between the VCSEL and layer 2 optical waveguide in a two-layer OPCB. The black line indicates the coupling efficiency of the single-layer waveguide, and the red and blue lines are those of the two-layer waveguides with and without the cube-core structure. The optical coupling efficiency with the cube core was about -1.3 dB compared to that of -1.9 dB without the cube core. The excess loss by using the cube-core structure was suppressed to as little as 0.18 dB from one to two layers compared to 0.82 dB without the cube core. The 1-dB optical coupling tolerance was also improved from +/- 13 μm without to +/- 17 μm with the cube core. These measurement results of the coupling efficiency in a two-layer waveguide are nearly agree with the simulation data, as shown in Fig. 3. This indicates that the excess loss can be further improved by the cube core in cases where there are more than three layers.

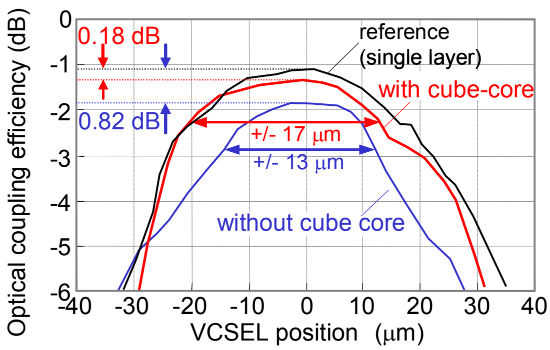


Fig. 5 Optical coupling efficiency between the VCSEL and layer-2 waveguide (2-layer OPCB)

Conclusion

We proposed an efficient optical coupling method using a cube-core optical confinement structure integrated into a multilayer OPCB. With this structure, we succeeded in suppressing excess optical coupling loss to less than 0.2dB in a two-layer waveguide. This OPCB is suitable for large-capacity optical interconnections.

References

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