Optical Through-Hole With High Aspect Ratio for On-Board Optical Transmission

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Abstract: We developed optical I/Os in packages for chip-to-chip interconnections. The I/Os of 55-µm-diameter and 1.2-mm-long optical through-holes demonstrate low loss and 10-Gb/s transmission. This package aims at future CPU systems with embedded capacitors.

OCIS codes: (200.0200) Optics in computing; (200.4650) Optical interconnects

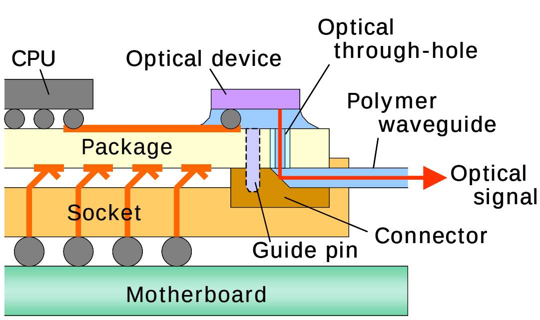
1. Introduction

High-speed and multi-CPU operations are required in high-end systems such as supercomputers and routers. In order to achieve these requirements, some problems should be solved in both signal integrity and power integrity.

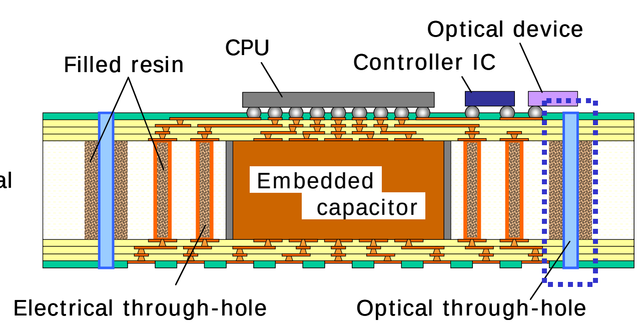
The main issue in the signal integrity is the limit of input/output (I/O) bandwidth for the CPUs because of transmission loss and crosstalk that result from copper transmission lines. Low-loss, low-crosstalk, and high-speed optical interconnections are developed with multi-channel optical waveguides instead of the copper lines [1, 2]. We have developed optoelectronic packages with the optical I/Os shown in Fig. 1(a) [3, 4]. On the other hand, in order to solve the power integrity problems, future packages necessitate mitigating IR drop of power supply plane and improving the power delivery to the CPUs. For these purposes, a package with a built-in capacitor is developed [5]. The capacitor, which is a bulk array ceramic capacitor, is located under the CPUs and embedded into a core substrate of an organic package.

These technologies of the optical interconnection and the embedded capacitor should be combined. In the near future, the package that has optical I/O ports and the embedded capacitor will be required. For the optical I/O ports, surface-type optical devices such as vertical-cavity surface-emitting lasers (VCSELs) are useful and effective because of their low cost. We have flip-chip-mounted the optical devices on substrates of 0.4-mm thick and demonstrated 10-Gb/s chip-to-chip optical transmissions using the optical through-holes of less than 100 µm in diameter [3, 4]. However, the 0.4-mm thickness of the substrate is insufficient to embed the capacitor inside. Therefore, the chip-to-chip optical technology field demands techniques to fabricate high-aspect optical through-holes through the substrate with over 1-mm thickness as shown in Fig. 1(b).

In this paper, we have developed 55-µm-diameter and 1.2-mm-long optical through-holes depicted in the broken line of Fig. 1(b). Each optical through-hole has a core and a cladding layer like an optical fiber to enhance coupling efficiency. Optical characteristics for high-speed chip-to-chip interconnections are evaluated. This substrates aim at future packages with the embedded bulk array capacitors used for the power delivery to the CPUs.



(a)



(b)

Fig. 1 Cross-section of proposed optoelectronic package. (a) Overall structure. (b) Package with optical I/Os and embedded capacitor for power delivery.

2. Fabrication and performance of optical through-holes

We have fabricated optical through-holes shown Fig. 1(b). Fig. 2 describes a production procedure using microdrilling. 1. The fabrication of the 1.2 mm high-aspect through-holes was started from filling resin material in a substrate. Popular substrates such as FR-4 are made up of epoxy resin and fiberglass. The anisotropic fiberglass interferes with precise microdrilling. In order to improve machnability of the substrates, we filled isotropic resin that is the same as material plugging in electrical through-holes. 2. The straight holes with 55-µm diameters were precisely machined as shown in Fig. 3(a). 3. The cladding material was applied on wall of the machined hole by vacuum suction printing to form the cladding layer of 2-µm thickness. 4. The core material was filled into the holes. 5. Both surfaces of the package were polished to obtain smooth surface until the surface of the optical through-holes was the same height with the substrate thickness. The core and cladding materials we used have refractive indices of 1.57 and 1.41, respectively. The difference of refractive index is about 10% to enhance the optical coupling efficiency.

Fig. 3(b) shows optical throughput effect in the 10-channel optical through-holes filled with core and cladding. Optical loss is compared to through-holes without the core and cladding. We used a graded index multimode fiber with a 50-µm core diameter (GI-50MMF) to input 850-nm light and a GI-62.5MMF to receive the propagating light. The GI-62.5MMF has wide diameter enough to measure optical loss of the optical through-holes with 55-µm core. The average loss of the core-cladding through-holes was 1.25 dB with a standard deviation of 0.13 dB. The average loss of the through-holes without core-cladding was 5.11 dB with a standard deviation of 0.14 dB. Making core and cladding structure improves 3.8-dB coupling efficiency. Therefore, we have demonstrated that the optical through-holes with high aspect ratio enhance optical coupling efficiency.

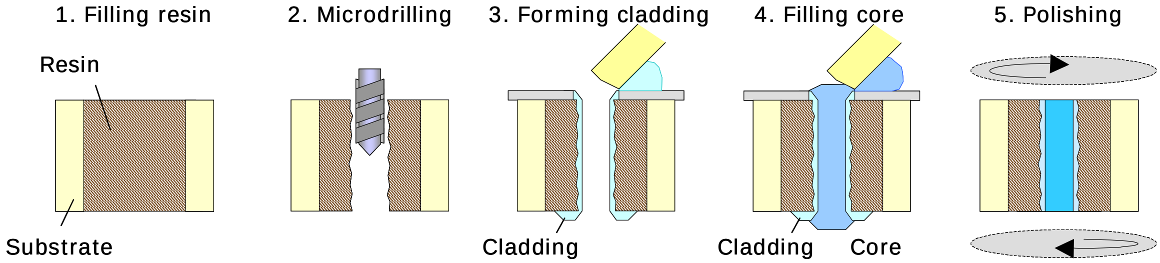
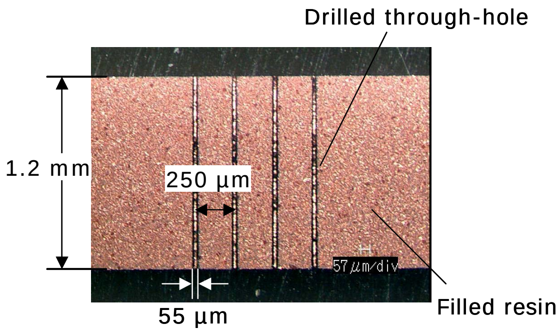
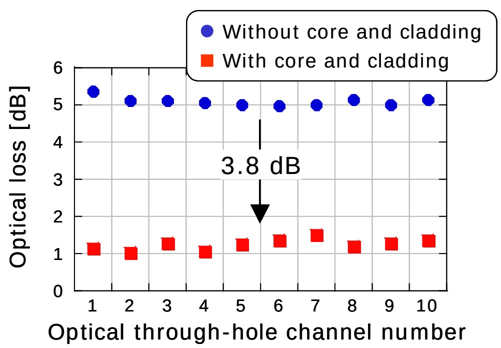


Fig. 2 Fabrication of optical through-hole.



(a)



(b)

Fig. 3 (a) Cross-section of 4-ch machined holes that measured 55 µm in diameter and 1.2 mm in length (an aspect ratio of 22). (b) Optical throughput effect of core and cladding in optical through-holes.

3. Evaluation

3.1 High-speed optical transmission with optical through-hole

The high-speed transmission was performed using the same GI-MMFs as used in measuring the optical loss, section 2. Fig. 4(a), (b) show representative eye diagrams measured with and without the optical through-holes at 10 Gb/s, respectively. Input eye diagram shown in Fig. 4(a) was measured with immediate coupling two fibers without the optical through-hole as a reference. Regarding 10 channels of the optical through-holes, uniform characteristics were obtained. The representative horizontal eye opening and extinction ratio in Fig. 4(b) was 77 ps and 3.7 dB, respectively, measured with the optical through-hole. Even though there was the optical through-hole in optical path, the optical signal quality showed good characteristics. The optical through-holes we developed are suitable for transmitting optical signal through the thick package.

3.2 Alignment tolerance with polymer waveguide

We measured alignment tolerance and optical coupling efficiency between the optical through-hole and a thin-film waveguide. Fig. 5(a) shows a schematic of a measurement setup. The waveguide has 50-µm square cores and 45º-ended mirrors that turn optical signal 90-degree in order to couple toward an optical device mounted on the optical through-holes. Optical signal from an 850-nm VCSEL was inputted to the optical through-hole and then received with the waveguide. The alignment tolerances were measured with moving the waveguide to both x and y directions from the core center. The 1-dB-down tolerance measured ± 12 µm in both x and y directions as shown in Fig. 5(b). The receptive waveguide core of the y-direction was slightly wider than 50 µm, so that the tolerance along the y-direction was slightly wider than the x-direction. We combined the package and thin-film waveguide using two guide pins assembled in the package and reported high positional accuracy of within ± 8-µm [4]. Therefore, the 1.2-mm-long optical through-holes that have the ± 12-um alignment tolerance and transmit 10-Gb/s optical signals can be applied to the chip-to-chip optical interconnections.

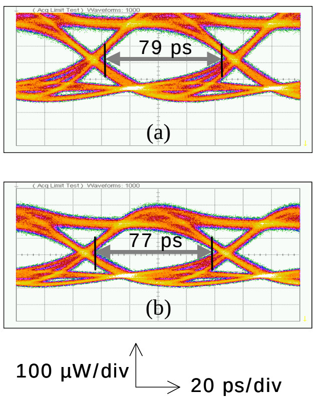


Fig. 4 10-Gb/s optical eye diagrams, (a) without optical through-hole as a reference, and (b) with optical through-hole.

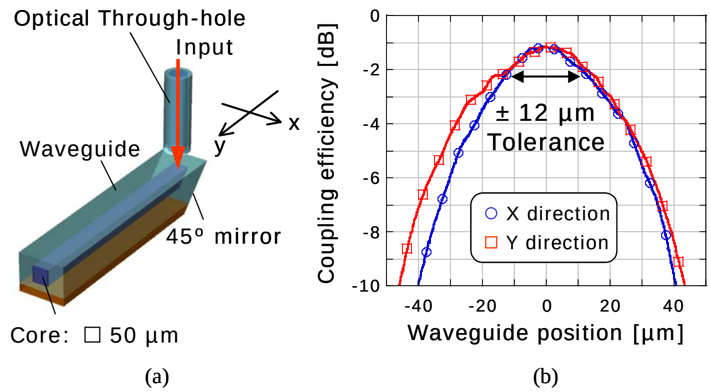


Fig. 5 Alignment tolerance with waveguide, (a) schematic of measurement, (b) measured coupling efficiency in both x and y directions.

4. Conclusions

We have successfully fabricated optical through-holes that have high-aspect ratio of 55-µm-core and 1.2-mm-long in a substrate for on-board optical interconnections. Optical loss measured 1.25 dB and 10-Gb/s transmission are demonstrated. This substrate with the optical I/Os aims at a future package with an embedded capacitor used for power delivery to a CPU.

5. Acknowledgement

The thin-film waveguide was designed and manufactured by Hitachi Chemical Co., Ltd.

6. References

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