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Published in:
[Host publication title missing]

DOI:
10.1117/12.810220

2008

Optical Link by Using Optical Wiring Method for Reducing EMI

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ABSTRACT

A practical optical link system was prepared with a transmitter (Tx) and receiver (Rx) for reducing EMI (electromagnetic interference). The optical TRx module consisted of a metal optical bench, a module printed circuit board (PCB), a driver/receiver IC, a VCSEL/PD array, and an optical link block composed of plastic optical fiber (POF). For the optical interconnection between the light-sources and detectors, an optical wiring method has been proposed to enable easy assembly. The key benefit of fiber optic link is the absence of electromagnetic interference (EMI) noise creation and susceptibility.

This paper provides a method for optical interconnection between an optical Tx and an optical Rx, comprising the following steps: (ⅰ) forming a light source device, an optical detection device, and an optical transmission unit on a substrate (metal optical bench (MOB)); (ⅱ) preparing a flexible optical transmission-connection medium (optical wiring link) to optically connect the light source device formed on the substrate with the optical detection device; and (ⅲ) directly connecting one end of the surface-finished optical transmission connection medium with the light source device and the other end with the optical detection device. Electronic interconnections have uniquely electronic problems such as EMI, shorting, and ground loops. Since these problems only arise during transduction (electronics-to-optics or optics-to-electronics), the purely optical part and optical link(interconnection) is free of these problems. [1]

An optical link system constructed with TRx modules was fabricated and the optical characteristics about data links and EMI levels were measured. The results clearly demonstrate that the use of an optical wiring method can provide robust and cost-effective assembly for reducing EMI of inter-chip interconnect. We successfully achieved a 4.5 Gb/s data transmission rate without EMI problems.

Keywords: Interconnect, electromagnetic interference, chip-to-chip interconnection, metal electro-optical bench(MOB), optical interconnection technology, Plastic optical fiber(POF), EMI

1. INTRODUCTION

The demand for very short-length high data rate interconnections is increasing considerably. The parallel links are expected to be widely used in telecommunication switching systems, local computer networks, server clusters and computer systems with a multithreading CPU. However, as information is usually transferred by means of an electrical signal over a relatively short distance such as between two chips or between two boards, there is a limit in increasing signal transfer speed and line density. Thus, there is a need for an alternative strategy for realizing a high-speed system.[2,3,4] In recent years, many studies have reported developments on board and backplane solutions,[5,6,7] plastic-optical-fiber-based inter-chip interconnection concepts[8,9,10] in order to reduce the microelectronics interconnection

Smart Structures, Devices, and Systems IV, edited by Said Fares Al-Sarawi,
Vijay K. Varadan, Neil Weste, Kourosh Kalantar-Zadeh, Proc. of SPIE Vol. 7268, 72680I
 · doi: 10.1117/12.810220

problem. Furthermore, solutions for optical free-space interconnects for inter-chip and backplane applications[11,12,13] have been demonstrated. In general, when an optical glass fiber does not have a jacket, it is lack of flexibility. Also, finishing of a cut end is not easy and requires a dedicated cutting machine.

In this paper, we propose an optical wiring method and the optical transmission media to interconnect between an optical Tx and an optical Rx, e.g. POFs instead of multimode glass fiber which used largely for optical parallel interconnection. The results clearly demonstrate that the use of optical wiring method can provide a robust and cost-effective assembly for VCSELs and PDs. We successfully achieved a 4.5 Gb/s data transmission with this system.

2. ARCHITECTURE OF OPTICAL LINK SYSTEM

This paper provides a method for optical interconnection between an optical transmitter and an optical receiver, comprising the steps of: (a) forming a light source device, an optical detection device, an optical transmission unit on a substrate (metal optical bench (MOB)); (b) preparing a flexible optical transmission-connection medium (optical wiring link) to optically connect the light source device formed on the substrate with the optical detection device; and (c) directly connecting one end of the surface-finished optical transmission connection medium with the light source device and the other end with the optical detection device.

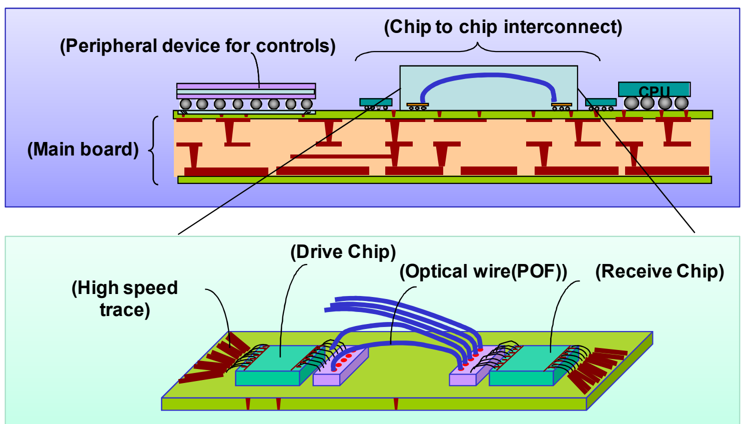


Fig. 1. Architecture of an optical link system using an optical wiring link block.

Figure 1 depicts the schematic diagram of the optical inter-chip interconnect system. The main components are low-loss graded-index (GI) multimode and downsized POFs in order to mount directly the POF without any mirror and lens. The TRx boards contain Tx and Rx modules that consist of metal optical bench (MOB), VCSEL arrays, PD arrays, an optical link, and high-speed access lines. The POF is cheap, flexible, easily connectable and it has very small bending losses. The principle of optical link between the VCSEL array chips and the PD array chips is as follows. The emitting beams from VCSELs are coupled into POFs with a core diameter of 62.5 ㎛ Subsequently, the beams are guided through the POFs with a 180° bended shape and then focused into the aperture of PD with a diameter of 70 ㎛ For fabrication of optical system, firstly we designed a differential trace with the ability to reject common mode noise[12] for the high-speed optical module. By ADS Momentum simulation, the width and thickness of the trace and the separation of the inter-channel were determined as 75 ㎛ 40 ㎛ and 90 ㎛ respectively for the differential impedance of 100 Ω.

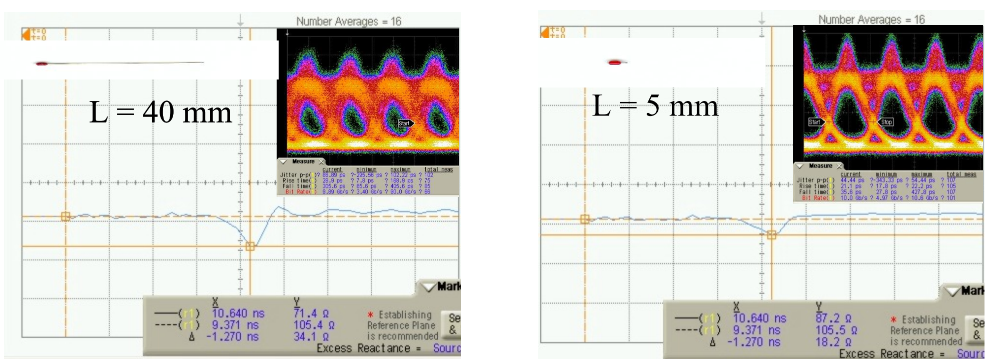
3. FABRICATION OF PCB and OPTICAL LINK SYSTEM

3.1. High-speed Access Line PCB

In the electrical input/output access lines, differential signaling is usually employed to ensure reliable operation. This differential signaling has the ability to reject common mode noise.[12] To support differential signaling, differential transmission lines are required.

Differential impedance is a critical factor for design of the differential line. The impedance affects signal qualities, such as reflections and crosstalk in driver and receiver. The structure of differential line was simulated with ADS Momentum simulator. Simulated structure is an edge coupled stripline of which length, thickness and width of trace are 9 mm, 40 ㎛ and 75 ㎛ respectively. Simulated dielectric material is SBC (Speed Board C) with relative dielectric constant 3.1. We finally determine the width and thickness of trace and the space within differential pair as 75 ㎛, 40 ㎛ and 90 ㎛ respectively. Time domain measurement is a useful technique for analyzing the pulse propagation on interconnects in digital systems. Time domain reflectometry (TDR) represents the time signature of the reflected waveform. The pulse generated propagates through a coaxial cable, through the transmission line on the evaluation board, through the transmitter module and reaches the input stage of IC Driver chip where it gets absorbed by termination resistors. The differential impedance of all transmission line and discontinuity points is about 100 ± 10 Ohm.

Figure 2 shows TDR and Eye diagram of Tx module to see the importance of impedance mismatching. Figure 2(a) is the figure of the electrical interconnects between the module PCB and the evaluation board, which were made up by using long pin inter-connectors. Figure 2(b) shows the figure of the electrical interconnects with short pin inter-connectors. Here, we can see that the longer interconnect has the more discontinuous and the more discontinuous results in a lot of distortion of the eye pattern.



(a) (b)

Fig. 2. (a) Processing board with long interconnects. (b) Processing board with short interconnects.

3.2. Optical link system

For an optical alignment between VCSELs and optical wiring link with POFs at Tx module packaging, the process is as follows. Referring to Figure 3(a), the POFs prepared for optical link packaging are cut using a cutting scissor or a razor. In the next step, referring to Figure 3(b), the cut ends of the cut POFs are thermally annealed. In the thermal annealing process, the cut ends of the cut POFs may be easily hard-faced using an iron(@150℃, 1sec.). Once the prepared POFs are cut and the cut end surface-finishing is completed, a post process of inserting the cut portions of the plastic optical fiber into aperture on the VCSEL device is performed by using the ball-wedge wire bonder (7730E). Referring to Figure 3(c), the cut POFs are inserted into the aperture on the VCSEL device, and an adhesive is used to fix them therein. An ultraviolet (UV) epoxy, a UV hardening resin, or so on may be used as the adhesive. An injector, a pipette, or so on may be used to precisely drop the adhesive into the aperture on the VCSEL device. Figure 3(d) illustrates a process of inserting the POFs into the aperture on the VCSEL device and then irradiating them with UV light using a UV irradiation device. In the next step, the other end of the POFs was inserted and fixed in the openings of the PD device with the same method as a former. If this kind of a method is used, the manual packaging for optical packaging is possible with the method that is the same with a wire bonding process. By this method, passive alignments can be provided for us. However, there are some problems of adhesion between VCSEL aperture and the front face of POF because of a protected layer of VCSEL' top surface. In order to solve this problem, we coated VCSEL's top surface with a thin layer (15 ㎛) of UV epoxy.

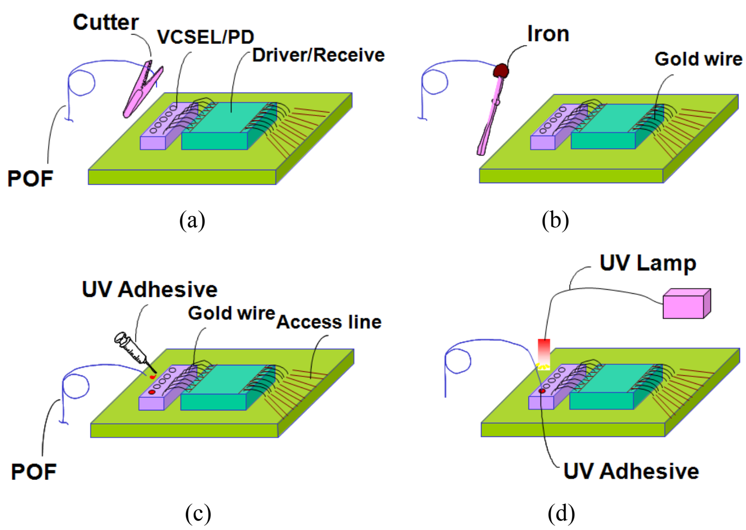


Fig. 3. Packaging process for an optical alignment and coupling between VCSELs and optical wiring link (POF).

The graded-index POF was fabricated for very short-distance data-communication application by Nuvitech Co. Poly methyl methacrylate (PMMA) was used as the core material. The relative index profile of POF core ranges from 1.49 to 1.52. The core diameter and the clad diameter of the POF are approximately 62.5 ㎛ and 250 ㎛ respectively. We downsized the POF's core to 62.5 ㎛ to match with the size of the VCSEL and PD aperture. The size reduction of the clad diameter allows us to couple directly in a row between VCSEL and optical link (POF) without any lens or tapered fiber. The propagation loss of the POF was 0.002 dB/㎝ at λ = 850 ㎚

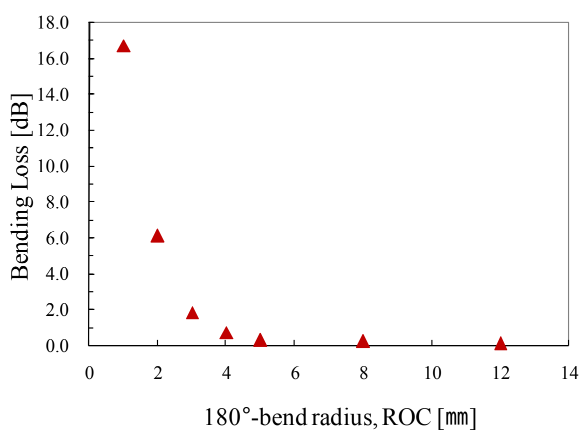
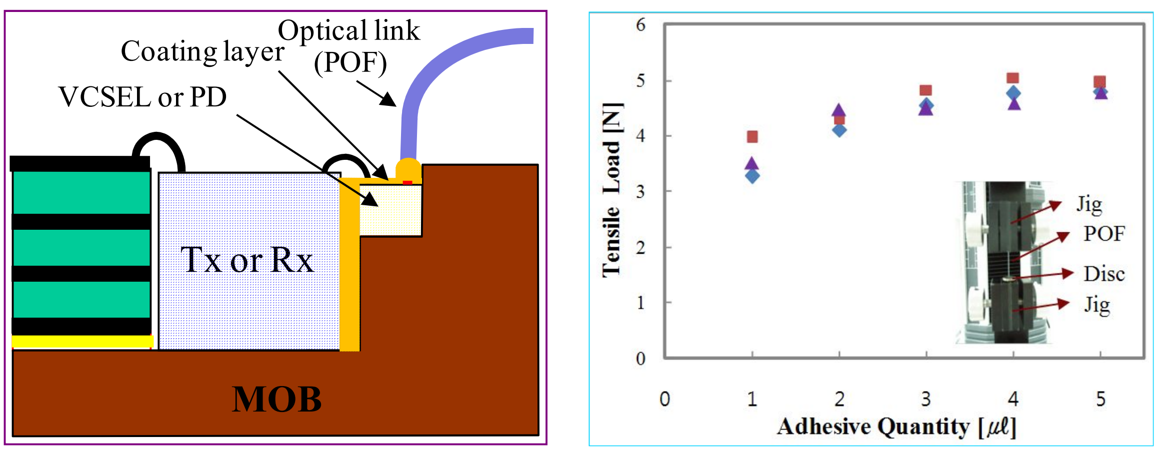


Fig. 4. The bending loss of the POF as a function of radius of curvature (ROC).

The 180° bending loss of the POF was measured as less than 1.0 dB beyond a radius of curvature (ROC) = 4 ㎜ as shown in Figure 4. In case that 180° bending radii of POF are 1.0 ㎜, 2.0 ㎜ and 4 ㎜, the bending loss are 16.68 dB, 6.08 dB, and 0.71 dB respectively. The 180°-bent fiber block is expected to be popular bent interconnects for a high-dense, small and 3D optical interconnection because of the characteristics of a small ROC, a low insertion loss and crosstalk, a high accurate channel pitch, a high-density interconnection, and a simple fabrication process.

Figure 5 (a) shows the structure of metal optical bench. MOB(20 ㎜ x 22 ㎜ x 3.2 ㎜ (W x L x H)) has a three-step trenched structure. Using of this stepped trench structure can provide high-speed bandwidth by shortening the length of wire bonding to less than 500 ㎛. That is because the wire-bonding pad of each component (driver chip, VCSEL, receiver chip, PD) which has different height of each component, can be at the same height by stepped trench structure. This MOB packaging also provides safe ground plane and heat spreading effects for high-speed circuit boards. The 1×12 channels VCSEL from Avalon photonics and PD array from Albis Opto were used for 4.25 Gb/s/ch. The 1×12 driver/receiver IC from Helix was used.

Figure 5 (b) shows the tensile load of single lap joint between POF and UV curable adhesive as a function of the volume of UV epoxy. Test was conducted by using LLOYD instruments'LRX Plus. The test speed were 1㎜/min. The samples were prepared by coating a thin layer (15 ㎛) of UV epoxy on metal disk. In order to ensure the reliability of test, tests were repeated with three identical samples, respectively. From the figure 5(b), it can be seen that as the volume of UV epoxy is increasing, the tensile load is higher. The maximum tensile load of joint will be saturated if the joint is filled with UV epoxy to be able to make the single lap joint sufficiently. In this case, a volume of UV epoxy to make a good joint is 3 ㎕. The maximum load of joint can be accepted to be suitable for a practical use compared with tensile load of POF, 5N.



(a) (b)

Fig. 5. (a) Structure of metal optical bench. (b) Test of tensile strength for UV epoxy.

4. TRANSMISSION CHARACTERISTICS OF OPTICAL LINK SYSTEM

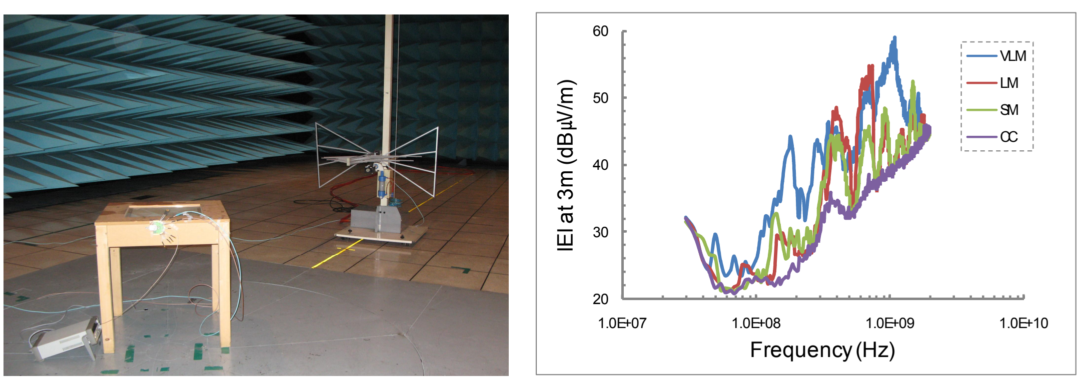
4.1. EMI characteristics of optical module

It's believed that all EMI problems of electronic components can be solved in a single, uncomplicated way by using fiber-optic technology. Actually fiber-optic technology offers unique advantages in achieving a total EMI-free signal transmission within PCB module and system. The optical cables are immune from EMI because they transmit signals as light rather than electrical current. However, electromagnetic interference sources exist in E/O conversion part, optical driver circuits, electrical pin interconnects and access PCB lines.

EMI consists of unwanted, spurious, conducted, or radiated signals of electrical origin that can cause degradation in equipment performance. To overcome these problems, all components must comply with specifications to ensure electromagnetic compatibility (EMC), and there are numerous design methods that can be used to prevent EMI. High-speed PCB and its system, high-frequency signal line, IC pin, various types of connectors, etc, may have antenna interference characteristics of the radiation source, emitting electromagnetic wave, affecting other systems and easily produce EMI. In order to avoid electromagnetic interference and to achieve electromagnetic compatibility, it is required that the PCB board be designed to meet the high-speed circuit design theory.

This paper explores an important factor that causes EMI radiation in an optical module and system. We designed and fabricated the optical transmission module with various electrical interconnect pin such as shown in figure 3. Figure 6(a) represents the EMI measurement set-up of an optical module at SAC(semi-anechoic chamber). An optical module is attached on the table with 0.8 m height. The test was performed in 3 m range chamber and receive antenna was scanned from 1m to 4m at a vertical direction. The test results show that the EMI radiation noise at the optical module with long pins(VLM) is by 10 dB more than EMI radiation noise of the optical module with short pins(SM). There is little noise in chip-to-chip optical system. The only difference between optical modules and inter-chip optical system is connector type. The contact between PCB module board and bare coaxial cable without connector is made by soldering method. On the other hand, the contact in inter-chip optical system is based on SMA connector of 4 pin vertical mount jack type.

Connectors are contacts that either separate two cables or other boards. There may be anywhere several individual wire-pins or coaxial sheaths making simultaneous contact via a connector. Poor contact connections can also result in driven-circuit voltage variations from the contact impedance modulation of the driving-circuit source. Impedance coupling from outside sources can happen in connector grounding paths. Improperly shielded connectors or poor cable-connector-board contact can cause radiated emission penetration or leakage through apertures. This result shows that EMC must be taken into consideration during the design stage.



(a) (b)

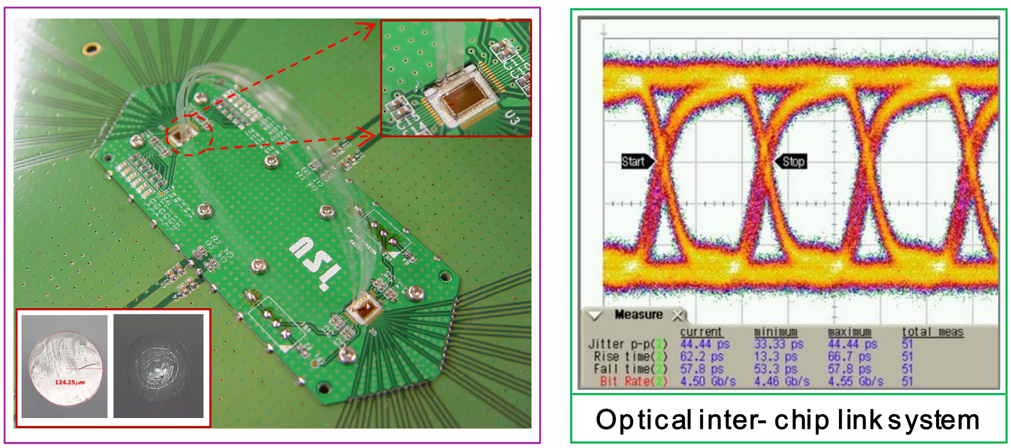
Fig. 6. (a) EMI test set-up, (b) EMI characteristics of optical modules.

4.2. Transmission characteristics of optical system

Figure 7 shows inter-chip link system with an optical link. The number of channels for the optical link is 10. The eye-diagram for the transmission of 4.5 Gb/s PRBS NRZ data is symmetric without any significant relaxation oscillation. The figure on the upper right represents the enlarged photograph and the figure on the bottom left shows the sectional picture of the cut POF and the annealed one by using a razor and an iron respectively.

The channel's skew, the jitter peak to peak and the rise time of the optical link system are below 29 ㎰, 44.4 ㎰ and 62.2 ㎰ respectively. In this system, while the power budget of the optical link system was 18 dB, total power loss of the optical link was only 5.7 dB.

In our optical wiring link, we used a downsized POF that allows directly connecting one end of the POF with the light source device and the other end with the optical detection device with simple thermal annealing. This method simplifies a fabrication process, can be easily applied regardless of various device modifications, and can reduce time taken to assemble an optical connection structure. However, we have a difficulty bonding between optical link block and optical components due to a little low adhesive strength of UV-epoxy and somewhat low flexibility of POF. Further research is needed to devise adhesion materials with a high adhesive strength and a high flexible POF.



(a) (b)

Fig. 7. (a) Inter-chip link system with an optical link.
(b) Eye-diagram measured for 4.5 Gbp/s transmission of a 2^{31}-1 PRBS NRZ data.

5. CONCLUSION

We have developed an optical link system using optical wiring method. We used a metal optical bench and optical links for the packaging of opto-electronic chips and connecting between chips. For the packaging of the VCSEL/PD arrays, driver/receiver ICs, and the POFs, a metal optical bench was used. These optical link blocks based on POFs can provide can provide a robust and cost-effective assembly for vertical-cavity surface-emitting lasers (VCSELs) and photodiodes (PDs) with micron-scale accuracy. We explore an important factor that causes EMI radiation in an optical module and system and the transmission lines in the transmitter and receiver boards were designed with consideration of the differential impedance matching for high-speed operations for reducing EMI noise. In our system, we demonstrated a 4.5 Gb/s data transmission rate between the Tx chips and the Rx chips. The eye was wide open and showed no relaxation oscillation.

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