Optical Components for High-Density Optical Inter-Connect System: OptoUnity

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ABSTRACT Electric transmission in a system and in such equipment as a high-speed server, a router, and an LSI tester is reaching its limit, and introduction of optical transmission is considered. We are developing the OptoUnity products as an effort in providing the optical inter-connection technology that realizes high-speed transmission and a high density package with a concept of miniaturization. This paper introduces the development of small clad diameter optical fiber ThreadWave, micro multi-core ferrule μ-Joint, MU type plug, back plane connector, and right-angled connector μ-Curve, and passive alignment assembly plastic package parallel optical module μ-POEM.

1. INTRODUCTION

In recent years, larger amount of information and telecommunications and improvement in the speed are called for by the rapid spread of the Internet. In order to improve the speed of the computer which processes the information, the clock speed of CPU unit has been improved. But also there is a trend to process the information through parallel operation of two or more CPUs. Therefore, with large-scale computers, such as server computers and mainframe computers, a large scale, high speed and high-density transmission is required between boards and between racks, and the optical-inter-connection market which transposes the conventional electric wiring to optical wiring is expected to expand.

The standardization of optical-inter-connection is considered with IEEE by establishing the 100 GbE (100-Gigabit Ethernet) standard in 2009. As far as the market is concerned, the standardization is expected to be introduced to the high-end field in sometime around 2010, and is expected to be deployed to personal computers, digital-appliances products, etc. in 2020. As an optical inter-connection technology that meets the demand in highly-dense package for the high-end market, we are developing OptoUnity products; down-sized optical fiber, optical connector, and high-speed optical module.

This paper introduces the product concept and the status of prototype development.

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2. TARGET SPECIFICATION OF THE OPTICAL INTER-CONNECTION SYSTEM

2.1 Benefits of Optical Inter-Connection

The benefits of providing an optical transmission of high-speed electricity signal are; 1) Provides solution for access speed and loss limitation (10 Gbps, several meters), 2) Improvement in packaging density, and 3) Weight saving of wiring material. There are, however, some issues to be solved in applying the present optical parts as it is. Here, the required specification of high-end optical inter-connection is considered first.

2.2 Configuration of the Optical Inter-Connection and Transmission Loss Design

The configuration assumed by optical inter-connection is shown in Figure 1. It assumes transmission between the boards in a rack, or between racks, and the maximum transmission distance is 20 m. The transmission system that is currently adopted is a parallel transmission by VCSEL (Vertical cavity surface emitting laser) with a wavelength of 850 nm and a multimode fiber with a transmission speed of 2.5 Gbps now in practical use and 10 Gbps is considered to be used in the future. The loss design of the trial transmission path was performed based on such background.

In order to obtain high quality transmission with the multi-mode link using VCSEL, the performance of Tx and reduction of loss (transmission fiber loss, mode dispersion loss and loss in connection with Rx receiving sensitivity) are important. The mode dispersion loss of an optical fiber is smaller with Tx that has a smaller gap from 850 nm of the oscillation wavelength of VCSEL, a narrower width of wavelength, and a larger optical extinction ratio.

Although the increase in Tx optical power extends transmission distance, there is a limit with the increase amount considering the eye safety and the reliability of VCSEL. The increase in a bandwidth of an optical fiber and reduction of bending loss and connection loss is important for the reduction of transmission path loss. As for Rx, the improvement in the absolute characteristic of receiving sensitivity (it is dependent on the amplifier IC characteristic) and reduction of an electric cross-talk noise are needed.

The loss L of the transmission path between Tx module on one board and Rx module on another board is estimated as 4.2 dB maximum taking into account the following: 0.5 dB each for four optical connections including the module connectors, the rack or backplane connectors in addition to four places of small bending diameter; and 0.2 dB for 20-m optical fiber having a propagation loss of 10 dB/km. When the fiber input power of Tx is set at -3 dBm minimum, the minimum received input power of the target single channel of Rx will be -10.7 dBm calculating an electric cross talk penalty of 1.5 dB, the mode dispersion penalty of 1.0 dB with optical fiber bandwidth 200 MHz-km and $L=$ 4.2 dB of a transmission path, and coupling loss of 1 dB to Photo Detector (PD). The target performance of an optical fiber, an optical connector, and the optical module were set to make these losses to be the maximum level.

2.3 Target Density of the Optical Connector

The mounting board of high-end transmission equipment has parts height restrictions (the pitch of a board is determined) for a high dense package, and the standard of the board pitch is 10 mm or less. Therefore, it is difficult to pile up an optical connector perpendicularly. Here, the bandwidth density required for optical inter-connection is expressed by multiplying the number of fibers per cm in width of a mounting board with the access speed per channel. Figure 2 shows the predicted increase of the transmission bandwidth per cm in width of an optical connector. Now, the access speed of an optical module is 2.5 Gbps/channel, and since the 12-MPO connector (about 20 mm in width) is used for the optical connector, bandwidth densities are about 15 Gbps/cm. When the total signal bandwidth per board necessary for high-end transmission equipment is assumed to be 3 Tbps and access speed is assumed as 10 Gbps/channel, the required number of fibers is 300. This is equivalent to 25 pieces of the 12-MPO connectors, and a required board frontage is about 50 cm in width. In this case the mounting board will be full with optical connectors since a mounting board is generally 50 cm. It is necessary to mount not only an optical connector but an electric connector in a mounting board, and also to secure the air inlet for air cooling.

As shown in Figure 2, by increasing the access speed of one channel to 5 Gbps and 10 Gbps, bandwidth density increases to twice and 4 times, respectively, and the required number of connectors can be decreased. However, in order to make increase it by 8 times and 16 times, it is necessary to increase the number of the fiber ribbon per connector from 12 to 24, 48, etc. There is a limit in the production of connectors with multiple-fibers since it increases the production cost due to the fall of the yield in the polishing process. Moreover, when multiplying the fiber in one connector, the branching for the purpose to increase the thickness of a fiber code and connection with an optical module etc. becomes a problem and cannot be easily adopted.

Downsizing the connector itself is one of the solutions in order to raise the packaging density without increasing the number of fibers per connector. The packaging density required in high-end application is said to be 100 Gbps/cm or more, and the present target is 10 Gbps/channel and have 12 fibers to be set within 1 cm width. By making connector width into 50 % of the present condition, it becomes possible to increase the density by 8 times with 12 fibers compared with the conventional product. It is possible to set the access speed to be 20 Gbps/channel or to have 24 fibers while maintaining the speed by further bandwidth expansion. In the former case it is also necessary to increase the transmission bandwidth of an optical fiber, which may require an application of a single mode fiber. Moreover, the miniaturization of an

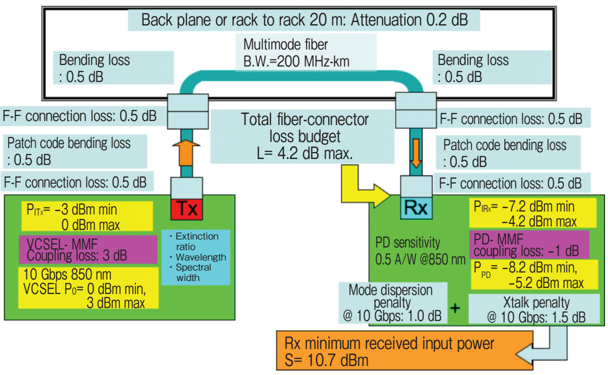


Figure 1 Structure and transmission loss budget design of Optical-Interconnection System.

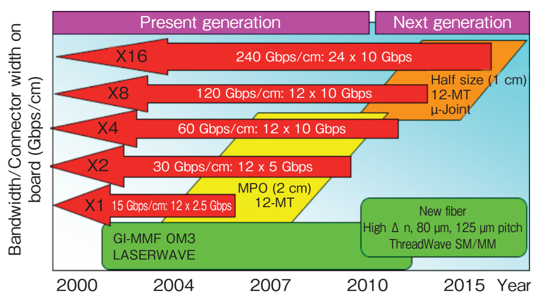


Figure 2 Expectation of bandwidth per optical connector width of one centimeter.

optical fiber size and improvement in ease of mounting may also be needed.

3. CONCEPT OF OPTOUNITY

The OptoUnity products, which are the optical components for optical inter-connections are developed based on the target specification expressed above. OptoUnity is a coined word literally formed with “Opto” and “Unity”, signifying the unification of the opto-electronic technology of our company and the products were named as OptoUnity. The OptoUnity product group will open the optical market of the next generation. The concept of OptoUnity products are to miniaturizing conventional optical components, raising affinity with electronic product mounting, and realizing high-density mounting. The four products under development are as follows.

1. Small diameter and small bending radius optical fiber: ThreadWave, fiber ribbon, and code.
2. Micro multi-port ferrule: μ-Joint, MU type connector plug, adapter, and back plane connector.
3. Right-angled connector: μ-Curve
4. Passive align type parallel optical module: μ-POEM

Figure 3 shows the pictures of products under development, and conventional components for comparing the size.

In the following, the trial production result of the prototype of each part article is introduced.

4. PROTOTYPES OF OPTOUNITY PRODUCTS

4.1 ThreadWave

4.1.1 ThreadWave Fiber

The limitation in bending size of an optical fiber is a big challenge to meet with high-density mounting requirement. Comparison of minimum bending radius of various optical fibers is shown in Figure 4. The minimum bending radius of a conventional optical fiber is 30 mm in relation to loss and fracture strength. On the other hand, a fiber (FlexiWave), which guarantees 15 mm of bending radius was recently produced commercially for interior use by FTTH (Fiber To The Home). However, in optical inter-connection, since it needs to be wired in a narrower board and rack, there is a demand to have the bending radius similar to that of electric wiring. We developed a single mode (SM) type and a multi-mode (MM) type ThreadWave fiber, setting a goal to guarantee the bending radius of 5 mm.

A clad diameter of 80 μm was used for the ThreadWave fiber to assure mechanical reliability in bending radius of 5 mm. Fiber structure is shown in Figure 5. The clad/diameter of covering is 80 / 125 μm, respectively. Although covering is included, the outer diameter is equivalent to the

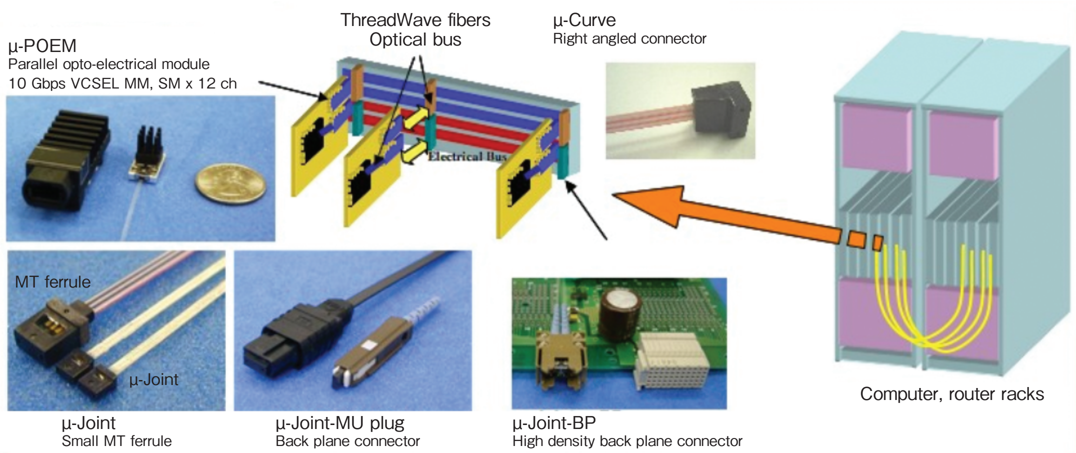


Figure 3 Products of OptUnity.

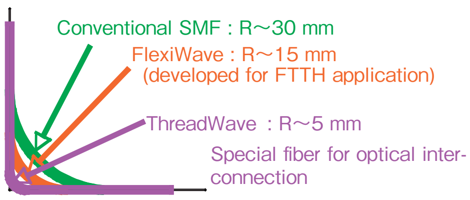


Figure 4 Comparison of fiber bending radius.

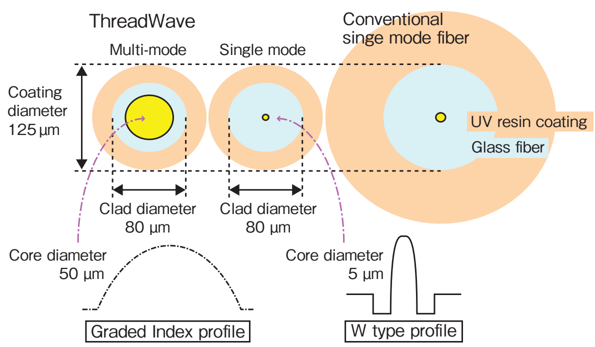


Figure 5 Cross-section of the ThreadWave fibers.

conventional glass fiber part of a fiber. SM type has adopted the W-type refractive-index profile to be a broadband and with low loss. The mode field diameter of the optical fiber was set at the level similar to that of VCSEL, which is approximately 5 μm, so that the maximum coupling efficiency with the long wavelength VCSEL of a single mode would be acquired. Propagation loss is 0.5 dB/km, and transmission of 10 km or more is possible.

For the MM type, in order to secure the characteristic equivalent to that of GI-50 conventional fiber and to realize 5 mm in bending radius, it adopted a diameter clad of 80 μm, which is the same as SM. The refractive-index profile of the core is the GI-type which increased the core/clad refractive-index ratio by 1 % to 2 % compared to the conventional one to reduce the bending loss. The propagation loss in the transmitted wavelength of 850 nm is 3 dB/km or less, the bending loss is below 0.1 dB/turn (3.18 dB/m) at a bending radius of 5 mm, and for a transmission bandwidth of 200 MHz-km or more is obtained, which makes the 20m-long transmission to be possible at 10 Gbps.

4.1.2 ThreadWave 12-Fiber Ribbon

A ThreadWave fiber can be formed as a ribbon of 125-μm pitch, which is half in size when compared with the conventional 250-μm pitch, since the clad and the diameter of coating are 80 and 125 μm, respectively. A comparison of cross-sections of the conventional 12-fiber ribbon and a ThreadWave 12-fiber ribbon is shown in Figure 6. More flexible application is possible by downsizing the width and thickness for about 50 %.

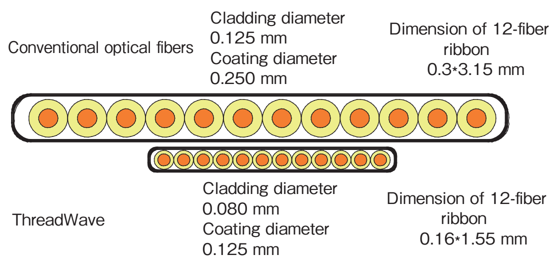


Figure 6 Comparison of cross-sections: Conventional 12-fiber ribbon and ThreadWave 12-fiber ribbon.

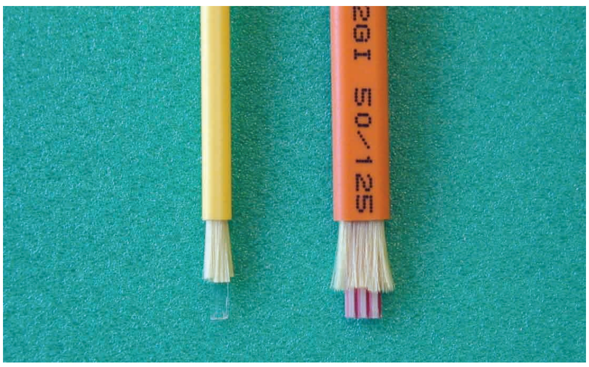


Figure 7 Pictures of ThreadWave 12-fiber ribbon cord and conventional 12-fiber ribbon.

4.1.3 ThreadWave Fiber Ribbon Cord

The code that is used to connect a ThreadWave fiber ribbon with apparatus cases is shown in Figure 7. In order to bear the mechanical stress at the time of construction, it is covered with aramid fiber material, and the outer diameter has been halved from the conventional 12-multimode fiber cord.

4.2 μ-Joint

4.2.1 μ-Joint Ferrule

μ-Joint ferrule was developed as a multi-core light connection ferrule adapted to a ThreadWave fiber ribbon. A comparison of sectional view with the conventional MT ferrule is shown in Figure 8. The cross-sectional size of μ-Joint ferrule is about half (3.4 mm in width, and 1.2 mm in thickness) of conventional MT ferrule, and is 25 % in facet area. Length is 4 mm. Moreover, a 0.4 mm diameter stainless steel pin is used as the guide pin. The fiber hole diameter is 80 μm and the pitch is 125 μm.

4.2.2 μ-Joint-MU Connector Plug and Adaptor

Taking advantage of the size of μ-Joint, MU connector is adopted as a connector housing which can be mounted with high density [1]. It is standardized as a JIS C5983: 1997 F14 type single-optical fiber connector, and MU connector is put in practical use with the FTTH access system termination equipment in a telephone station, etc. It is possible to install two or more plugs with a spacing of 4.5 mm in between by applying an attachment-and-detachment mechanism with a slider. Figure 9 shows the picture of plugs, which applied μ-Joint ferrule to MU housing. Moreover, a μ-Joint-MU plug and 2 plugs adapter are shown in Figure 10.

The connection loss in the multimode fibers without matching fluid measured by this plug and the adapter was 0.2 dB or less, as shown in Figure 11. Moreover, more than -25 dB of reflective loss was obtained. When the gross loss (loss budget) of the transmission way (20

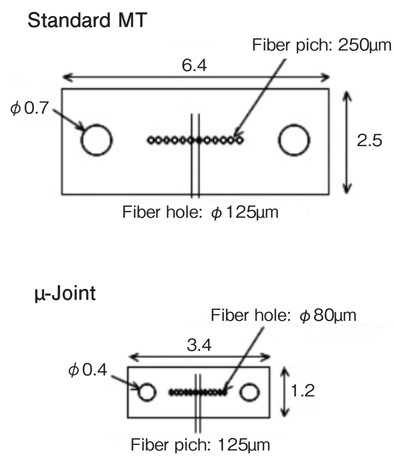


Figure 8 Cross-section of conventional MT ferrule and μ-Joint ferrule.

m) shown in Figure 2 of Section 2.2 is calculated using the result obtained above, the calculation will be; 0.2 dB×4 connector connection + 0.1 dB×4 bending loss + propagation loss of 0.06 dB = 1.26 dB, and the margin close to 3 dB is obtained against the initial target, which is 4.2 dB.

4.2.3 μ-Joint-MU Backplane Connector

The product of single MU connector is available as a back plane connector. It is possible to detach and attach two or more plugs simultaneously as a whole board by using the print board housing and back plane housing. Also MU connector can be combined with electric connectors, such as HM connector [1]. Utilizing this mechanism, super high-density back plane connection is realized by adopting a multi-fiber connector by μ-Joint ferrule. This is another reason of adopting the MU connector design.

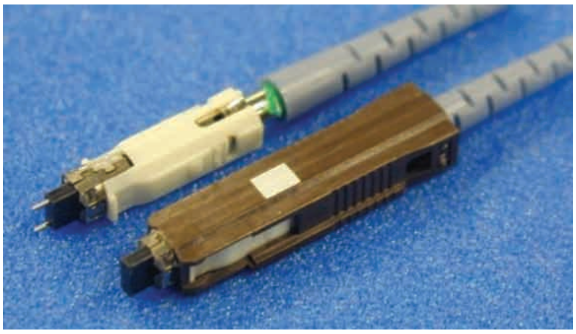


Figure 9 μ-Joint-MU plugs, upper: without slider, lower: with slider.

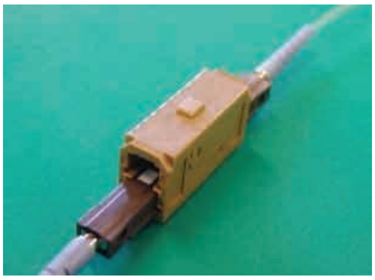


Figure 10 μ-Joint-MU plug and adaptor.

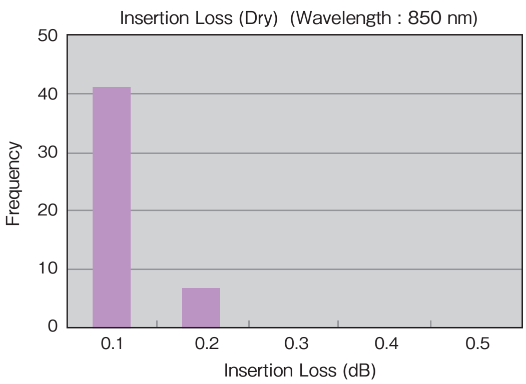


Figure 11 Connection loss of the μ-Joint-MU multi-mode type plug in adaptor.

Figure 12 shows the back plane connector housing of 2 plugs made as an experiment. In a single-MU connector, the back plane connector with a maximum of 8 plugs is put in practical use, a 12-μ-Joint plug is applied, and, as for the case of 96-fiber and 10 Gbps/channel, 960 Gbps package attachment/detachment are attained. Since the width of the back plane adapter at this time is about 45 mm, the bandwidth density is calculated to be more than 200 Gbps/cm.

4.3 μ-Curve

Although 5 mm in bending radius was realized with the ThreadWave fiber, the application of an optical fiber can be expanded if more smaller bend radius is realized. For example, in a surface mount type optical module, arranging an optical fiber in parallel direction to a substrate is required. Conventionally, the size of the module and the bend radius was restricted when VCSEL or PD --- which are used for an optical module --- and an optical fiber are coupled to bend the optic axis by means of the fiber. Therefore, the method of using reflective mirror combination for miniaturization has been taken. However, since the spread of the light beam during space propagation increases coupling loss, expensive parts such as a lens are required when using the reflective combination method to reduce the loss.

As a solution, we have developed a new technology in which an optical fiber is processed at a temperature near the glass melting point to be bent to almost 90° with a bending radius of 1 mm or less [2]. Figure 13 shows the photograph of the fiber ribbon by which the right-angled bending processing was carried out.

Figure 12 μ-Joint-MU backplane connector (Left: print board connector, Right: backplane connector).

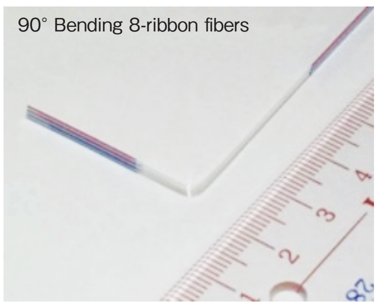


Figure 13 90-degree bending fiber ribbon.

μ-Curve is the connector, which has this right-angled fiber ribbon and is placed in a ferrule of the same size as the conventional MT. The photograph of a prototype is shown in Figure 14.

The loss of the bent fiber was 0.1 dB or less in ThreadWave SM. As for ThreadWave MM shown in Figure 15, by optimization of internal structure of the ferrule, even if it included connection loss, a loss of 0.5 dB or less was obtained.

4.4 μ-POEM

4.4.1 Structures

Parallel optical module μ-POEM which performs an electric/optical signal conversion has taken a substantial portion of the costs for optical inter-connection parts, and is the part that especially needs cost reduction. We have been developing the lens-less passive alignment assembly which combined the high precision plastic package and silicon substrate by MT ferrule molding technique as the package to reduce the cost [3)-5)]. This time, two concept-trial-production modules; the reflective coupling type (R-PACK) and a butt-joint coupling type (V-PACK) shown in Figure 16, were examined as an optical connection type of an optical fiber and an optical element.

R-pack is the module that was designed to pursue miniaturization, uses 12-fiber μ-Joint for an optical interface and is performing reflective combination with an optical element using the 45-degree polished short length fiber with metal mirror inside the optical module. In the prototype, the optical element (850 nm VCSEL and Pin-PD array) of 250-μm pitch 4 ch was used.

In contrast, V-pack is the module in which the optical element and the short length fiber are simply butt-joined together inside an optical module, so that direction of light outputs are perpendicular to printed circuit board plane. The feature of it is to change, outside the module, optical direction into the optical interface using 12-fiber μ-Curve of 250-μm pitch. 12 channels of 250-μm pitch were used for the optical element.

Both modules have optical elements mounted with an accuracy of ±1 μm on the silicon substrate, and the grooves on the silicon substrate are engaged with the projections on the high-precision body, thereby achieving passive alignment.

An electric interface is the surface mountable type package, which used the plastic printed circuit board. A signal electrode is LGA (Land Grid Array) of a 0.5-mm pitch and there are 78 pads. On the electric substrate, a VCSEL driver IC for multiple channels or a receiving amplifier IC was installed through the ceramic substrate for heat dissipation, and connection with an optical ele-

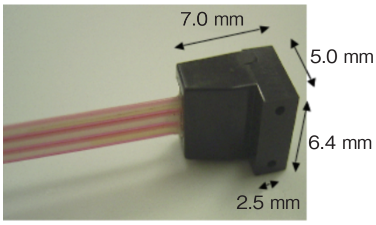


Figure 14 μ-Curve connector.

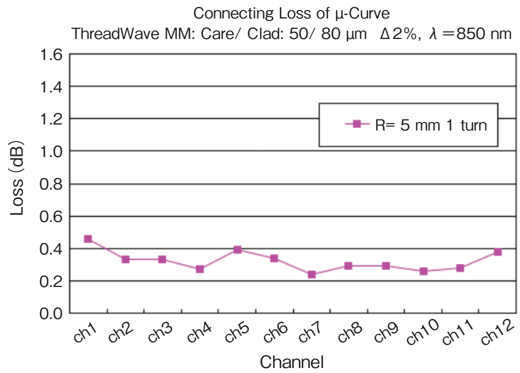


Figure 15 Connection loss of the μ-Curve.

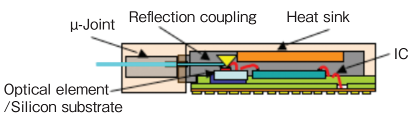
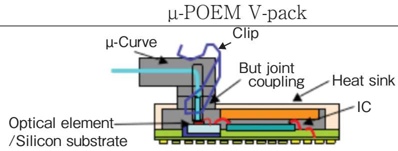
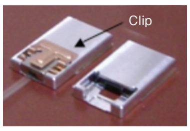
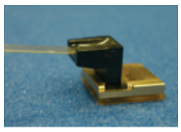
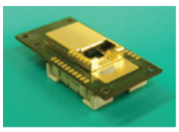
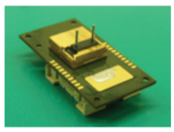
	μ-POEM R-pack		μ-POEM V-pack	
Structure				
Optical coupling method	Internal light path transfer, using 45° mirror reflection at fiber end face		External light path transfer, using right-angle bent optical fiber connector μ-Curve	
Size (W/L/H in mm)	10.0 × 16.5 × 4.0		10.0 × 10.0 × 10.0	
Optical element	850-nm 4 ch multimode VCSEL/Pin PD	μ-POEM with μ-Joint	850-nm 12 ch multimode VCSEL/Pin PD	μ-POEM with μ-Curve unit
IC	10 Gbps x 4 ch SiGe BiCMOS, power supply: 3.3 V		5 Gbps x 4 ch SiGe BiCMOS, power supply: 3.3 V	
Optical connector I/F	80 μmϕ, 125-μm pitch fiber ribbon, μ-Joint connector		80 μmϕ, 250-μm pitch fiber ribbon, right-angle bent optical fiber connector μ-Curve	
Electrical I/F	0.5-mm pitch LGA	Pluggable interposer implementation	0.5-mm pitch LGA	Pluggable interposer implementation
Features	Optical elements and ICs are surface mounted; ultracompact connectors are used; low-profiled		Optical elements and ICs are surface mounted; simplified module structuring due to the use of right-angle bent optical fiber connector μ-Curve	

Figure 16 Structure and feature of μ-POEM parallel optical modules.

ment and board trace lines was set with a gold wire. The footprint of R-pack and V-pack are common. BiCMOS type IC with the power supply voltage of 3.3 V was used.

The width size of both modules was designed as 10.0 mm to fulfill the requirements for a high dense package.

R-pack installs, in the metal heat sink, the receptacle mechanism for detaching and attaching a μ-Joint connector and module length is 16.5 mm. 4.0 mm in height was realized by installing the 45-degree polished fiber, which serves as a reflective mirror built in a molded package.

On the other hand, by carrying out optical direction changing outside the module using a μ-Curve connector, V-pack eliminates reflective mirrors and is attaining simplification of module composition. An optical emitting part is placed at the package upper surface, and the length of the package has been downsized to 10.0 mm and the height to 4.0 mm. When μ-Curve is connected with spring clip, the height is 10.0 mm.

A Pb-free solder that can handle a low-temperature process was used for mounting on the board of μ-POEM. The interposer board with an electric socket (pluggable) which can be detached and attached as shown in the photograph of Figure 16 was produced and mounted to increase efficiency of evaluation of solder mounting and characteristic evaluation.

4.4.2 Characteristics

The characteristic of the prototyped module is described.

The eye patterns at the time of whole-channel simultaneous operation of V-pack type 5 Gbps, 12 channels Tx, and Rx module are shown in Figure 17. Good eye patterns were obtained by a total of 12 channels. The average optical power of Tx is estimated to be -2.0 dBm, and optical coupling loss is estimated as about 3 dB. Remarkable cross talk degradation according to simultaneous operation in both modules was not seen.

Figure 18 shows the transmitted waveform at the time of connecting Rx module with the V-pack type Tx using a ThreadWave MM fiber. The optical quenching ratio was set at 3.0 dB. The light waveforms after transmission when the length of an optical fiber is 4 m (back to back), 40 m, and 54 m, and an electric waveform of Rx are shown. As for the light waveform of Tx, degradation of an eye is seen according to the increase in transmission distance, and the increase in jitter was seen in Rx electricity waveform.

The measurement result of a bit error rate is shown in Figure 19. Minimum received input power at 4 m (back to back), NRZ, PRBS 2^{31}-1, and bit error rate 10^{-12} and at 40-

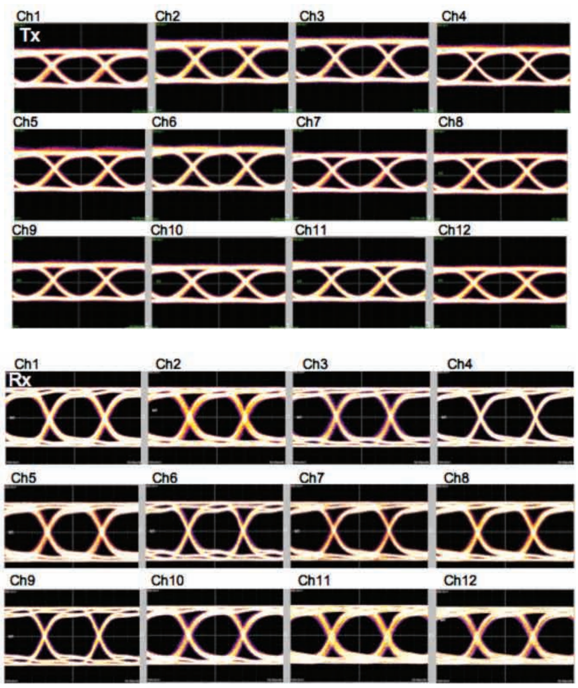


Figure 17 Optical and electrical waveform of 5 Gbps, 12channels transmitter and receiver module.

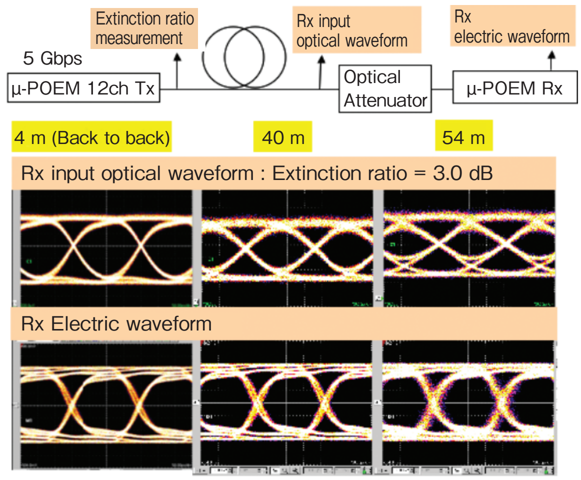


Figure18 Optical waveforms of 5 Gbps x 12 channel transmitter module over ThreadWave MM.

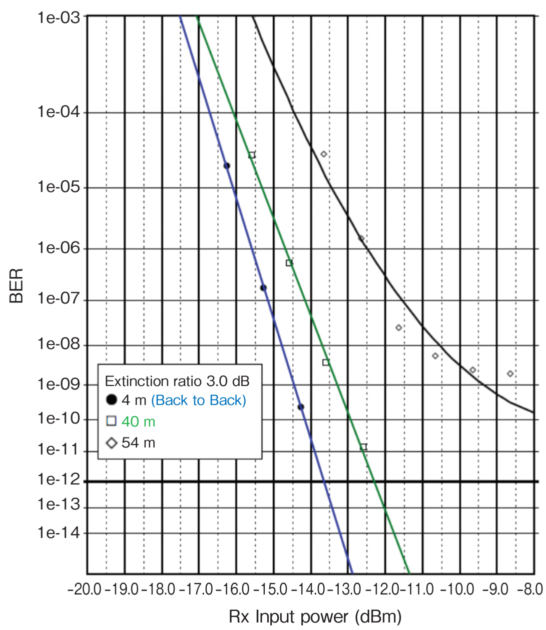


Figure 19 Bit error ratio test of the 5 Gbps μ-POEM V-pack type over ThreadWave MM fiber.

m transmission was -13.7 dBm and -12.3 dBm, respectively, and the power penalty was 1.4 dB. It is thought that 40m-long transmission is satisfactory. On the other hand, the error floor was observed in 54 m. The transmission bandwidth of the ThreadWave MM fiber was 200 MHz-km, and since it is 5 GHz at 40 m, it is thought that the evaluation result is appropriate and the bandwidth of the optical fiber has restricted the transmission distance. From this result, it has been shown that 5-Gbps transmission using μ-POEM V-Pack is possible.

The power consumption of 5 Gbps, 12 channels Tx module and Rx was about 960 mW (80 mW/channel), and about 1320 mW (110 mW/channel), respectively.

The trial production of 10 Gbps module was performed in R-pack. The optical power waveform of 10 Gbps module with 4 channels and the electric output waveform of Rx module are shown in Figure 20. Tx optical power is -2 dBm. In the transmission evaluation by Back to Back in NRZ, PRBS $2^{31-}1$, and bit error rate 10^{-12}, as for the minimum received input power, -8 dBm and -10 dBm were obtained with extinction ratio 3.9 dB and 6 dB, respectively.

As described in section 4.2.2, when the loss budget of a transmission path is 1.26 dB and mode dispersion penalty is set at 1.0 dB in 20-m transmission, the minimum received input power of Rx is presumed as -4.26 dBm when Tx output is -2 dBm. This shows a margin of 5.74 dB is obtained to minimum received input power -10 dBm obtained this time. Even if 1.5 dB of cross talk penalty is taken into consideration, it is thought that sufficient signal transmission at 10 Gbps is possible.

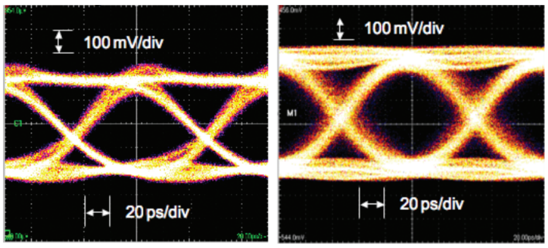


Figure 20 10-Gbps Waveform of μ-POEM R-pack type (Left: Tx optical, Right: Rx electrical).

5. SUMMARY

OptoUnity products will make a significant contribution in replacing electric transmission with optical transmission to enable bandwidth expansion. We have introduced here the development of components for optical inter-connection which makes high-speed transmission and high-density packaging possible. We intend to promote product developments in response to customers' requirements, firmly based on the concept and technologies described here aiming at miniaturization and high-density packaging.

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