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Optical Circuit Board for Optical VLSI Test System

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Advantest Corp announced last September that they had succeeded in “developing optical circuit board technology which enables data transmission up to 160 Gbps”.
The aim of development was to incorporate it into their semiconductor test system.
At the announcement, they stated the commercialization would be made “in three years”.

The background for Advantest to bring optical interconnection technology to “between boards” and “inside board” is the fact that they acknowledge the trend for higher capacity/higher density of MPU.
Advantest predicts: “ In the future, semiconductors having transmission rate beyond 10 Gbps with several dozen to several hundred channels will be used in information equipment”.
In general, a test system must be available before the device under test (DUT) is made.

Assuming that Advantest means the year of 2011 by “commercialization in three years”, the semiconductors “having transmission rate beyond 10Gbps in several hundred channels” will appear on the market around 2012 at the earliest.

The semiconductor with “several hundred channels” as stated here is “VLSI (Very Large Scale Integrated Circuit with optical I/O”, according to Advantest.

Advantest predicts that electric transfer capacity of printed wiring board will reach the limit at some point as the performance of MPU improves.
That is at 20 Gbps.

They believe that VLSI with optical I/O will emerge to overcome this limit.
Then, what is required to testing equipment to test this optical VLSI?

Mr.Naoharu Niki, Managing Director of Advantest Laboratories Ltd. says : “ In the test system, transmission capacity of tera bit order will be required since the test must be conducted many times, simultaneously”.

“To test one chip, 40 Gbps/ch x 24ch, 1 Tbps is needed. 10 Gbps is not sufficient. For high speed testing, electric signals of 10 Gbps must go through PCBs alone. To improve electric component capacity, we may not see advantage if the speed is slower than that level”.

Mr.Niki predicts that optical interface will be mounted on VLSI and MPU at some stage, and “optical VLSI” with optical I/O will be commercialized , although at present silicon photonics utilized in optical interface is showing no better results than transceivers.

Photo-electronic Integrated Board

Optical interconnection between equipment is already used in Advantest’s memory test system , connecting the test head and the main frame.
Parallel transmission is employed and multi-channel data of about 3,000 signals are sent by light.
In the next generation, optical interconnection within the board of the test head becomes necessary (Fig.1).

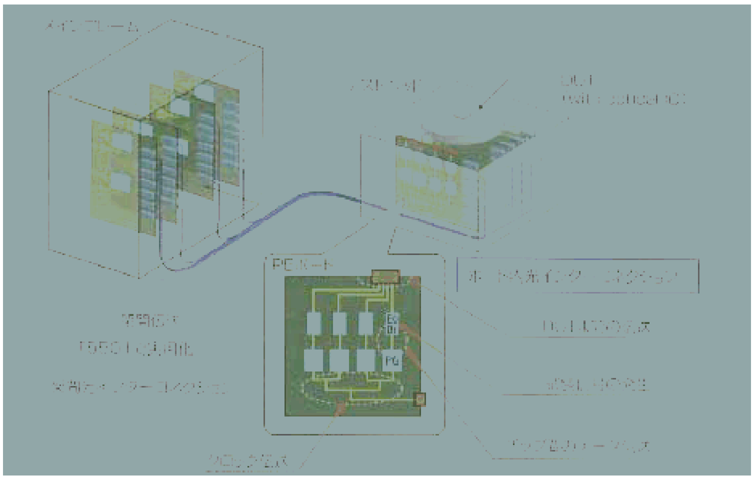

Fig.1
In the optical VLSI tester, optical interconnection is applied within the board.
In Pin Electronic Board (PE) which generates test signal, high speed/high precision electric signal is generated and then converted to light.
The optical test signal of 40 Gbps from signal generator (EO Dr) goes through the board, and is transported to DUT on the performance board (PB) from the board edge.

The circuit of this board is complex, with electronic parts and wiring integrated in high density.
If you want higher mounting density, it is necessary to employ a newly-designed photo-electronic integrated board (optical PCB).

In collaboration with Advanced Photonics Inc, Advantest developed an optical PCB which has optical waveguide within the multi- layer board for higher speed transmission (Fig. 2).

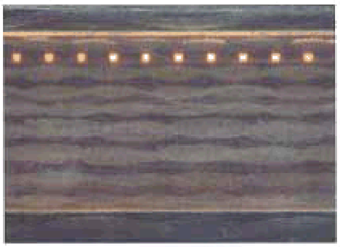

Fig.2

Cross-section photo of optical PCB.

The waveguide is 50 x 50 μ m in size and is formed in the 4th layer of 10 layer FR4 board.

According to Mr.Shin Masuda of Advantest Laboratories Ltd, the prototyped board has 10 layers and the optical waveguide is embedded in the fourth layer.
The manufacturing process of this board is same as that of ordinary PCBs.
But, the layer to contain the optical waveguide is separately prepared, utilizing semiconductor technology , and laminated as in the multi-layer PCB production.

The prototype board is of 300mm x 250mm in size.
" Conventional method is to form the waveguide on the surface rather than within the board, but it becomes restrictive of mounting chips when we think of coexistence with electronic circuit. We made this prototype based on the concept of minimizing interference with electronic parts mounting" (Mr.Masuda).

Advanced Photonics Inc, the partner for this joint development, has an established mounting technology to " deliver the optical signal as closely as to LSI" by embedding both optical waveguide and OE-EO module in the board.
Advantages of this mounting method includes superior transmission property resulting from the fact that neither mirror nor collecting lens is used, and higher mounting density enabled by embedding OE-EO module in the board.

Advantest's port design assumes that the optical I/O is integrated in DUT, the photo-electronic integrated board has the embedded optical waveguide without OE-EO conversion part.
But the design concept demands the bandwidth of 40 Gbps in the optical waveguide.
According to Mr.Masuda, " The larger refractive index （Δ） between core and clad tends to give bigger influence on mode dispersion.

To get the wider bandwidth, this mode dispersion must be reduced , “and so we made the structure of the waveguide for lower Δ and decreased the mode dispersion to achieve wider bandwidth” (Mrt.Masuda).

The details of the optical waveguide including its composition are not made public, but the material is of epoxy –based resin.

According to Mr. Masuda , the reason for using the epoxy-based resin is; “ It may peel off when electronically implemented, unless the material for it is of the same kind as that of PCB. We must consider durability and reliability.

And so, we made the optical PCB using the material of epoxy-based resin which is used in the ordinary PCBs , not going for fluoride-based resin or polymer-type resin.

We did not newly develop the material, but its composition is a little different from that of ordinary epoxy-type resin”.

His explained that the use of the same type of material in the optical waveguide and FR5 board enhanced adhesion strength.

The prototype waveguide is of multimode type and 50 x 50 μ m in size with 205 μ m gap between the waveguides.

The length of the optical guide is one meter in spiral form. The length of up to one meter is thought to be necessary if the waveguide is pulled around on 300 x 250 mm board.

Evaluation of the prototype board

The prototype is made of FR4 board with 10 layers and embedded optical waveguide.

The optical guide is made in spiral form, having 4ch fiber arrays attached to it for input and output purpose.

A through via hole was made near the waveguide placed inside to evaluate reliability of the optical PCB.

A dummy IC is placed on the board (Fig.3).

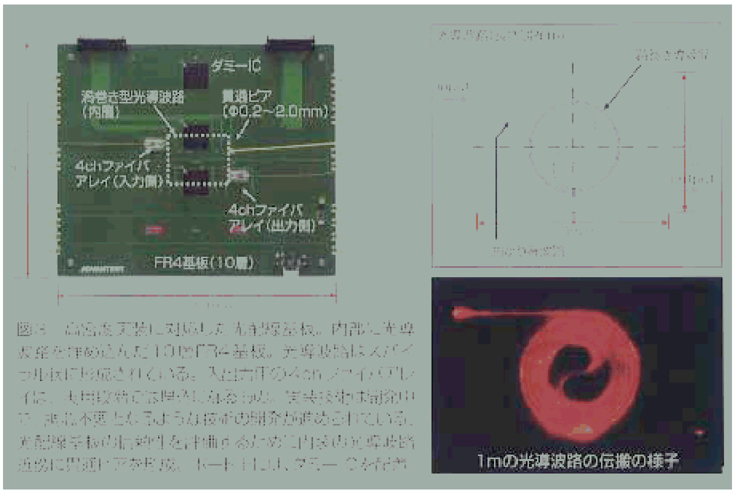

Fig.3

The optical PCB of 10 layer FR4board, compatible with high density mounting, with optical waveguide embedded inside.

Optical waveguide is formed in spiral form.

The 4ch fiber array for I/O will be embedded when it is put into practical application.

Mounting technology is under development, and it includes the technology to eliminate aligning.

To evaluate reliability of the optical PCB, a through via was made near the optical waveguide and a dummy IC was placed on the board.

Reliability test and evaluation of transmission characteristics were conducted to this prototype board. In thermal cycle test (125/-40℃、500 cycles), it was reported ,[1] " Transmission loss and electrical characteristics in the through via hole and the dummy IC were evaluated before and after the thermal cycle test.

The evaluation found that there was no transmission loss, and no disconnection was found either in the through via hole nor the dummy IC".

As for transmission band width, impulse response was measured and evaluated, using femtosecond laser.

The pulse light was generated by converting the wavelength of 1560nm to 780 nm using Periodically Poled Lithium Niobate (PPLN).

Its pulse width is 100fs and its jitter is 750 fs rms.

The pulse light was put into the waveguide, undergone OE conversion by high speed response photo-diode (PD) and its wave profile was monitored by sampling oscilloscope.

The pulse width in the measurement system was compared to the pulse width after transmission through the waveguide, and " band width over 75GHz/m was gained" (Fig. 4).

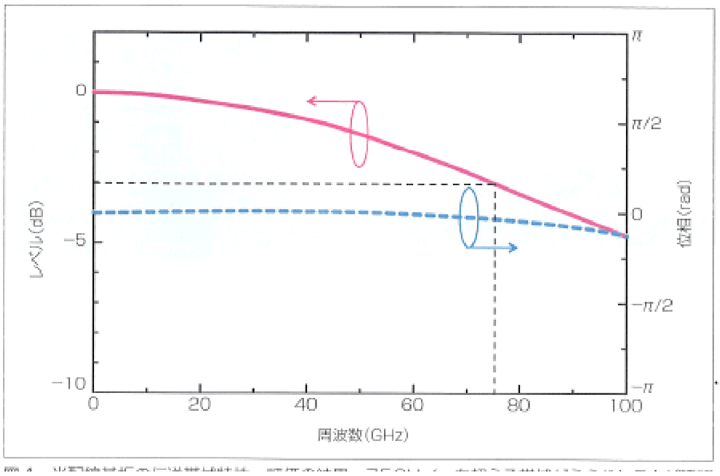

Fig.4

Transmission characteristics of the optical PCB.

The evaluation confirmed that the bandwidth of over 75 GHz/m was obtained.

Based on this result, simulations were made and it was concluded that transmission at the rate of 40 Gbps is possible (Fig.5).

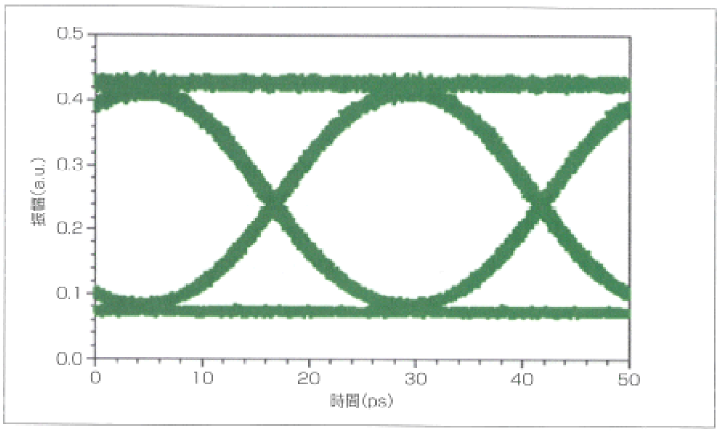

Fig.5

Evaluation result of the optical PCB

NRZ signal (PRBS: 2^{31}-1) was put in the optical waveguide and simulations of transmission characteristics were conducted. A sufficient eye opening was observed and it was confirmed that transmission at 40 Gbps is possible.

At the next step, optical parts will also be mounted.

Advantest defines the current stage of development as “ the stage where each of the elemental technologies should be firmly established”.

The elemental technologies include, in addition to the optical PCB, optical modulator which generates test signal, light source technology which generates optical clock and mounting technology of optical parts.
The optical modulator and the light source must be small in size to be mounted on the board.

The optical modulator which generates test signal must have modulation capacity up to 40 Gbps and must be able to generate complex wave profile with such technique of adding jitter.
Optical modulators may be uniquely developed by Advantest since the bandwidth other than those used for communication is expected to required.
Mode clock laser which generates clock must be stable in time axis and power , of low jitter and small in size.
Those light source and optical modulator were shown in Advantest Show last year. At the next stage of development, the board incorporating those optical parts will be realized.
In high-end computing system, LSI with 20 Gbps 1000 I/O is expected to come on the scene after 2010, and some of the computer manufacturers are developing optical interconnection for it.[2]

At this point of time, however, the forecast does not go that far as to predict that the LSI itself is equipped with optical I/O.
The development being carried out by Advantest will only find actual business opportunities when the semiconductors equipped with optical interface come on the market.
It looks like Advantest's development is getting far ahead of the times.

Mr.Niki states; " The press release stated that commercialization is to be done in three years. Actually, the commercialization will be made, looking at what's going on in the world. The point is that we must be prepared, anticipating the objects of measurement to come on the scene. We are not allowed to lag behind". Advantest Corp seems to be steadily making preparations for the times of optical VLSI.

Reference literature

(1) Kotaro Sakurai et al, BS-10-3-2008, The Institute of Electronics , Information and Communication Engineers, Communications Society Convention
(2) J. Sakai et al. We.2.D.5 ECOC2008