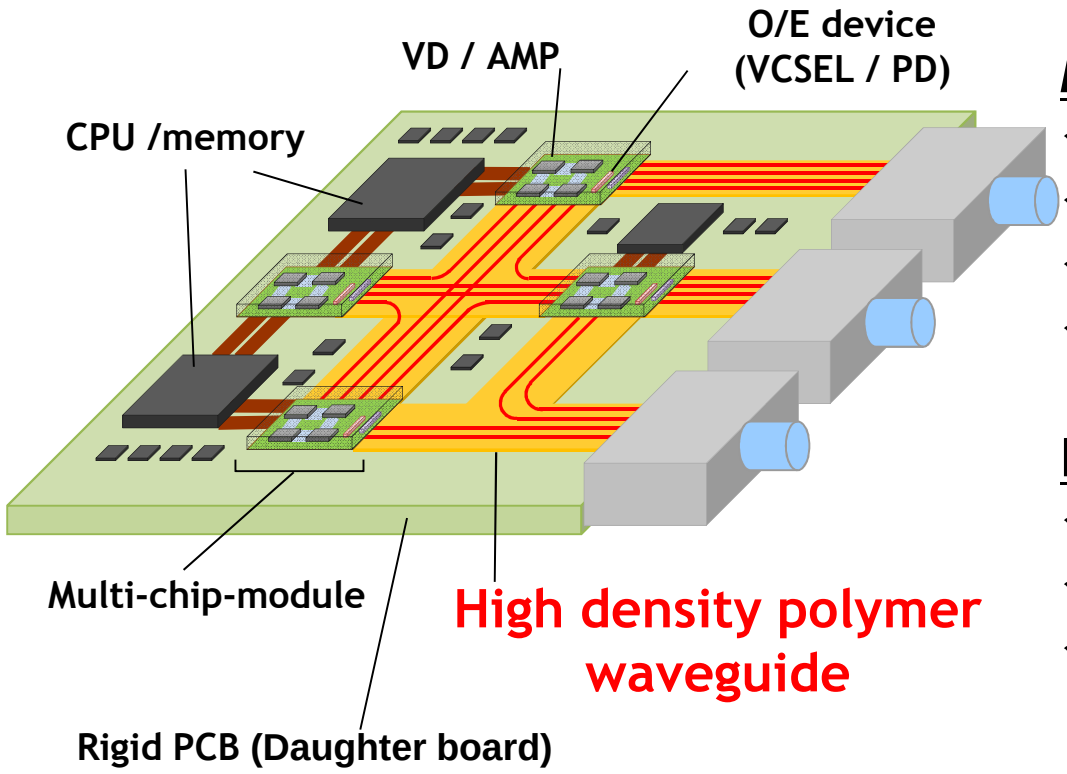
High Speed Practical Polymer Optical Waveguides Demonstrated in 24 ch x 16 Gbps Optical Interconnection Module for Computercom System

COIN Business Development Dept.
Utsunomiya, JAPAN

SUMITOMO BAKELITE CO., LTD.

Ideal Optical Interconnection Structure On-board Level[2]

Polymer waveguides are fabricated on PCB/ embedded in PCB



Model of O/E board example

Merits

- ✓High bandwidth,
- ✓Low-power dissipation
- ✓Compact-size
- ✓Available conventional SMT

Demerits as regards waveguide

- ✓Reliability after reflow process
- ✓CTE mismatching
- ✓Difference of allowance between electrical circuit and optical one

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Proposal of Flex Optical/Electrical (O/E) Module

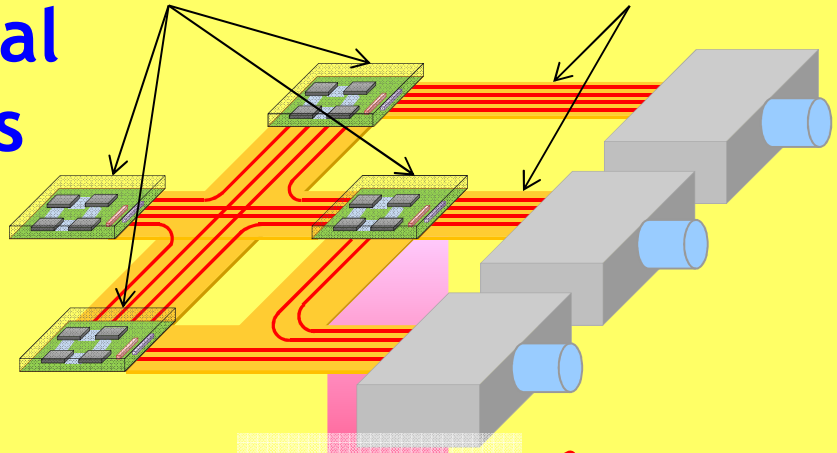
Separation of optical potion from PCB

the final function is same as general ideal structure

Known good(KG) MCM (O/E devices)

Known good(KG) flexible waveguide with optical connectors

Optical parts

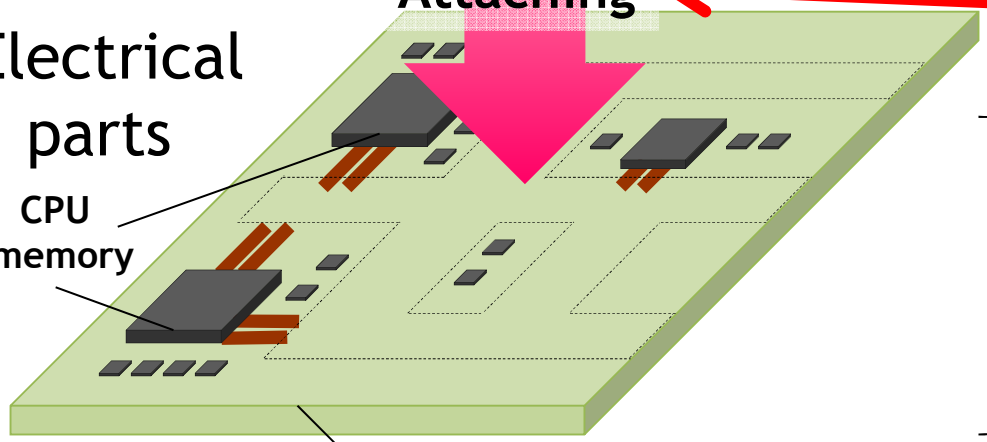


- 1st Assembling each KG parts
  ⇒High yield
- Easy to attach optical connector

- 2nd Precise alignment-less
- 3rd Flexible to attached
  ⇒need not redundant length
- Repairing

Attaching

Electrical parts



- Standard PCB Available
- 4th Standard SMT mounting

Rigid PCB (Daughter board)

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Comparison between Two Structures

		On board/ embedded waveguide in PCB	Flex O/E module
Design	Limitation	Circuit design specifications ☹	Thermal controls ☹
Fabrication	process	One by one, Continuous ☺	Separate, Assembly ☹
	Control of narrow allowance	All points at optics area on/in the board ☹	Waveguide ☺
	Yield	Low (Exponential function of each process) ☹	High (Separated each process) ☺
	Optical connector	Hard to fabricate ☹	Easy ☺
After fabrication	Mounting	conventional SMT ☺	Some assembling process ☹
	Reliability	Hard requirements ☹	Keeping each parts ☺
	Optics Repair	Depends on systems ☺	Possible ☺

Flex O/E module has a big potential to realize reasonably

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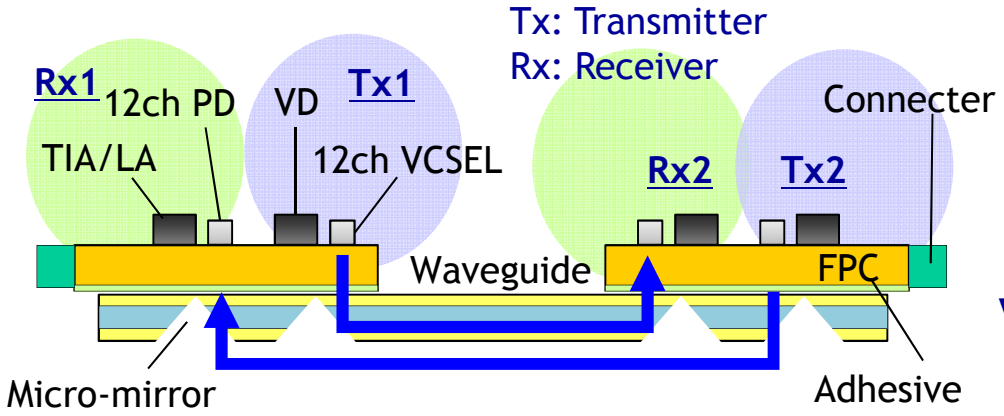
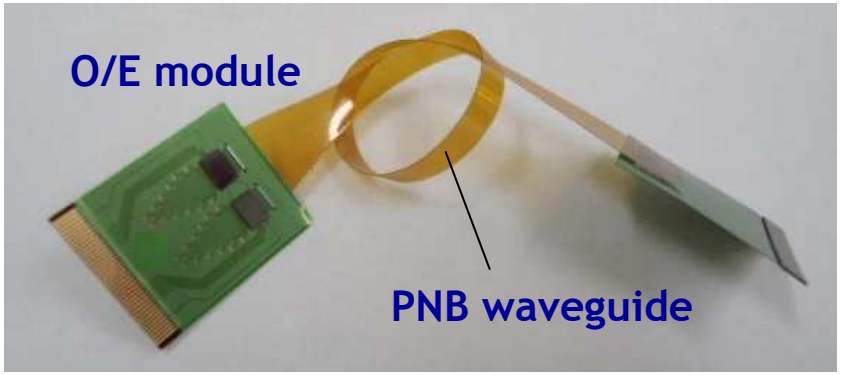
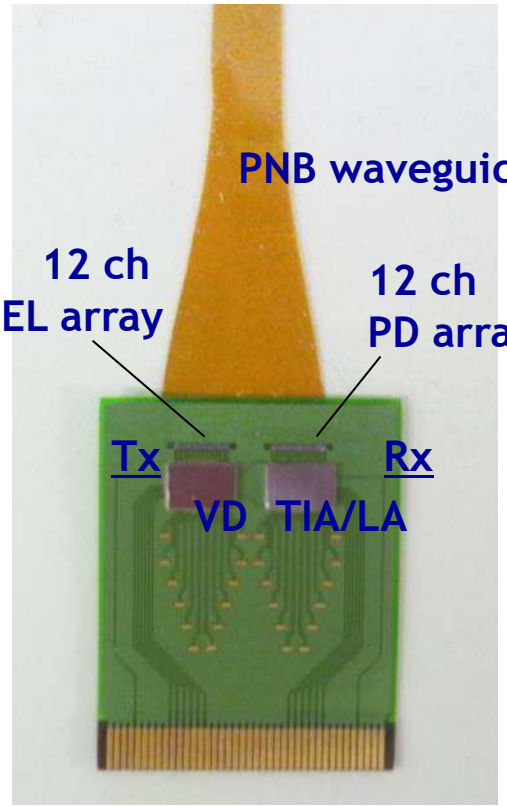
Demonstration of Simple Flex O/E Module

<Schematic module structure >







- Bi-directionally linking by waveguide
- Two flexible printed circuit (FPC) boards with12ch Tx &12ch Rx
- FPC and waveguide were independently fabricated and they are precisely hybridized by standard packaging process.

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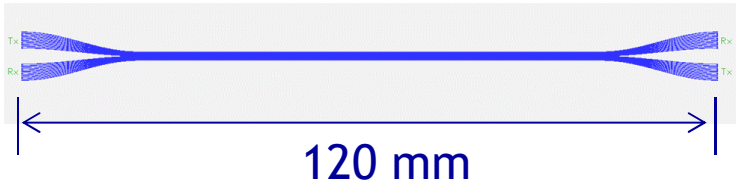
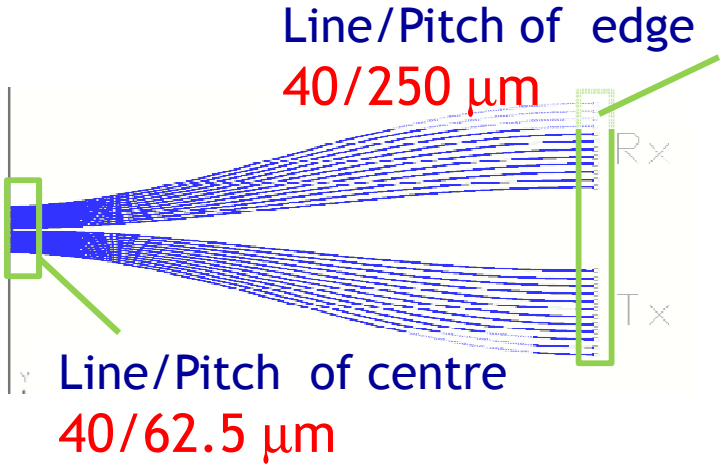
Optical Circuit Design (waveguide)

■ Waveguide design/ key properties

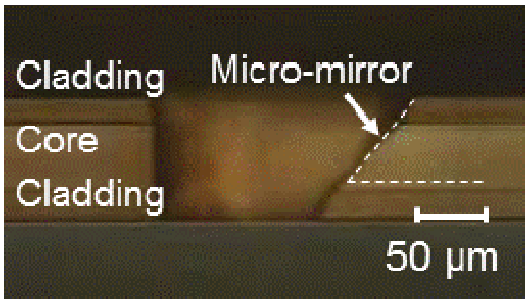


- Propagation loss: 0.04 dB/cm @850 nm
  (by cut-back method



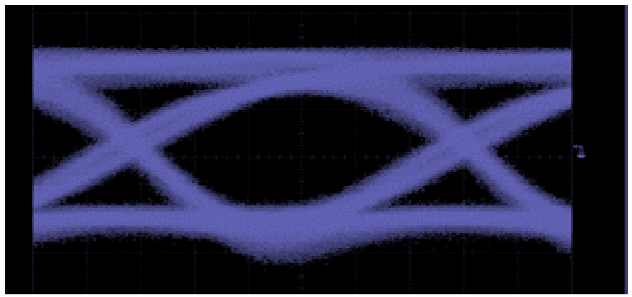
■ Micro-mirror

- Laser Processing
- Smooth surface



■ Eye diagram (waveguide only)

- Data transmission in 120 mm-long edge-to-edge @ 10 Gbps



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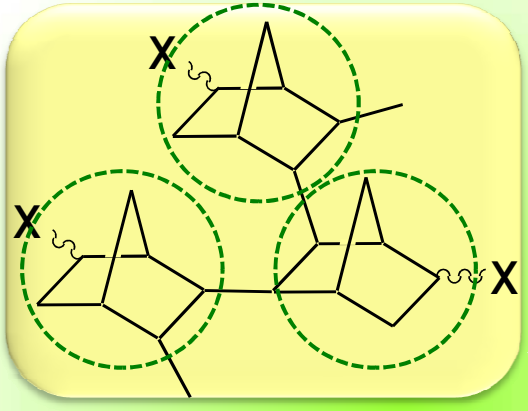
Unique Low Loss Polymer Waveguide

Original polymer material for waveguide



Properties

- High Tg
- Low Water Uptake
- Low ε
- Low tanD

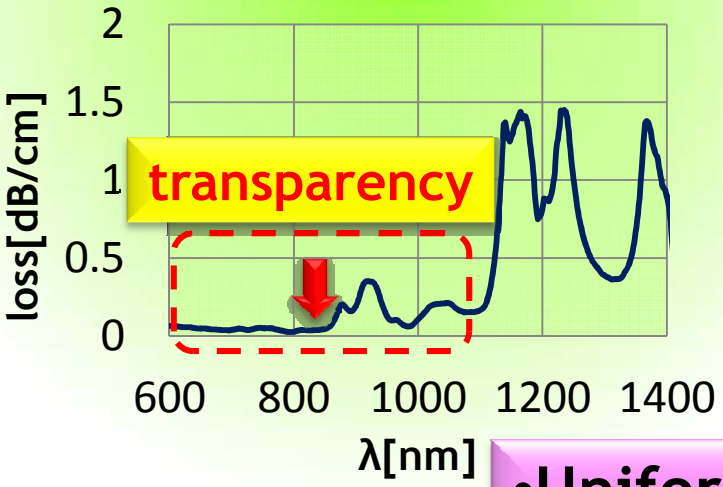
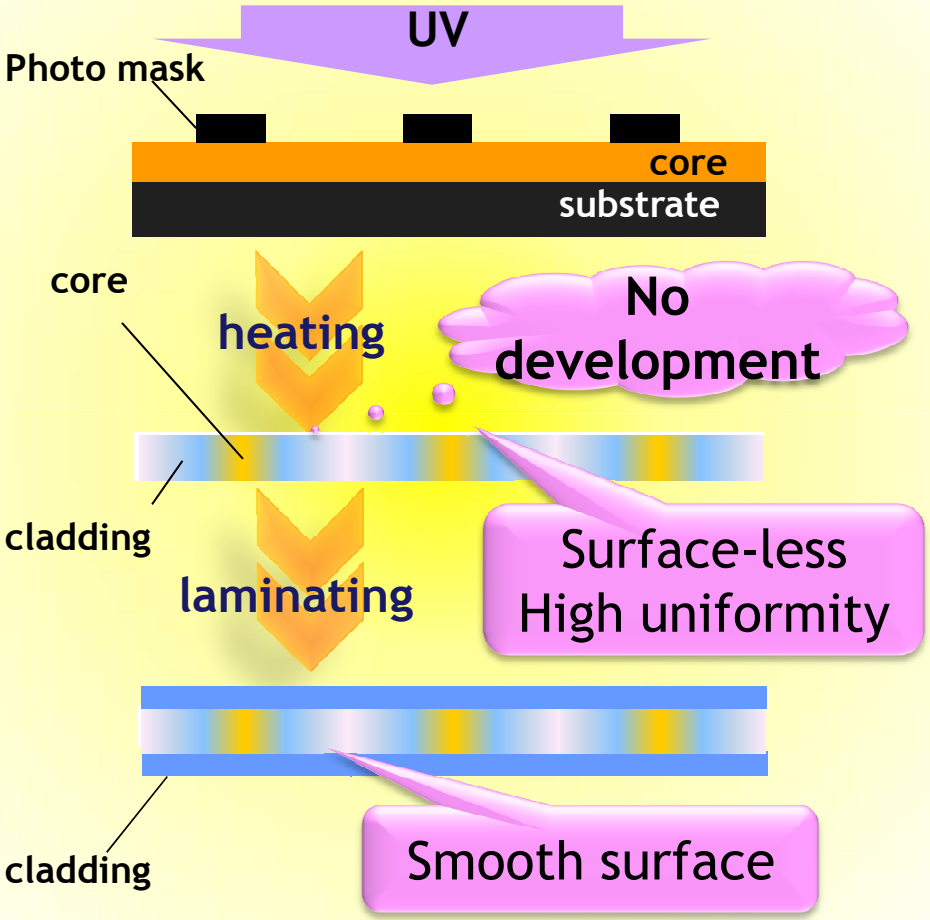


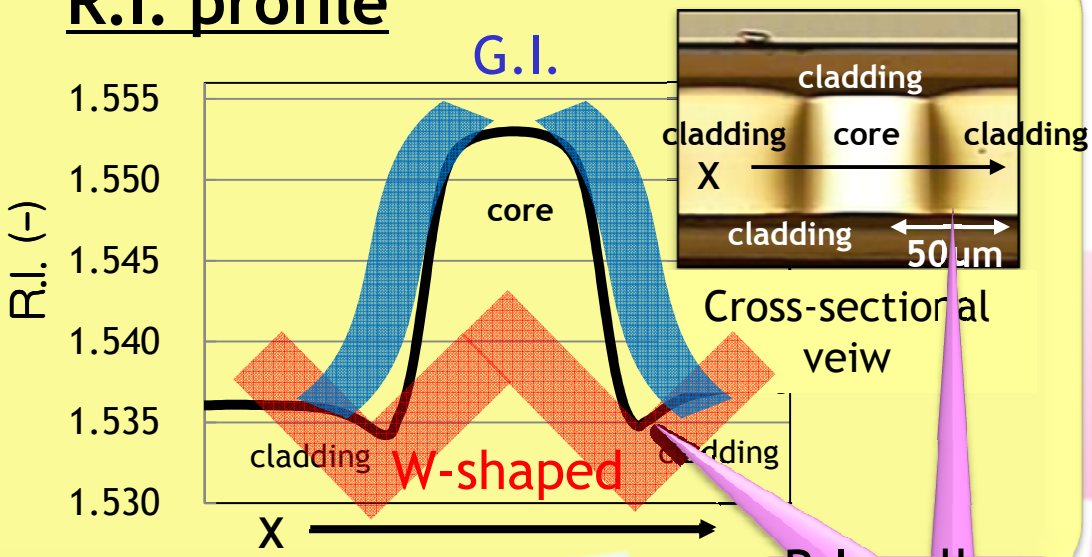
Photo-address method



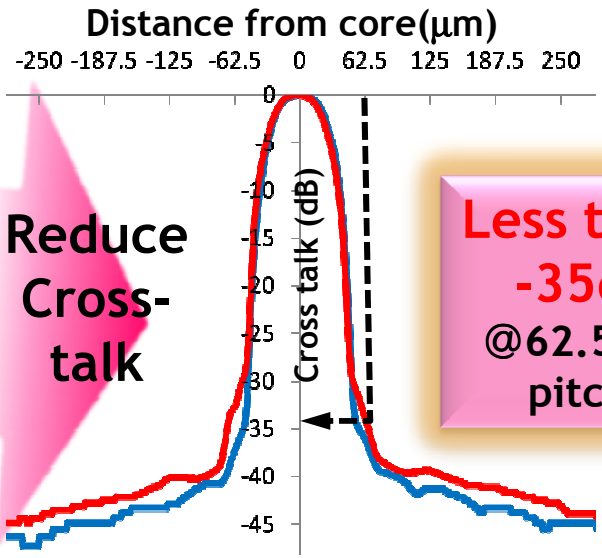
- **Uniformed optical properties**
- **Low propagation loss**

Merits of SB's Waveguides

R.I. profile



Cross-talk



Reduce Cross-talk

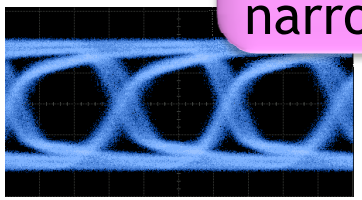
Less than -35dB @62.5μm pitch

Improve S.I.

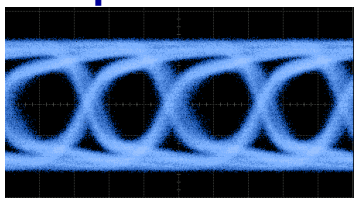
R.I. valleys correspond to dark narrow areas

Eye pattern

16Gbps



20Gbps



Signal Integrity Error Free @16Gbps/ch

Evaluation on O/E module

- High density L/P (Line an Pitch): 40 μm / 62.5 μm
- Low propagation loss: less than 0.04 dB/cm @850nm by cut-back method

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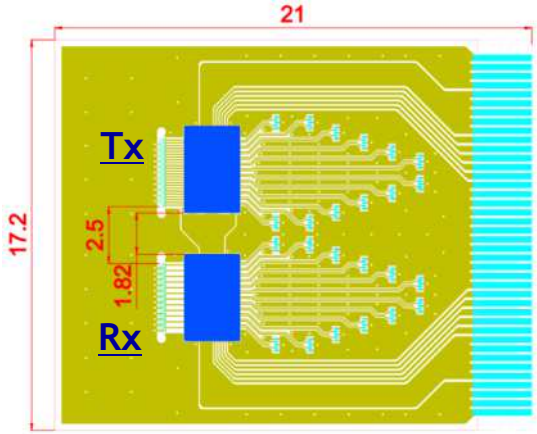
Electrical Board Design (FPC portion)

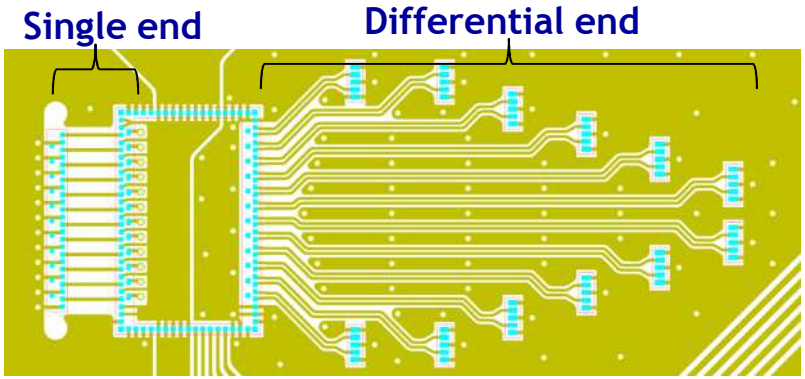
■Electrical board design as a platform for O/E conversion



Board size
: 21.00 mm x 17.20 mm
VCSEL-PD space
: 2.50 mm
VD-TIA space
: 1.82 mm

[μm]

Cross section	Design	Measure
Solder resist	15±10	15± 7
Cu plating	6± 3	14± 5
Cu foil	8± 2	
Polyimide	25± 3	25± 3
Cu foil	8± 2	14± 5
Cu plating	6± 3	



VCSEL-VD (Single end)
Line width : 50 μm Line length : 1 mm
VD-Probe (Differential end)
Line/Space : 40/40 μm
Line length : CH1,12 : 1.95 mm / CH2,11 : 3.55 mm
CH3,10 : 4.60 mm / CH4,9 : 5.75 mm
CH5,8 : 6.95 mm / CH6,7 : 8.10 mm

Related transmission loss was verified to be very small and negligible

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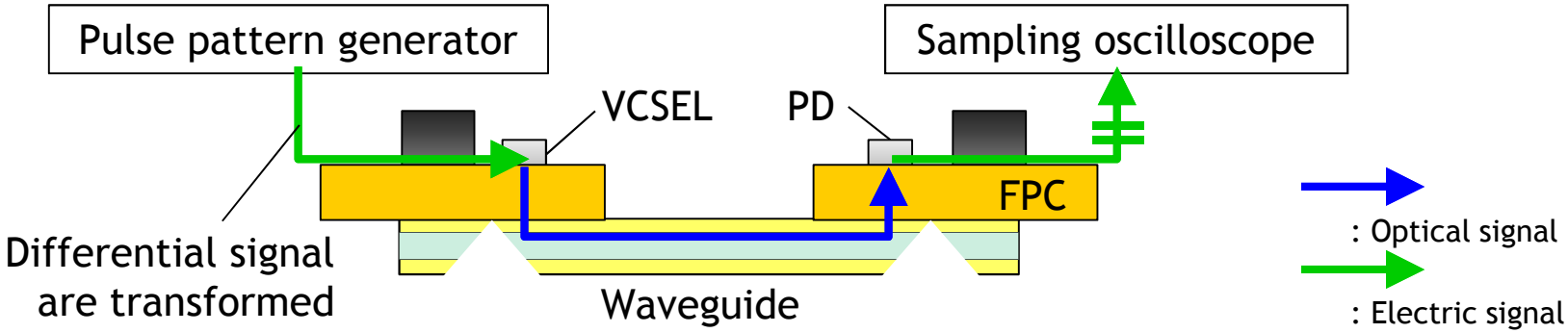
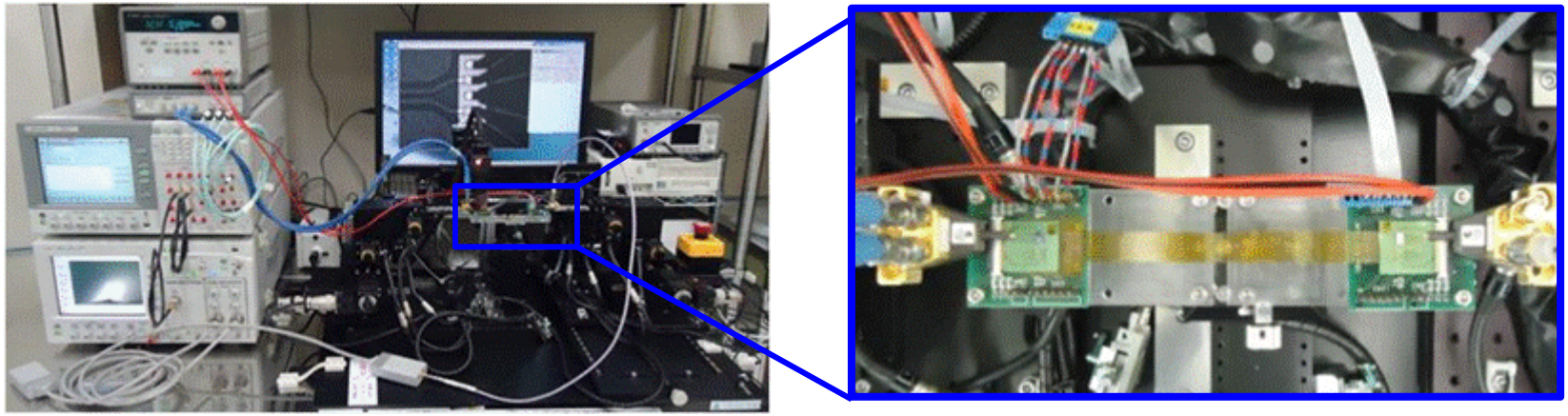
Data Transmission Measurement

■ Measurement set-up



O/E transceiver module



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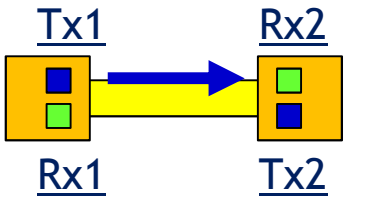
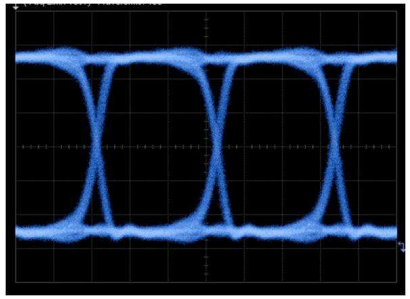
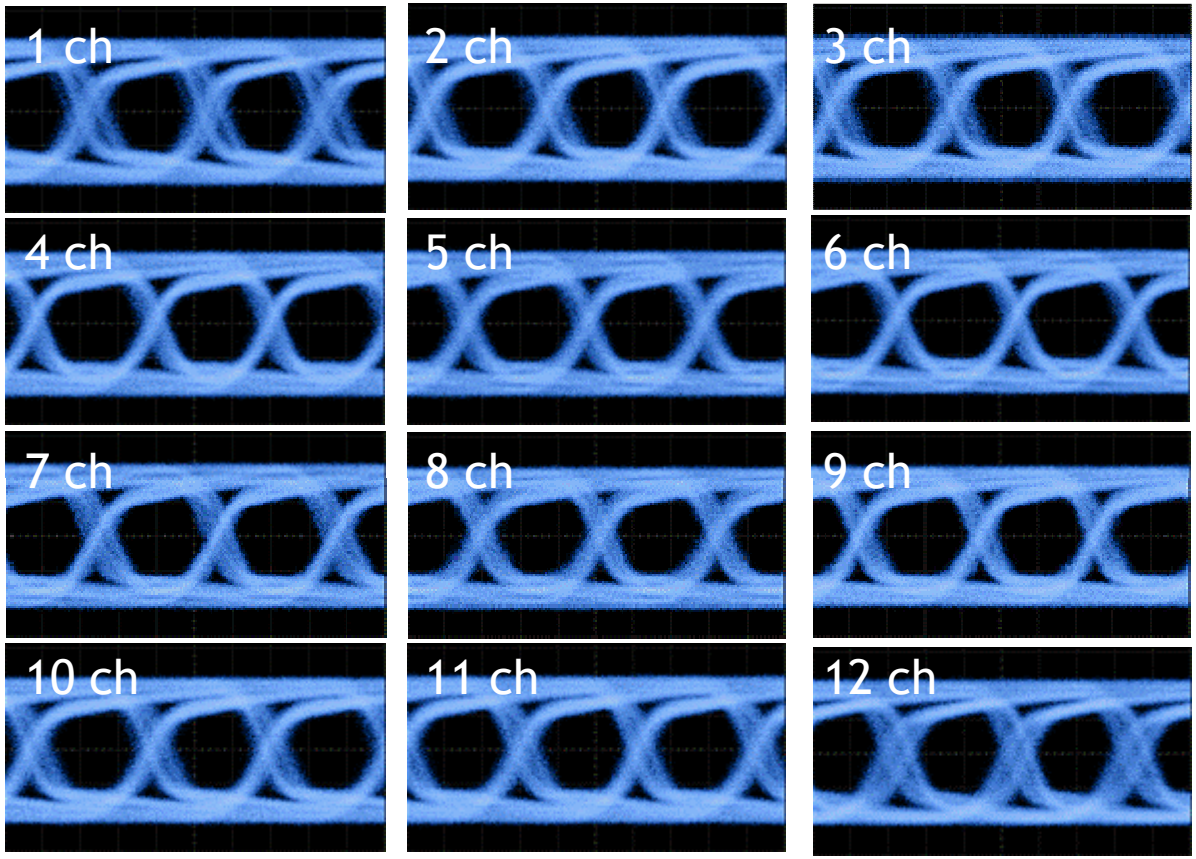
Data Transmission @16Gbps/ch



Reference





- Wide eye opening was observed under the condition of data transmission at 16 Gbps/ch.
- Bit error ratio of every channel was less than 10^{-12}.
- **Around 400Gbps data transmission(Tx1→Rx2,Tx2 → Rx1) was successfully achieved.**

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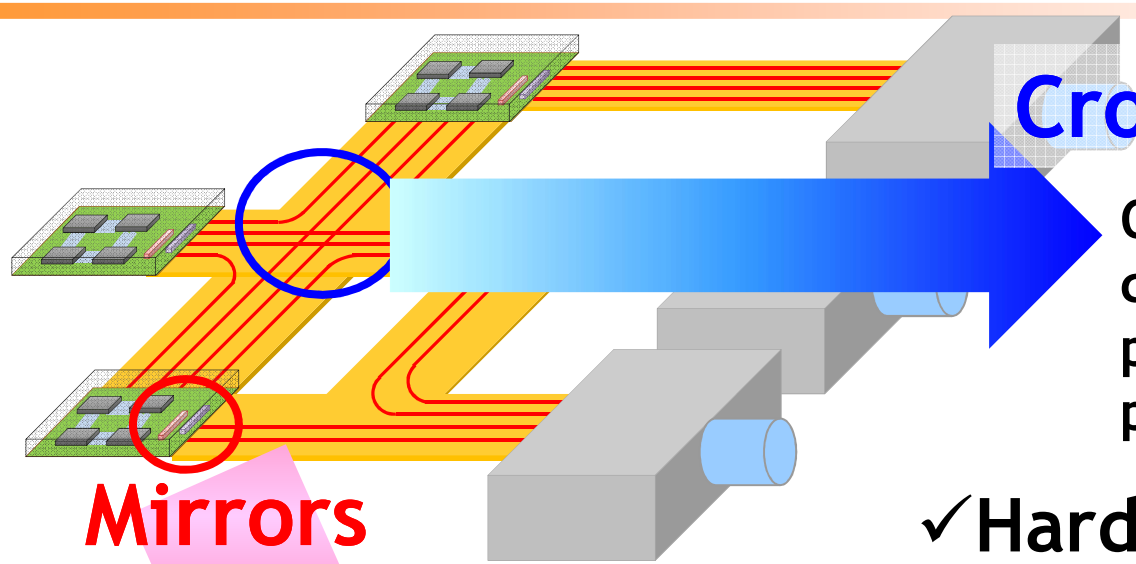
Key Points of Flex O/E Module



Crossed waveguide

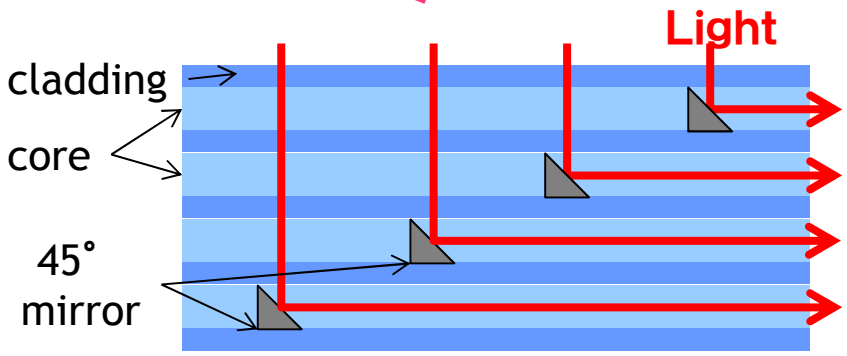
One of merits; waveguide can have crossed light paths in the same circuit plane.

Mirrors

To reduce the footprint of MCM, Optics & waveguide pitch need high-density

- ✓Hard to form uniformly
- ✓Bad crossing loss

Conventional method



Cross sectional view

- ✓Hard to stack multi layers
- ✓ Increasing cost
- ✓Hard to keep reliability

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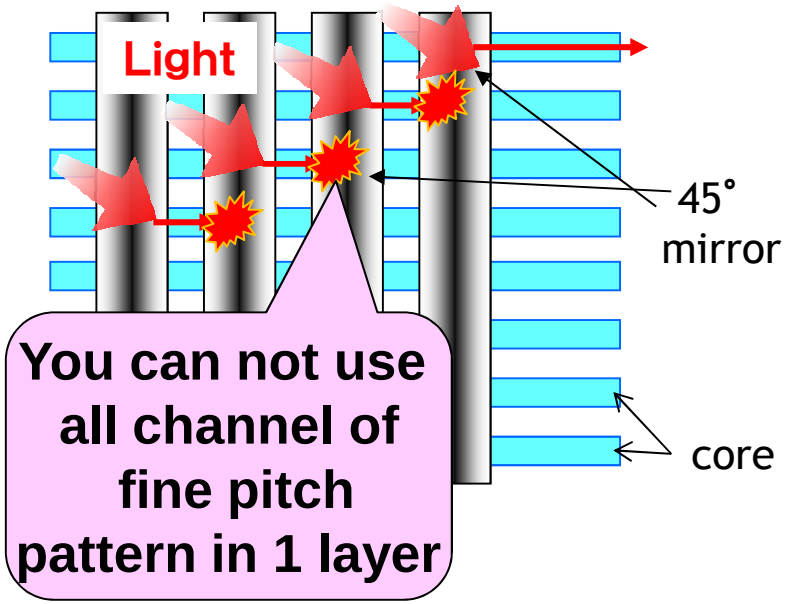
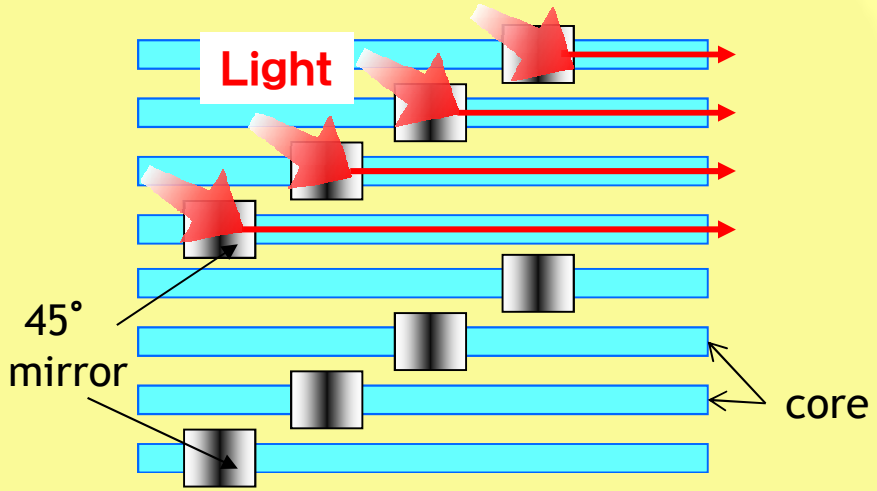
High density 45-degree Mirror

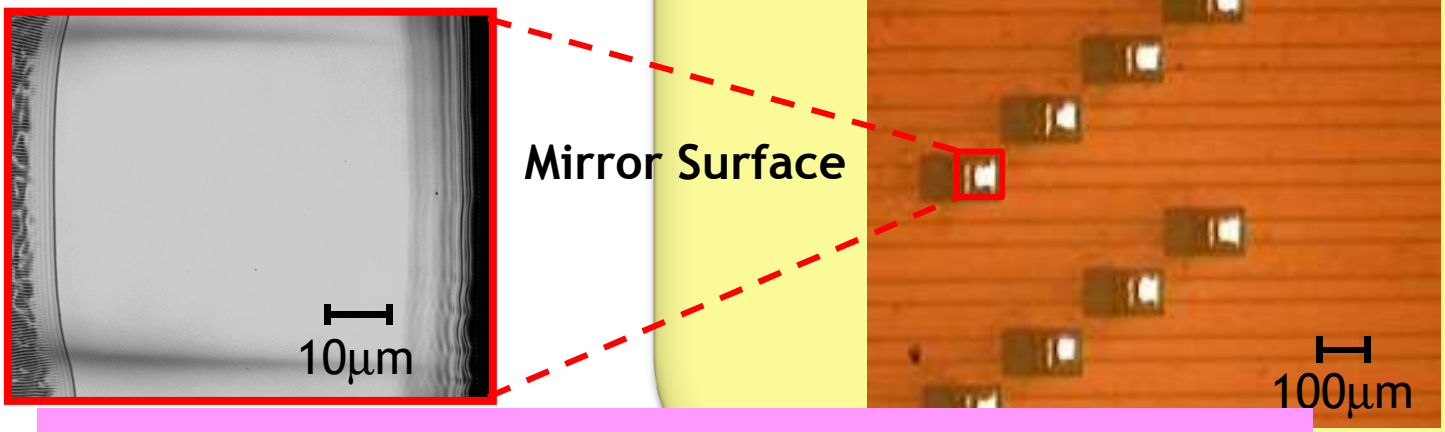
Dicing Mirror(Top view)



SB's Mirror(Top view)



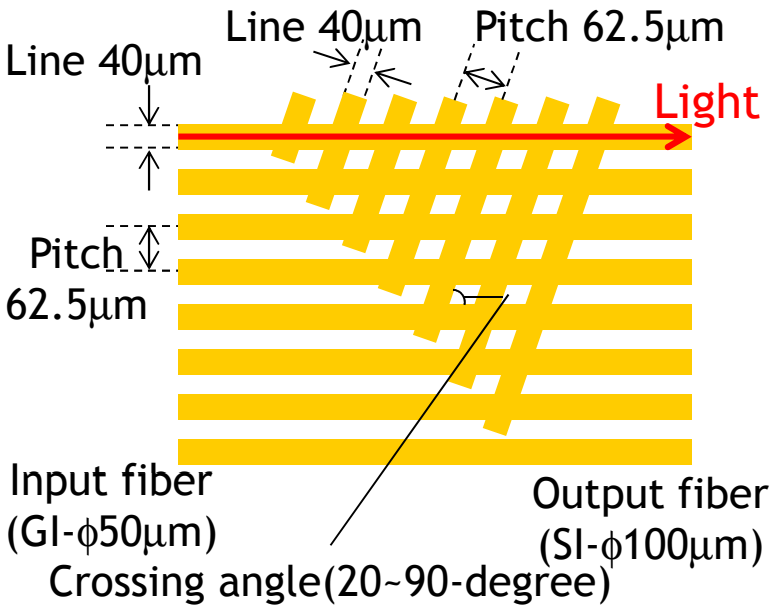
Picture of SB's Mirror (Top view)



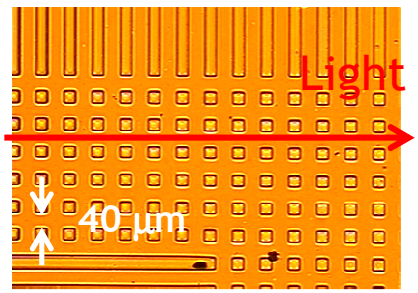
All channels can use core in 1 layer

Low Crossing Loss

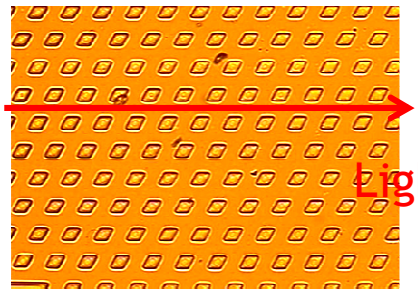
Top view of crossed waveguides design



Photos of top view

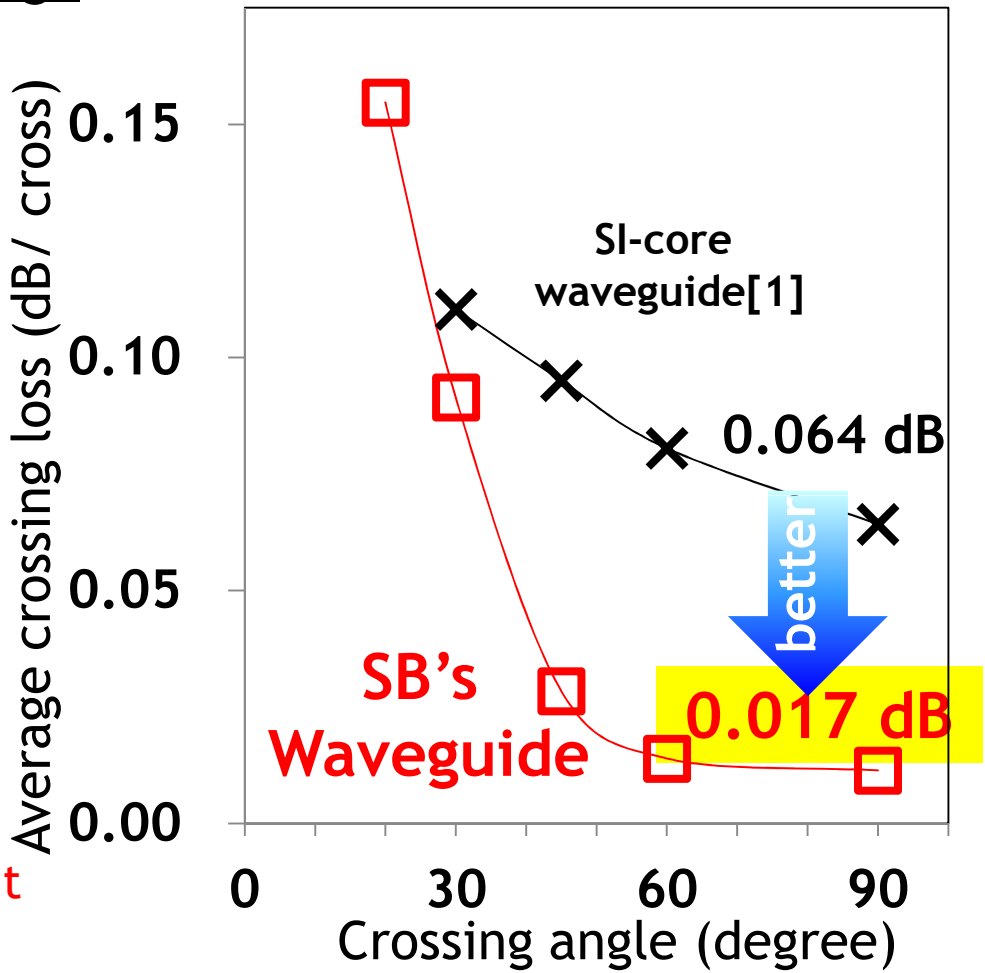


Top view of 90° pattern



Top view of 60° pattern

Average crossing loss of 48 crosses



[1] T. Sakamoto *et al*, *Journal of LightwaveTechnology*, Vol. 18, No. 11 (2000), pp. 1487-1492

- Crossing are successfully formed with no-defects
- Fabricate various angles under same condition

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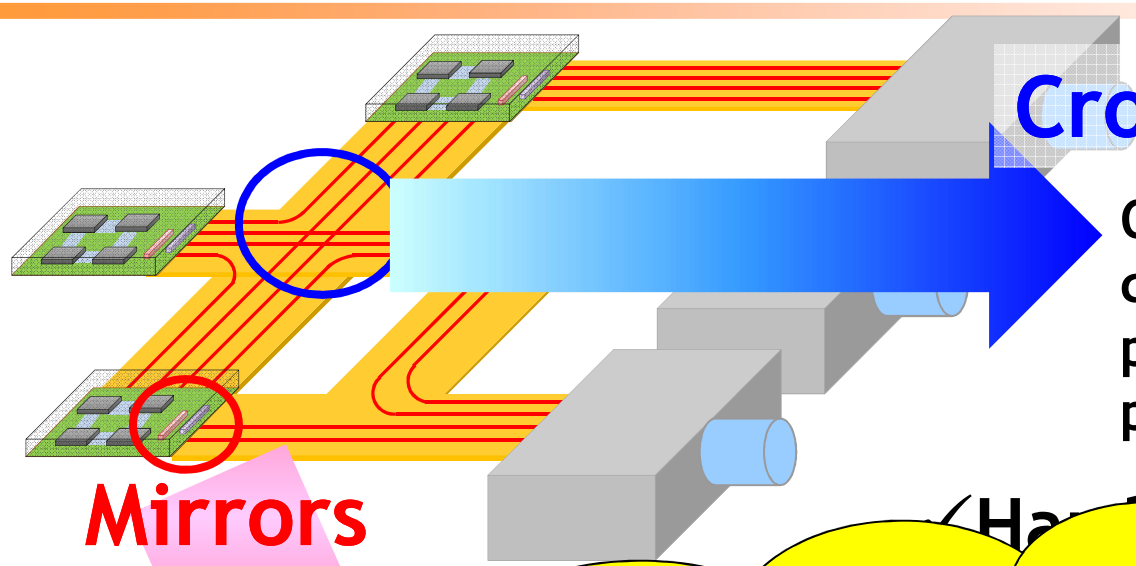
Key Points of Flex O/E Module



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Mirrors

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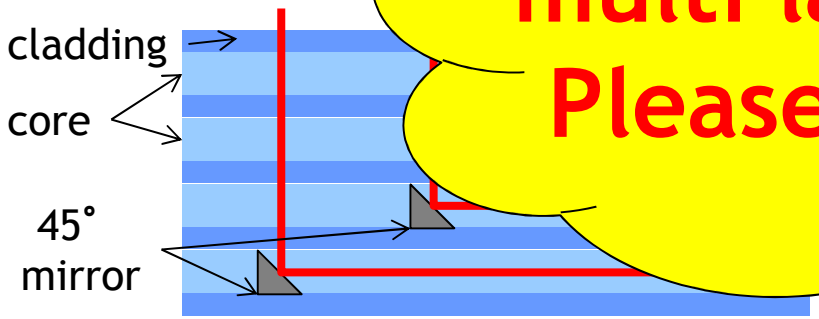
Optics & wavegr
high-density

Conventi



Cross sectional view

uniformly

ers

eep reliability

You don’ t need multi layers structure. Please make simple!

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Reliability of SB's Waveguides with 45-degree Mirrors

	condition	result
High Temperature Reliability Test	1000Hr at 125 deg. C	±0.3dB*
Low Temp. Reliability Test	1000Hr at - 40 deg. C	±0.3dB*
High Temp. and Humidity Reliability Test	85± 2 deg. C, 85± 5% (RH), 1000 Hr	±0.3dB*
High Temp. and Humidity Reliability Test	A. 75 deg. C, 85～95% RH, for 8hours B. R.T., 80～100% RH C. -40 deg. C, for 8hours 5 cycles	±0.3dB*
Thermal Shock Test	Temp. Time 1) - 40 ± 3 deg. C 30min 2) 85± 3 deg. C 30min 100 cycles	±0.3dB*

* ±0.3dB = the margin of error in loss measurement

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Comparison about Cost- effectiveness

decrease ↘ increase → same

		On board/ embedded waveguide PCB	Flex O/E module
Design	limitation	Circuit design specifications ☹	Thermal controls → ☹
Fabrication	process	One by one, Continuous ☺	Separate, Assembly → ☹
	Control of narrow allowance	All points at optics area on/in the board ☹	Care only Waveguide ☺
	Yield	Low (Exponential function of each process) ☹	High (Separated each process) ☺
	Optical connector	Hard to fabricate ☹	Simple fabrication process ☺
After fabrication	Mounting	Easy (only SMT) ☺	Some assembling proces ☹
	Reliability	Hard requirements ☹	Keeping each parts ☺
	Optics Repair	Depends on systems ☺	Possible → ☺

Total costs decrease

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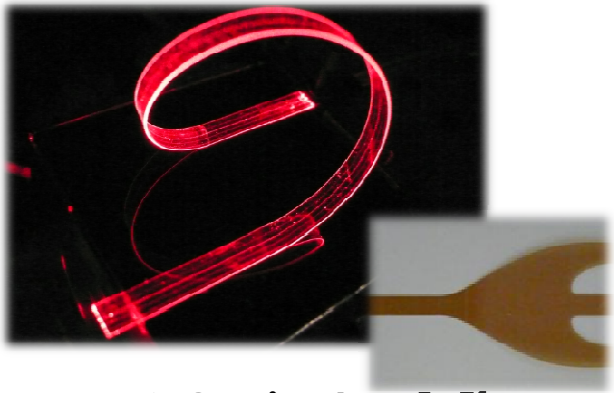
Developing Product Examples(Optical Circuit Sheet)

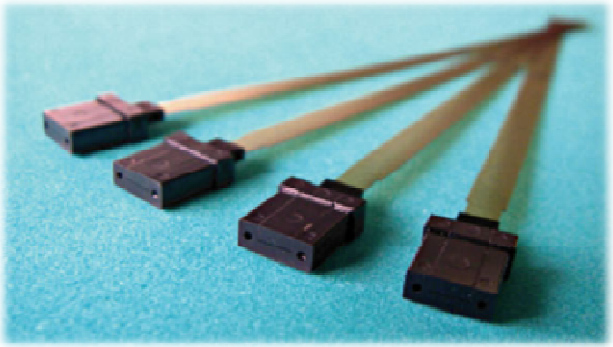
Representative Optical Performance & Design

Propagation Loss	*0.04dB/cm @850nm*
Demonstrated Data Rate	*20Gbps/channel*
Optical Core Pitch	*41.7, 62.5, 125, 250um…*
Crosstalk(with mirror)	*< -20dB @62.5um Pitch*
Length	*Max : 450mm*

2014 -15 Start mass-production

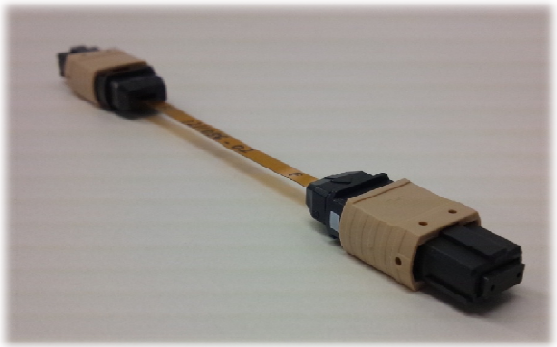


Type A) Optical WG Sheet /with 45° mirror



Type B) Optical WG Sheet with PMT connector

～12ch/250um pitch/1layer
～24ch/125um pitch/1layer



Type C) Optical WG Sheet with MPO connector (under development)

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