Optical Interconnection Technology at RCNS Hiroshima University

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1. Introduction

Signal delay in metal interconnects for ULSI is becoming a serious problem which limits the system performance. Low-resistivity metals such as Cu and a low dielectric-constant materials have been extensively developed to improve the processing speed [1,2]. Another approach to reduce the signal propagation delay in ULSI interconnects is to employ transmission lines, wireless interconnects or optical waveguides [3-5].

At the Research Center for Nanodevices and Systems (RCNS), Hiroshima University, we are studying optically-interconnected systems which enables high-speed parallel pattern recognition. In this paper, some of the research topics developed so far are demonstrated and the future plan is introduced.

2. Why optical interconnection?

As the reason for the optical interconnection, we can stress (1) speed and (2) size. Figure 1(a) shows the signal delay for the metal and optical interconnections. When a RC line consisting metal wire is used, a longer time delay than optical interconnection occurs for the length longer than ~10 mm because of the delay time constant product RC, where R and C are, respectively, the resistance and capacitance of the signal line per unit length [6]. On the other hand employment of the transmission line, for which $R \ll \omega L$, results in the same signal speed as the optical waveguide [3,6]. Here, ω is an angle frequency of the signal and L is an inductance per unit length. Concerning the size of the signal line, the optical waveguide has a big advantage as shown in Fig. 1 (b). In this figure the attenuation constant of the optical waveguide is 0.6 dB/cm and that of the coaxial transmission line is 2.4 dB/cm. The size of the metal transmission line is much larger than that of the optical waveguide in spite of the higher loss. In case of the microstrip transmission line, the size becomes three times larger than that of the coaxial type to suppress the cross talk. From these viewpoints, the optical interconnection is more suitable for integration on the ULSI chips.

3. System suitable for optical interconnection

As shown in Fig. 1(a) the optical interconnection is more suitable for the system with longer signal line. Typical example of such system is "Kohonen net" [7] which implements the parallel pattern recognition as shown in Fig. 2(a). The input pattern signal is distributed to a number of processing units which include distance calculation circuits. The unit which has the minimum distance between the input pattern and the reference pattern is selected as the "winner". Since the total length of the signal line is very long in such a massively parallel processing system, the merit of the optical interconnection becomes more remarkable. An example structure of the optically interconnected chip is represented in Fig. 2(b).

4. Test chips fabricated at Hiroshima University

Optically interconnected test chips developed are shown in Figs. 3(a) and 3(b). The fabricated test chip has the optical waveguides consisting of Si_3N_4 core and SiO_2 cladding layers and CMOS chips bonded on it. The details of the CMOS chip is shown in Fig. 3(b), in which photocurrent amplifiers, LED drivers and other signal processing units detecting minimum distance are integrated. Figure 3(c) shows the measured waveforms for the fabricated circuit, which indicate a correct pattern matching operation. The flag signal becomes "High" only when the reference pattern is "A". For this test chip the LEDs are not integrated on the chip, but the laser input light is incident from the edge of the optical waveguide from the outside.

5. Elemental fabrication technologies

We are developing various elemental fabrication technologies to realize the structure shown in Fig. 2(b). For example, the grating coupler, which guides the LED light to the waveguide, is developed as shown in Fig. 4. The optimum grating material is selected as SiO_2 which gives the coupling efficiency of 25%. The bonding method of GaAs LED onto the chip is developed using epitaxial lift-off technique and low-temperature reaction of GaAs with Pd metal at ~100°C (see Fig. 5(a)) [8]. We have succeeded in the signal transfer from the bonded LED to the Si photodetector integrated in the chip. Figure 5(b) shows the photocoupling characteristics for the bonded LED and the Si photodetector [8]. Although the coupling efficiency is low, the signal transfer from the LED to the Si photodetector is confirmed. The reason for the low coupling efficiency is that the LED was deteriorated by the electric noise before reaching the sufficient light intensity.

6. Research plan

(1) At first the developed elemental process technologies are integrated and the fundamental operation of the optically interconnected system is demonstrated. (2) In the second stage, the operation speed is increased and the superiority of the optical interconnection is verified. (3) In the third stage, the functions exclusively operational in the optically coupled system will be demonstrated. Figure 6 shows an example of such system which accomplishes wavelength division multiplexing (WDM) [9] using photonic crystals. By using the photonic crystals the size of the optical system is expected to become very small [10].

References

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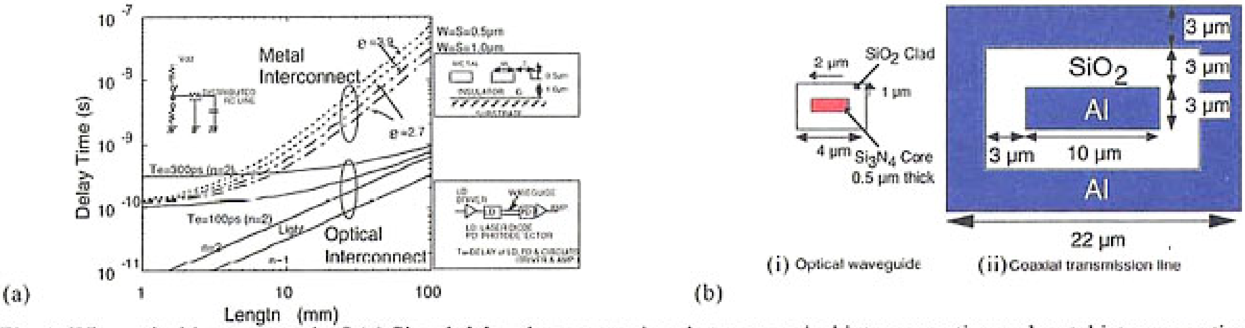

Fig. 1 Why optical interconnection? (a) Signal-delay-time comparison between optical interconnection and metal interconnection. (b) Size comparison between them.

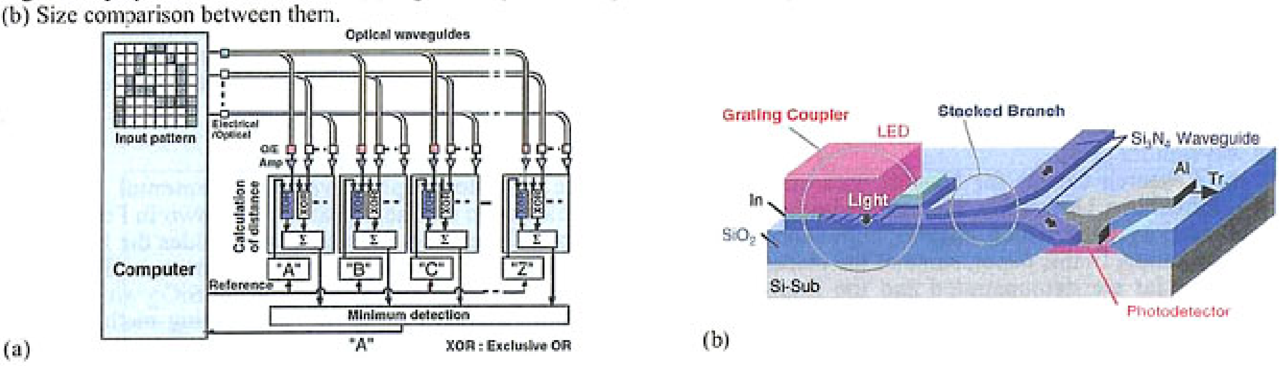

Fig. 2 (a) An example system utilizing the merit of the optical interconnection, i.e., a high speed at long distance wiring, called "optically interconnected Kohonen net" which implements pattern recognition. (b) An example structure of the optically interconnected LSI.

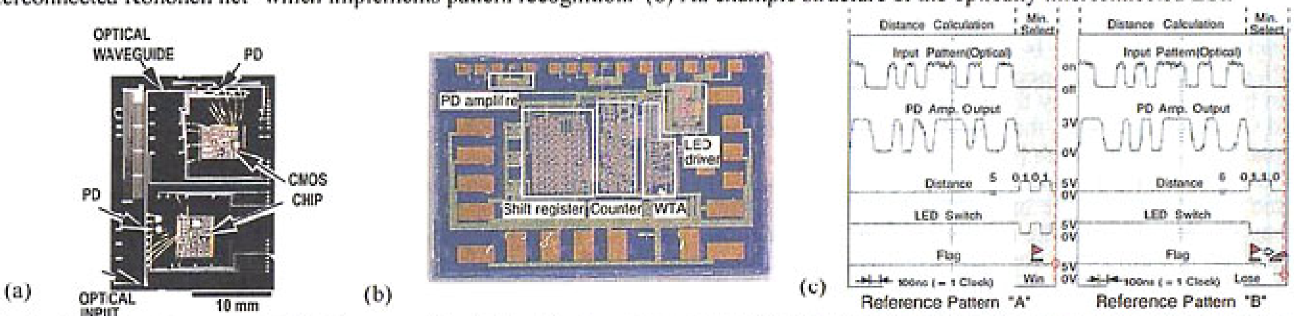

Fig. 3 Optically interconnected "Kohonen net" test chips for the pattern recognition fabricated at Hiroshima University. (a) Total system including optical waveguides, (b) electronic signal processing chip and (c) fundamental operation signals for the diffrent reference signals "A" and "B", which verifies the correct pattern recognition operation.

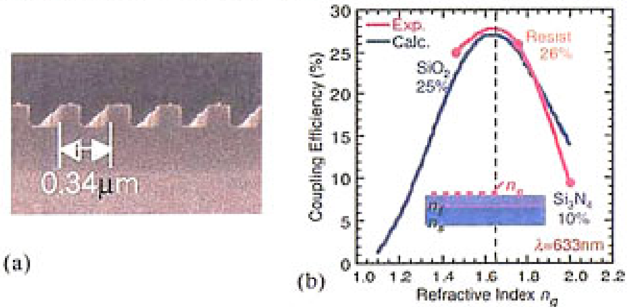

Fig. 4 (a) Cross section of the grating photocoupler which couples LED to waveguide. (b) Couping effciency of the grating couplers. The practically optimum material is SiO_2 which gives the coupling efficiency of 25%.

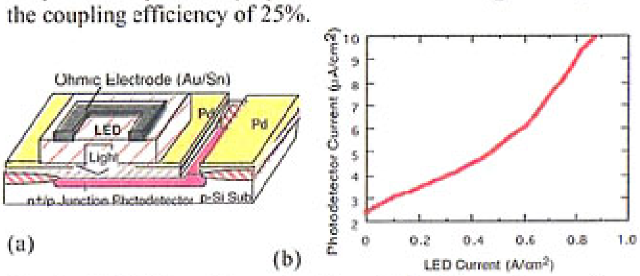

Fig. 5 (a) LED bonding method (metal bonding using reaction of GaAs with Pd at ~100°C) and (b) photocoupling characteristics between bonded LED and Si photodetector.

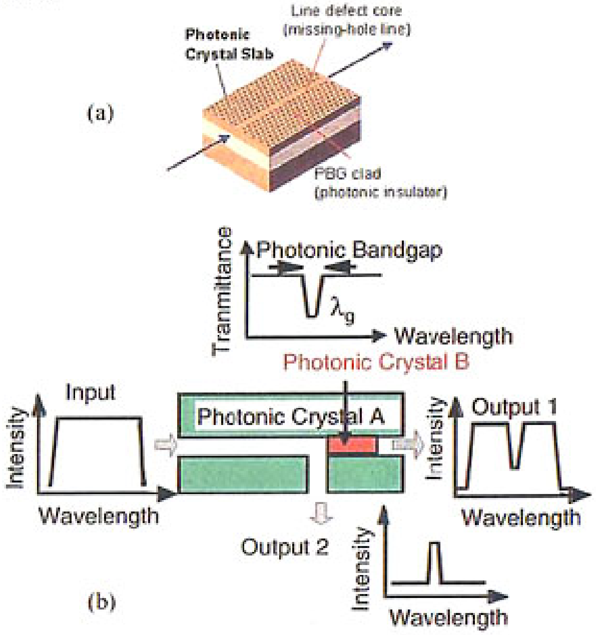

Fig. 6 (a) Principle of photonic crystal waveguide. (b) Example of wavelength division multiplexing (WDM) system using photonic crystals with different photonic bandgap.

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at Reserch Center for Nanodevices and Systems (RCNS)
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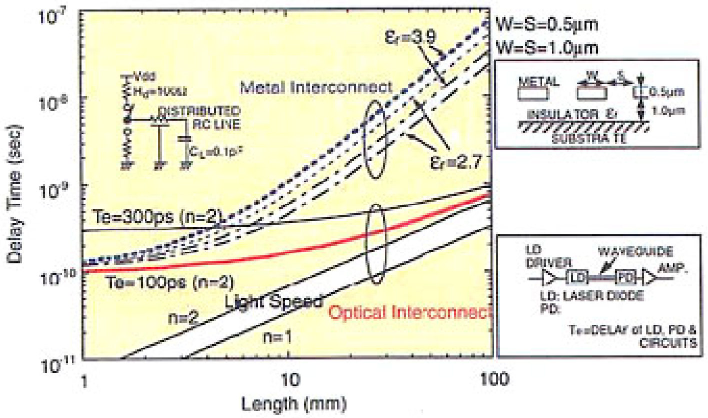
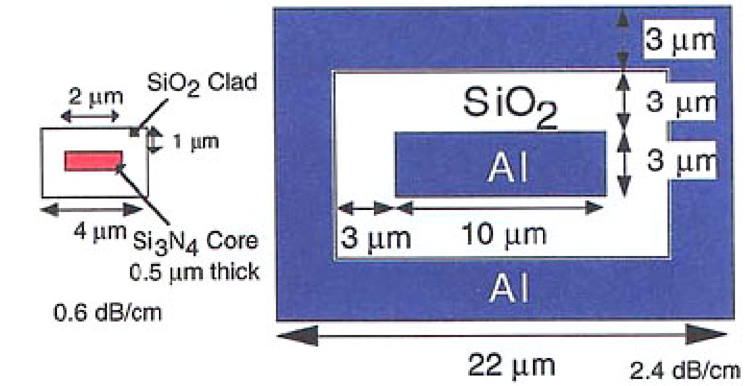
Outline

1. Introduction
   - Merit of Optical Interconnect
2. Research Target
3. Fabrication Technologies
   - Grating Coupler
   - Branched Waveguide
   - LED Integration
4. Research Plan
5. Summary

Why Optical Interconnct? (1) Speed



Why Optical Interconnct? (2) Size

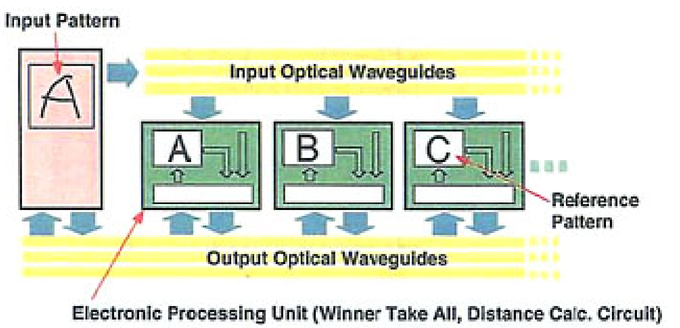


(a) Optical Waveguide

(b) Coaxial Transmission Line

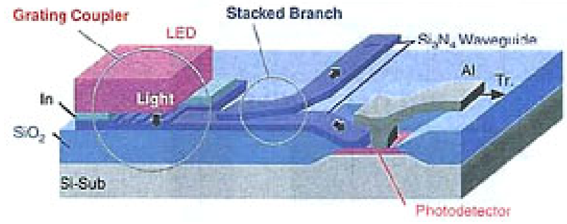
Goal of Our Work

Optically Interconnected Pattern Recognition System on Si Chip

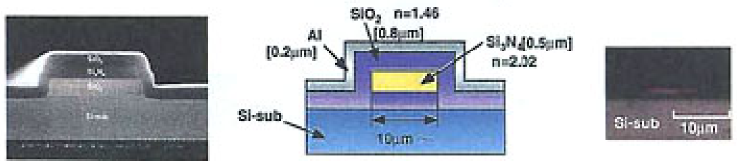


☆Optically Interconnected Kohonen Net

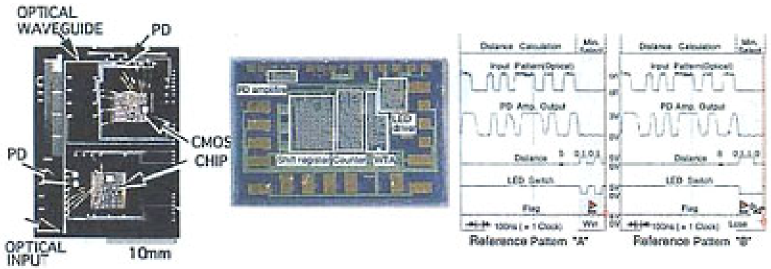
Example of Optically Interconnected LSI



Fabricated Optical Waveguide



Previously Developed Optically Interconnected Chip

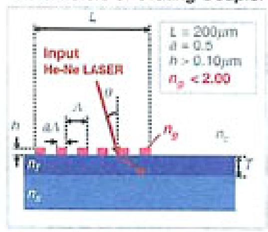


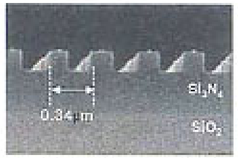
☆Optically Interconnected Kohonen Net

However, LEDs are not integrated.

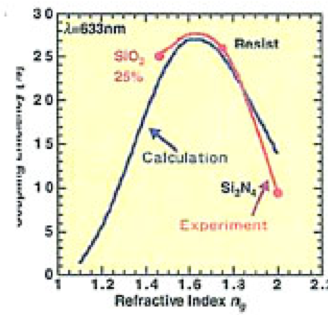
Grating Coupler (1) Normal Type

Parameters of Grating Coupler





SEM Micrograph of the Fabricated Grating Coupler (Cross Section)

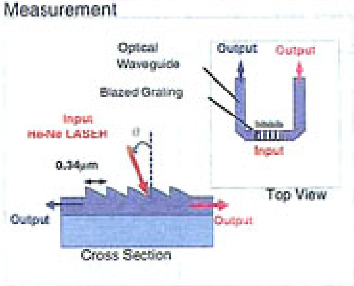


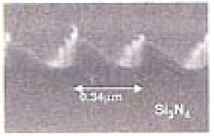
Dependence of Coupling Efficiency on the Refractive Index of Grating

The optimum material is SiO_2 which gives the coupling efficiency of 25%.

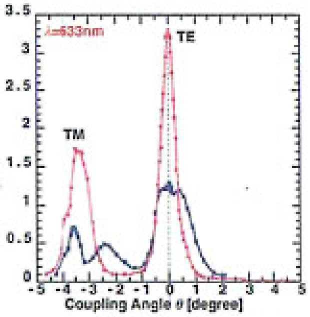
Grating Coupler (2) Blaze Type

Measurement





SEM Micrograph of the Measured Blazed Grating (Cross Secticn)



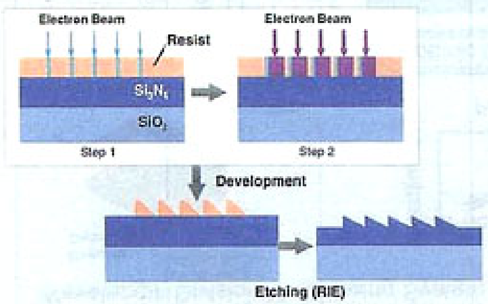
Comparison of Optical Output Power

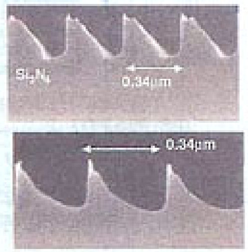
· The blazed grating gives the asymmetry to the direction of propagation.

· **The output ratio rate is 3:1.**

How to Make Blazed Grating

Electron Beam Exposure

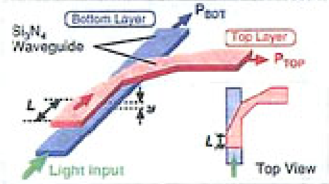


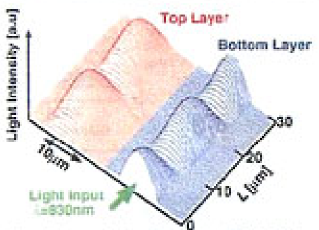


SEM Micrograph of the Fabricated Blazed Grating (Cross Section)

Branched Waveguide (Stack Type)

Structure of Stacked Branched Waveguide

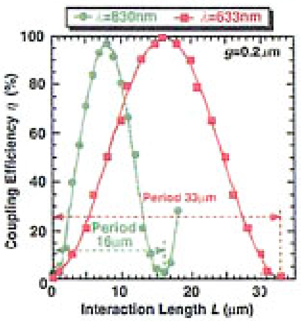




Bird's Eye View of the Simulated Light Power in the Stacked Optical Waveguide

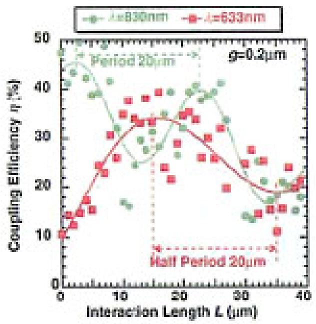
Definition of Coupling Efficiency

$$\eta = \frac{P_{TOP}}{P_{TOP}+P_{BOT}}$$

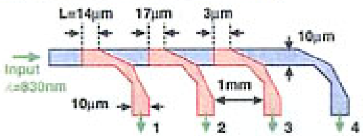


Simulated Coupling Efficiency of Stacked Branched Waveguide

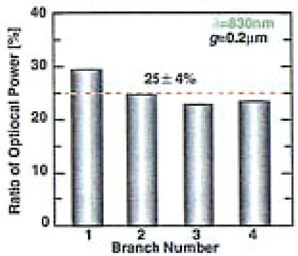
Performance of Stacked Branch



Measured Coupling Efficiency of Stacked Branched Waveguide for Different Wavelength

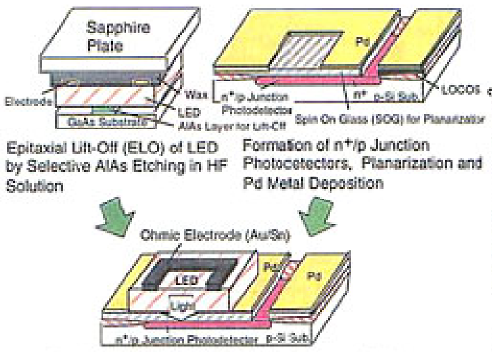


Four-Branch Optical Waveguide

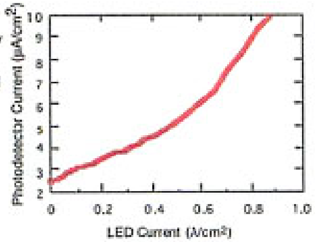


Measured Ratio of Optical Power from the Branched Waveguide

Integration of LEDs on Chip



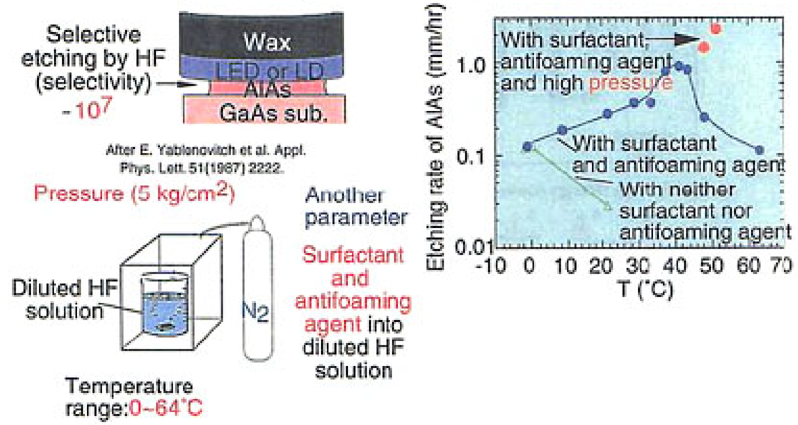
Bonding of LED on Si Chip using Pd as an Adhesive



Signal Transfer between integrated LED and Photodetector.

How to Remove LEDs from GaAs Substrate

— Improved Epiatxial Lift-Off Technique —



Next Resarch Plan

(1) Integration

Previously developed elemental process technologies are integrated and the fundamental operation of the optically interconnected system is demonstrated.

(2) High Speed Operation

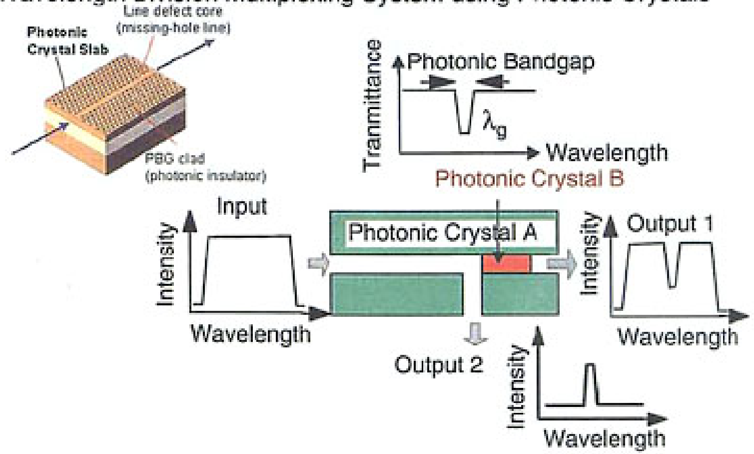
In the second stage, the operation speed is increased and the superiority of the optical interconnection is verified.

(3) Outstanding Function

In the third stage, the functions exclusively operational by the optically interconnected system will be demonstrated.

Future Resarch Plan

Wavelength Division Multiplexing System using Photonic Crystals



Summary

- Merit of the optical interconnection is represented in terms of speed and size.
- Various technologies for optical interconnection developed at RCNS is demonstrated.
- Next and future plan is introduced.