NTT Press Releases

(Press Release)

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Development of laser enabling data transmission with an ultra-low energy consumption of one-tenth the energy of the conventional approach

- Major progress towards optical interconnection for microprocessors -

Nippon Telegraph and Telephone Corporation (NTT, CEO: Hiroo Unoura, Tokyo) has developed an ultra-compact semiconductor laser (LEAP laser[*1]) enabling 10-Gbit/s data transmission[*2] with the world's lowest energy consumption. The energy consumption for 1-bit data transmission is 5.5 fJ[*3], which is less than one-tenth that of conventional semiconductor lasers.
Microprocessors in ICT equipment such as servers and routers consume a large amount of power. In terms of replacing the currently used electrical interconnection technique for data transmissions in/between microprocessors[*4], the optical interconnection approach using this laser will result in an approximately 40% reduction in the energy consumption of the microprocessors.
This result will be announced in detail as an Advance Online Publication in "Nature Photonics" magazine on May 26.

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1. Background

The explosive diffusion of broadband services such as FTTH and smartphones will increase network traffic 200-fold by 2025. The power consumption of ICT-related devices will increase significantly with increases in the data processing speed and throughput of computers as a result of the development of the cloud computing and supercomputer technology. It is estimated that the total power consumed by ICT-related devices will have increased fivefold by 2025 (Fig. 1).
NTT Laboratories have focused on finding a radical solution to the problem of high power consumption and heat generation in ICT equipment by reducing the power consumption of microprocessors (MPU). This is because MPUs consume most of the power in this equipment. NTT Laboratories have developed optical data transmission technologies for off-chip and on-chip optical interconnection in MPUs (Fig. 2).
NTT Laboratories have been developing the LEAP laser (Fig. 3) thus realizing the world's first continuum wave operation of a current-injection[*5] photonic crystal laser with the threshold current[*6] of 390 microamperes at room temperature (20°C-30°C). To employ this laser for optical interconnection between MPUs, one critical issue is to find a way to reduce the threshold current and thus realizing ultra-low energy consumption. An additional challenge is to realize the operation under the environmental temperature in the ICT equipment (80°C).

2. Results

NTT Laboratories have clarified that the reduction of the current leakage[*7] is significant for realizing the reduction of the threshold current and the operation with ultra-low energy consumption. NTT Laboratories have developed a LEAP laser employing a current blocking layer between the laser and the substrate, and current-blocking trenches in the cavity (Fig. 4). The world's lowest threshold current of 4.8 microamperes has been achieved. The use of the active region[*8] containing aluminum has enabled the maximum operating temperature of 95°C (Fig. 5).
The energy consumption for the 1-bit data transmission of 10-Gb/s signals is 5.5 fJ. This is the lowest energy consumption obtained by semiconductor lasers, and is less than one-tenth that of previous results obtained by using VCSELs (Fig. 6). The results confirm that the world's first semiconductor laser for computercom[*9] has been realized.

3. Technical point (Fig. 7)

(1) Reduction of leakage current outside active region

The LEAP laser has a p-i-n junction[*10] parallel to the substrate, which differs from conventional semiconductor laser structures. The previous LEAP laser suffered from current leakage because of a number of undesirable leak paths. NTT Laboratories have designed the device to concentrate the injected current only in the active region and so greatly reduce the leakage current.

1. A current blocking layer with large bandgap energy is installed under the photonic crystal slab to suppress the current leakage through the substrate.
2. A current blocking trench in formed on either side of the active region without degrading the cavity characteristics to suppress the in-plane current leakage of the photonic crystal.

(2) InGaAlAs active region[*11]

The temperature in the microprocessors exceeds 80°C. Therefore, high-temperature laser operation is indispensable. The characteristics of high-temperature operation and high-speed modulation have been improved by changing the active layer material from InGaAsP to InGaAlAs. It was considered difficult to fabricate a buried structure with a small active region such as a LEAP laser using InGaAlAs materials, because of the problem of aluminum oxidization. NTT Laboratories have successfully overcome the fabrication problem, and achieved high-temperature operation up to 95°C and the world's highest modulation efficiency[*12].

4. Future developments (Fig. 8)

This result confirms that photonic crystal lasers, which have been in the basic stage, can be put into practical transmitters for optical interconnections in the microprocessors. The high laser output power and high reliability are challenges for practical optical data transmission between MPUs. NTT Laboratories are aiming to market this laser in about 2016. The large-capacity data transmission between MPUs with low energy consumption will be achieved.
Next, NTT Laboratories will attempt to fabricate a large-scale photonic network circuit by around 2022 to make it possible to commercialize on-chip data transmission in MPUs. These results will lead to a 40% reduction in the power consumption of MPUs. The fabrication of large-scale photonic integration circuits is the challenge in the future.

Glossary

*1 LEAP laser (Lambda-scale Embedded Active-region Photonic crystal laser)

A laser employing a wavelength-scale active region buried in a photonic crystal cavity[*13]. A LEAP laser has the following features.

- High lasing efficiency is achieved. The light and carriers are effectively confined within an ultra-small active region because of the convergence of the buried active region and the photonic crystal cavity.
- The heat generated in the active region is effectively radiated since the heat conductivity of the buried InP layer is more than ten times that of the active layer.

*2 10-Gbit/s data transmission

Data transmission of 10 billion bits per second. Giga indicates a unit of a billion (10^9).

*3 fJ (femtojoule)

The joule is a unit for measuring energy. 1 joule consumes 1 watt of power in 1 second. Femto is a prefix describing a factor of 10^{-15}. The energy consumption of the lasers for the 1-bit data transmission used in present systems is several picojoules for telecom and several 100 femtojoules for datacom. Optical interconnection in/between processors requires a laser operating with an energy consumption of about 10 femtojoules.

*4 Microprocessor

A semiconductor chip consists of integrated circuits with a function for arithmetic processing in computers. Microprocessors are fabricated by the silicon CMOS[*14].

*5 Current injection

A bias voltage applied to a p-i-n junction[*10] generates an electric current, which in turn generates electrons and holes in the active layer for laser emission.

*6 Threshold current

The minimum current for lasing operation.

*7 Current leakage

The current flowing outside the active region[*8].

*8 Active region

The active region is a semiconductor layer where the electron and hole generate laser lights by stimulated emission. Indium, gallium, arsenic, and phosphorus (InGaAsP) materials are used for the laser for optical communication.

*9 Computercom

Computercom describes information communication in computers used as inter-microprocessors, between microprocessors and memories, and for intra-microprocessors.

*10 P-i-n junction

A structure where the intrinsic semiconductor layer is sandwiched between p-type and n-type semiconductors. This structure is used as a diode structure for forward bias stimulated emission. The main carrier of the p-type semiconductor is a hole with a positive electric charge, and the main carrier of the n-type semiconductor is an electron. p-type and n-type semiconductors are fabricated by doping the intrinsic semiconductors with impurities.

*11 InGaAlAs active region

The active region consists of InGaAlAs (indium, gallium, aluminum and arsenic) quantum wells. The energy gap between the well layer and the barrier layer is larger than that of the InGaAsP-based quantum well. This large energy gap features a large optical gain at high temperature.

*12 Modulation efficiency

The modulation efficiency is the ratio of the variation of the modulation speed to the variation of the current. The laser with large modulation efficiency can be operated with high-speed modulation with small current.

*13 Photonic crystal cavity

A photonic crystal is a structure where the refractive index changes periodically with the same scale of wavelength. Nano-fabrication techniques are employed to fabricate the structure from dielectric materials such as silicon. A photonic crystal works as an optical insulator, therefore strong optical confinement is achieved that cannot be obtained using conventional materials. A cavity is a device that spatially confines light and it is typically constructed of mirrors. It is difficult to make a small cavity because a normal reflective mirror cannot be employed.

*14 Silicon CMOS(Complementary Metal Oxide Semiconductor)

This is an elementary transistor structure with low power consumption that constitutes most large-scale integrated circuits. Microprocessors consist of silicon CMOSs and electrical interconnections.

Attachment·Reference

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- Fig. 2: Background (2) Power consumption of CMOS
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