A big leap in energy-saving lasers

A laser with a record low energy cost has now been demonstrated by using a laser cavity based on photonic crystals. Shinji Matsuo of NTT Photonics Laboratories in Japan talked to *Nature Photonics* about its significance.

Why are low-energy-cost lasers so important?

Information capacities are increasing rapidly as information technology infrastructure is improved to satisfy telecommunication needs and increasing Internet bandwidths. According to data published by the Ministry of Economy, Trade and Industry of Japan in 2008, the annual energy consumption for information technology equipment in the world is anticipated to increase from 500 TWh in 2006 to 4,600 TWh in 2025. The power used by servers and routers accounts for two thirds of the total power consumed by information technology in the world; of the power used by servers and routers, half is consumed by central processing units (CPUs). Thus, reducing the energy consumptions of CPUs is expected to significantly reduce the annual global energy consumption for information technology. Using low-power-consumption CPUs will result in additional energy savings because they will dissipate less heat, reducing the energy required for cooling. It is important to reduce the total power consumption because one third of the total power consumption of data centres is for removing dissipated heat by, for example, air conditioning. As CPU cooling technology is typically limited to air cooling or water cooling, cooling power has increased very little from approximately 200 W per CPU for several years. To save energy and increase the transistor density of CPUs, power-consuming parts of the electrical interconnects should be replaced by optical interconnects. According to a numerical analysis performed by David A. B. Miller of Stanford University in the USA, the operational energy of an on-chip light source should be less than 10 fJ bit^{-1} by 2022. Low-energy-cost lasers are required to achieve this target.

What were the key issues in developing low-energy-cost lasers?

As the laser operating energy is proportional to the laser active volume, many research groups have tried to fabricate photonic-crystal-based lasers. However, photonic-crystal lasers with in-plane positive–intrinsic–negative (p–i–n) junctions suffer from high electrical resistances and leakage currents. This results in enhanced heat generation,

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Akihiko Shinya, Masaya Notomi, Kengo Nozaki, Hideaki Taniyama, Koji Takeda, Takaaki Kakitsuka, Tomonari Sato, Koichi Hasebe, Wataru Kobayashi and Shinji Matsuo (left to right) have demonstrated a world-record low-energy-cost laser by using a laser cavity based on photonic crystals.

which increases the power consumption and reduces the emission efficiency in the laser active region. To improve the device performance, we used InAlAs for the sacrificial layer and InGaAlAs for multiple-quantum-well layers. However, this was not straightforward because InGaAlAs oxidizes readily. We developed crystal growth and etching procedures to prevent this oxidation. We succeeded in developing a technique for embedding InGaAlAs multiple quantum wells in an InP layer. Before starting this work, we had theoretically predicted that a laser with embedded InGaAlAs multiple quantum wells would generate significantly lower heat. However, we never anticipated that it would be possible to achieve continuous-wave operation at 95 °C by electrical injection. We were really surprised at this unexpected result. The surface leakage current was further suppressed by the trench between p-InP and n-InP, which was designed to preserve the high-*Q* factor of the laser cavity. We also found that the lasing characteristics are sensitive to the relative positions of the laser active layers and the p–i–n junction. Hence, the position of the p–i–n junction was determined with a precision of less than 0.1 μm so as to optimize the laser performance.

Are there any other required performance parameters besides a low operating power?

To transmit data by a laser beam, the output power should be sufficiently high for the signal to be detectable. If our goal was only to minimize the lasing threshold, we would have fabricated an embedded InGaAlAs single-quantum-well laser. Instead, we dared to fabricate a three-quantum-well laser, because we needed a high enough output power to realize data transmission. For example, to obtain a bit error rate of the order of 10^{-12} using an avalanche photodiode, the received power should exceed −28 dBm, which corresponds to about 2 μW; otherwise, it would be impossible to retrieve the signal, even with amplification. Thus, an output power of at least 10 μW is required to detect the signal when the loss between the laser and the detector is considered. If we had a more sensitive detector, we could implement data transmission with a lower output power. In addition, the modulation current efficiency is also an important parameter. In this work, we realized 10-Gbit s^{-1} optical data transmission with a bias current of only 35 μA.

What are your plans for the future?

From a fundamental physics viewpoint, we would like to further improve low-threshold lasers. Our challenge is to approach the ultimate limit of low-power light sources, which may allow us to observe unprecedented phenomena. From an engineering perspective, we are planning to use low-energy-cost lasers in practical applications by about 2016. To this end, we have to further improve the continuous operation time for lasing and the fabrication yield. However, these goals require more research. The fabrication processes for InP lasers (such as ion implantation and thermal diffusion) are very similar to those for silicon complementary metal–oxide–semiconductor circuits and are well suited for large-scale integration. We are aiming to produce low-threshold and high-quality InP-based lasers at high yields and in large volumes. Additionally, we would like to optimize the cavity structure of the laser. We believe that the laser performance can still be greatly improved.

INTERVIEW BY NORIAKI HORIUCHI

Shinji Matsuo and his co-workers have an Article on few-fJ/bit data transmission using photonic-crystal lasers on *page 569 of this issue.*