the nano-filter shown in **Fig. 5**. The first exposure and development formed the framework of the filter, and the second formed an array of small holes on the sidewalls of the framework. The smallest holes have a diameter of about 30 nm.

Future prospects

Plans call for the development of methods of applying this technique to nanofabrication of various materials, such as semiconductors. In addition, investigations will be carried out to determine how this technique can be used to make new types of highly functional nanoelectronic devices.

For further information, please contact

NTT Science and Core Technology Laboratory Group
Atsugi-shi, 243-0198 Japan
E-mail: st-josen@tamail.rdc.ntt.co.jp

Compact Lasers Generate Light of any Desired Wavelength Filling the Wavelength Gaps of Semiconductor Lasers—Suitable for Applications in Biotechnology, Medicine, and Environmental Measurement

NTT has developed a technique for making solid-state lasers that can be designed to emit at a specific desired wavelength within a certain range, which had been impossible with semiconductor lasers. This new technology is being promoted through the "Comprehensive Producer Function[*1]", a program that was started in July 2003 to promote the commercialization of prominent research achievements. Alliances with other corporations should lead to commercial products on the market in summer 2004. This new technology provides a high output, a longer operating life, and easy maintenance in a palm-sized device. The lasers are also less expensive than conventional lasers. We expect great demand in the fields where large gas lasers are currently used and also in biomedical fields such as DNA or cell function analysis and environmental measurement of NOx or SOx (oxides of nitrogen and sulfur).

Background

Lasers are categorized by their emission sources. For example, there are gas lasers (e.g., the argon laser), solid-state lasers (e.g., the Nd:YAG laser), and semiconductor lasers. Semiconductor lasers have become more common because they are small, light, and inexpensive. They are used mainly for the visible and near-infrared regions for recording media including CDs and DVDs as well as in the telecommunication field (**Fig. 1**).

However, there are wavelength gaps for which semiconductor lasers are not available: the 0.5–0.6-μm region (green, yellowish-green, yellow, orange) and the 2–5-μm region (mid-infrared). For these wavelengths, other emission sources are used and they are more expensive and consume more power than semiconductor lasers. NTT has developed a series of compact lasers that cover these regions. Each laser can be designed to generate a specific

*1 Comprehensive producer function: Special producers appointed for commercialization directly promote the prominent research of NTT Laboratories to put products on the market in cooperation with NTT Group companies and other outside companies.

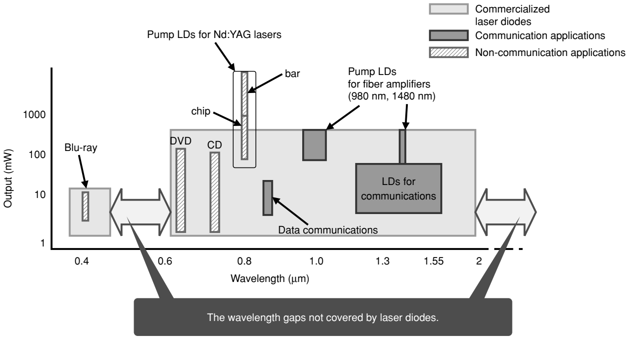

Fig. 1. Commercially available laser diodes.

desired wavelength. Our goal was to create a "custom-made compact laser".

Technological points

The essence of the technology is to combine the outputs from two semiconductor lasers using a highly efficient optical non-linear crystal*2 for optical wavelength conversion (**Fig. 2**). The output wavelength is a function of the two input wavelengths, so by choosing available lasers with appropriate input wavelengths, we can obtain a specific desired output wavelength. This technique is not new, but wave-

*2 Optical non-linear crystal: A crystal whose refractive or absorption index depends on the intensity of the incident light. It is used for wavelength conversion including optical modulation and second harmonic generation (SHG).

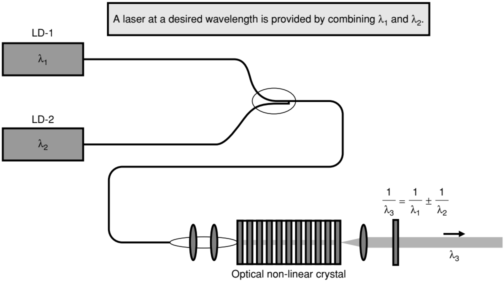

Fig. 2. Technological principle.

length mixing is usually very inefficient. NTT Photonics Laboratories has been researching and developing wavelength converting technology for optical communication using $LiNbO_3$ (lithium niobate)*3 as the optical nonlinear crystal. As a result, we devised a new method of producing crystals that exhibit high conversion efficiency and reliability. A conventional $LiNbO_3$ waveguide exhibits photorefractive damage when it is injected with high-power pump light. We fabricated a ridge waveguide using the direct-bonding technique. This waveguide shows high resistance to photorefractive damage. We succeeded in obtaining a converted light intensity ten times higher than usual by combining an optical non-linear crystal designed for out-of-band communication wavelengths and high-output telecommunication-use semiconductor lasers. This technology can produce a laser that emits light with any desired wavelength in the region from 500 nm to 5 μm (**Figs. 3** and **4**).

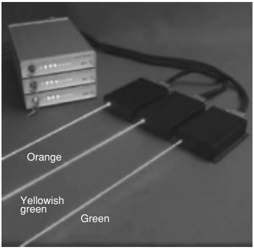

Fig. 3. Compact lasers at specific wavelengths.

Technical features

The laser's features are described below.

- Output power is 10 mW (30 mW is also available)
- Smaller size and lower operating power than a conventional gas laser
- Easier to maintain than a gas laser because of its long operating life
- No need for an external modulator because direct modulation is possible
- Continuous operation at room temperature is possible even in the mid-infrared region (>2 μm).

Applications

The expected application areas are shown below and summalized in **Table 1**.

*3 $LiNbO_3$ (lithium niobate) exhibits the highest electro-optical effect of all practical materials. It is widely used for high-speed modulators for optical communication.

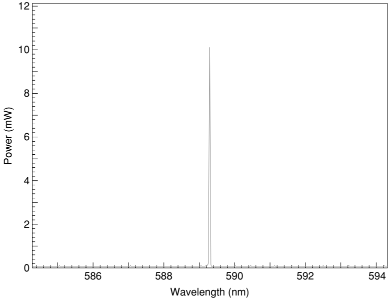

Fig. 4. Example of LD emission spectrum.

Table 1. Product lineup.

Product group	Wavelength	Output power, etc.	Main application fields
Visible laser	0.5–0.6 μm (green, yellowish green, yellow, orange)	3 mW (CW) (>10 mW class under development)	Flow cytometers used in bio-fields, such as cell and DNA analysis, source of excitation light for laser microscopes, etc.
Laser for gas analysis (single longitude mode)	0.65–0.9 μm (near-infrared)	1 mW (CW)	Light sources for sensors of environmental and various organic gases, etc.
	2–5 μm (Mid-infrared)	approx. 1 mW (under development) Room temperature CW operation	

CW: continuous wave

- Flow cytometers or confocal laser microscopes, which are used for applications in biotechnology such as cell or DNA analysis
- Light sources for sensors of environmental gas such as carbon dioxide (CO_2), nitrogen oxides (NOx), sulfur oxides (SOx), and various organic gases
- Replacement for sodium D-line lamps used to analyze the components of medical products, foods, and chemicals

We also expect our lasers to meet demands for new or replacement products in various wavelength regions. For this purpose, we are considering alliances with Kyoto Electronics Manufacturing Co., Ltd. and SC Bioscience Corporation.

Prospects

The technology is expected to be made commercially available by NTT Electronics Co. and marketed in summer 2004, taking full advantage of the "Comprehensive Producer Function".

For further information, please contact

NTT Science and Core Technology Laboratory Group
Atsugi-shi, 243-0198 Japan
E-mail: st-josen@tamail.rdc.ntt.co.jp