Low-power-consumption Module with Widely Tunable DFB Laser Array (TLA)

Hiromi Oohashi†, Hiroyuki Ishii, Kazuo Kasaya, and Yuichi Tohmori

Abstract

The tunable laser is expected to play an important role in the backup light source and reconfigurable optical add-drop multiplexer in wavelength division multiplexing systems. We have developed a widely tunable distributed feedback Bragg (DFB) laser that consists of 12 DFB lasers, a multiplexing coupler, and a booster amplifier integrated monolithically. In this paper, we show the structure and principle of this tunable wavelength laser. We have measured a tuning wavelength range as wide as 40.6 nm, high fiber output power of 20 mW, and low power consumption of less than 2.5 W.

1. Introduction

The rapid increase in Internet traffic has been accelerating the growing demand for greater traffic capacity in recent years. This has stimulated technical development based on wavelength division multiplexing (WDM) systems, which are expected not only to increase the transmission capacity by increasing the number of channels, but also to lead to the next-generation intelligent all-optical networks based on wavelength switching by systems using reconfigurable optical add-drop multiplexers (R-OADMs) and optical cross connects (OXCs). Various kinds of tunable laser have been developed for the light sources in WDM systems. For many years, these trends have driven the studies on tunable lasers, which are the key devices in these systems. In terms of applications, tunable distributed feedback Bragg (DFB) laser arrays [1]-[5] are very attractive.

A tunable DFB laser array (TLA) with temperature-controlled tuning that contains DFB lasers, a multiplexer coupler, and a booster amplifier is an attractive candidate for practical use because the main structure is based on the conventional DFB laser, which is widely used in existing optical network systems. It can provide one wavelength from a wide wavelength tuning range when we select one DFB laser and control its temperature. The characteristics of these DFB lasers, for example output power and lasing wavelength, change continuously without any abrupt change, such as mode hopping. This continuity is important in a working optical communication network system. The system can monitor the change in laser performance due to degradations, so the light source can alert the system before it fails. These characteristics are very attractive for some applications, especially for use as a backup light source, which requires long-term wavelength stability but can tolerate relatively slow wavelength switching. However, high output power, especially in the wavelength range of the L-band, has been a major challenge because a TLA uses temperature-controlled tuning of the DFB lasers.

In this paper, we present a widely tunable TLA with low power consumption that is suitable for use as a backup light source. We fabricated 12 DFB lasers integrated with a multimode interference (MMI) coupler and semiconductor optical amplifier (SOA). These DFB lasers cover a wide wavelength range and their wavelengths depend on the laser temperature.

† NTT Photonics Laboratories
Atsugi-shi, 243-0198 Japan
E-mail: hiromi@aecl.ntt.co.jp

The tunable lasing wavelength range of all 12 DFB lasers is as wide as 40.6 nm for a temperature change of 35°C. The TLA provides a high fiber output power of 20 mW in the L-band wavelength range. High-temperature operation of the TLA makes it possible to lower the power consumption to less than 2.5 W.

2. Structure

The structure of the TLA is shown in **Fig. 1**. It consists of an array of 12 DFB lasers, a 12×1 MMI optical coupler, and an SOA. The output light from each DFB laser is introduced into the MMI coupler through an S-bend waveguide, and the light from the MMI coupler is amplified by the SOA.

The DFB lasers and SOA have an active layer composed of compressively strained multiple quantum wells, which is designed to achieve low-threshold operation in a wide range of DFB laser temperature. A $\lambda/4$-shifted grating is formed on the DFB laser region by electron beam lithography and wet etching to determine the lasing wavelength precisely. The wavelengths of the lasers are initially set roughly to nominal values with a spacing of 3.4 nm by designing the grating pitch, which corresponds to wavelength tuning with a temperature change of 34°C. The laser cavity length is 450 µm and the separation between the lasers is 30 µm. After removal of the active layer in the MMI coupler and waveguide region, the InGaAsP layer, corresponding to an energy band gap of 1300 nm, which is effective in reducing the bending radius of the S-bend waveguide and consequently reducing device size due to the high refractive index, is butt-jointed to the active layer of the DFB lasers and SOA. The DFB lasers, SOA, and waveguide are buried by a p-n current blocking layer. The MMI coupler size is 47×390 µm^2. The length of the SOA region is 1200 µm. The overall size of the devices is 620×2600 µm^2. The end-facets are both coated with anti-reflection film, which reduces the facet reflectivity to less than 0.05%.

The chip is packaged in a 26-pin 12.7×20.8 mm^2 standard butterfly package. A schematic diagram of the TLA module is shown in **Fig. 2**. It consists of the TLA chip, two lenses, an isolator, and a wavelength locker. The wavelength locker is set in front of the TLA chip and the isolator is set between the TLA chip and wavelength locker. The wavelength locker has two photodetectors, two beam splitters, and an etalon filter. Small amounts of the output power are extracted by the beam splitters and fed to the photodetectors. One photodetector is used for monitoring the output power. The second photodiode has an etalon filter in front of it for monitoring the lasing frequency. An etalon filter has periodic transmission characteristics that depend on the wavelength, so we can monitor the wavelength (and hence the frequency) by obtaining the signal from the photodetector. The module includes two thermoelectric coolers based on the Peltier effect. One (TEC1) is for controlling the temperature of the TLA chip, which in turn controls the wavelength of the TLA chip, and the other (TEC2) is for keeping the temperature of wavelength locker constant.

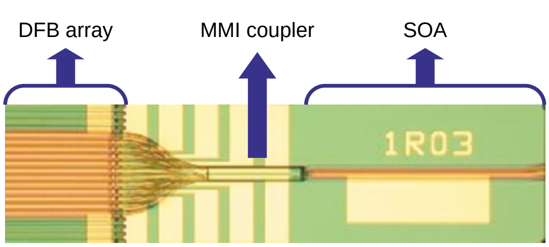

Fig. 1. Structure of tunable DFB laser array.

3. Characteristics

The lasing wavelengths of the DFB laser array can be changed by controlling the temperature of the TLA chip using TEC1. A temperature change of 35°C caused each DFB laser to exhibit a wavelength change of 3.5 nm. The wavelength difference between neighboring lasers was set to 3.4 nm so that the 12 DFB lasers would cover a wavelength range of over 40 nm. The dependence of the TLA module's lasing wavelength on temperature in the range between 15 and 50°C is shown in **Fig. 3**. The chip's output wavelength was selected by choosing one of the 12 lasers and setting it to the desired temperature with the chip cooler, TEC1. In this experiment, we set the driving currents for one DFB laser and for the SOA to 100 mA. The center wavelength was around 1590 nm in the L-band. The total wavelength tuning range of the TLA was 40.6 nm from 1567.6 to 1608.2 nm, which corresponds to a frequency tuning range of 4.8 THz.

The spectrum of the TLA module is shown in **Fig. 4**. The 48-channel spectrum with 100-GHz (0.8-nm) spacing shows single-mode operation with a side-mode suppression ratio of more than 40 dB. It covers a wavelength range of 39.6 nm between 1569.59 and 1609.19 nm, which is a frequency range of 4.7 THz between 186.3 and 191.0 THz. In this case, the fiber output power was kept at 20 mW over the entire tun-

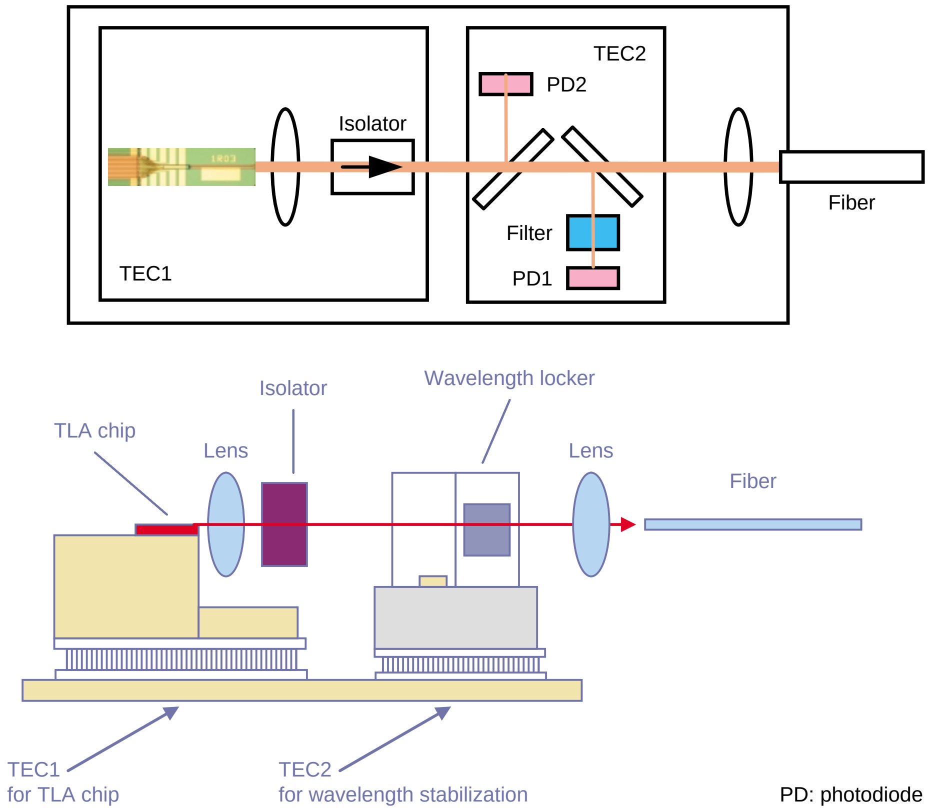

Fig. 2. Schematic diagram of TLA module. The upper figure shows the top view of the TLA module and the lower figure shows the cross section.

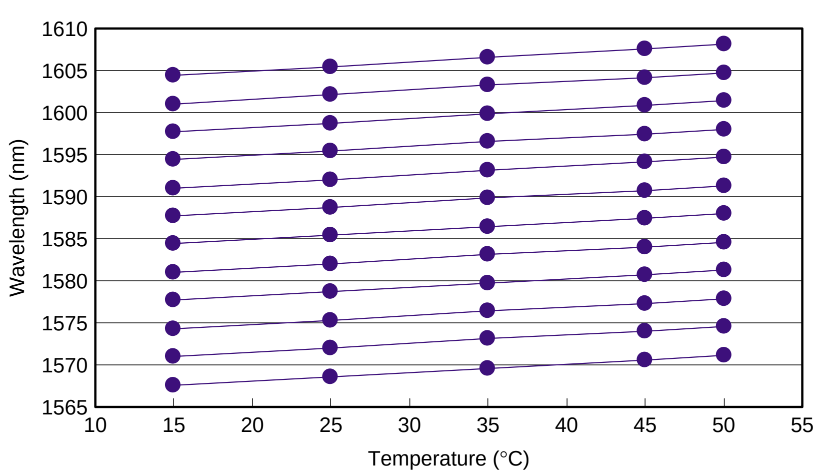

Fig. 3. Dependence of lasing wavelength on TLA chip temperature.

ing range by tuning the SOA driving current (from 90 to 130 mA).

The output power of the TLA is controlled using the SOA driving current. The relationship between fiber output power and SOA current at room temperature (25°C) is shown in **Fig. 5**, where I-L curves of the 12 DFB lasers are plotted. The current to each laser was kept constant at 100 mA and the threshold currents of the 12 DFB lasers were 6.7–10.0 mA at 25°C. We obtained a high fiber output power of more than 30 mW at 25°C.

We measured the power consumption of the TLA module for an ambient temperature range from 0 to 70°C. The total power consumption is the sum of the

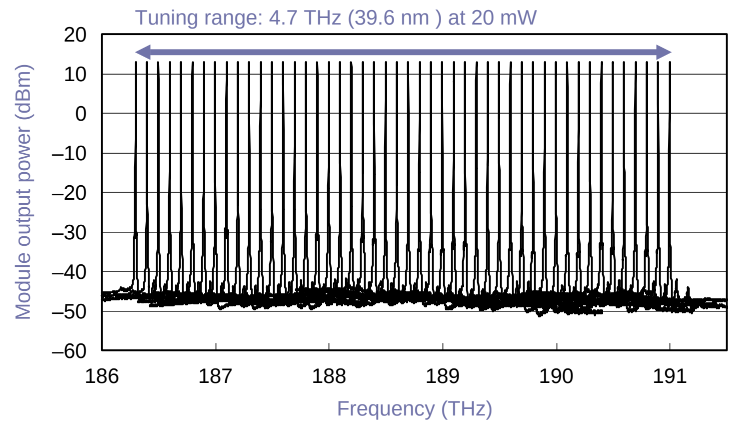

Fig. 4. Lasing spectrum of TLA module with 100-GHz spacing.

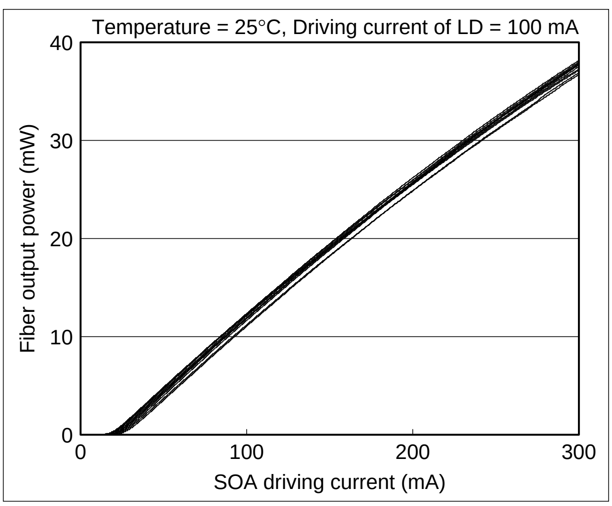

Fig. 5. Dependence of fiber output power on SOA driving current at room temperature (25°C).

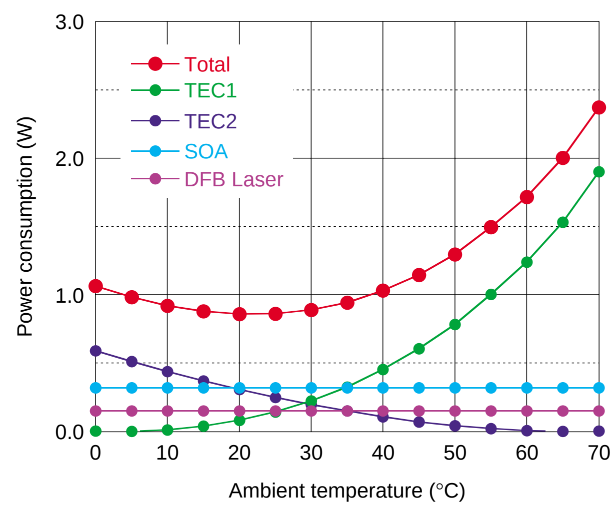

Fig. 6. Power consumption of TLA module versus ambient temperature.

power consumed by the two coolers, one DFB laser, and one SOA.

To select the desired wavelength of the TLA chip, we set the temperature of TEC1 while the temperature of the wavelength locker was maintained at a certain value. The temperature difference between the TLA chip and the environment increased with the power consumption of TEC1. The operating temperature of TLA is set between 15 and 50°C. Thus, the maximum temperature difference between the TLA and ambient temperature is 55°C when the temperature of the TLA is 15°C. The temperature of the wavelength locker is designed to be 45°C. Considering the fabrication tolerance, the setting temperature can be between 30 and 60°C. Consequently, the maximum temperature difference between the wavelength locker and ambient temperature is 60°C when the temperature of the wavelength locker is 60°C. The power consumption of the TLA module versus ambient temperature is shown in **Fig. 6**. The temperatures of the TLA and wavelength locker were set to 15 and 60°C, respectively, which represent the worst case. The driving currents of the DFB lasers and SOA were constant at 100 and 200 mA, respectively. The power consumptions of TEC1 and TEC2 changed to maintain the temperature of the TLA chip and wavelength locker when the ambient temperature was changed between 0 and 70°C. The power consumption of TEC1 is the dominant component in the total power consumption of the TLA module. The highest power consumption was less than 2.5 W at an ambient temperature of 70°C, which is not so large compared with that of the conventional DFB laser module.

4. Discussion

A TLA with temperature tuning has shown good potential for optical transmission systems. The most important feature of the TLA module is stable operation without any abrupt change. The barrier to expanding its range of application beyond use as a backup light source is its relatively slow wavelength switching. If the switching time can be reduced, then its applicability will be much greater.

To shorten the wavelength switching time, current control rather than temperature control is an attractive method for changing the lasing wavelength of the TLA. The driving current also causes a change in laser temperature, which produces a change in the laser's wavelength. This means that changing the driving current to a particular DFB laser is a useful way to switch its wavelength. The switching time for this scheme is a few milliseconds, which is very attractive for applications using dynamic wavelength switching.

5. Conclusions

We have developed a high-performance tunable laser array. It provides a wide wavelength range of 40.6 nm in the L-band that can be controlled by means of temperature. The power consumption is less than 2.5 W. These results show that a high-power L-band TLA module can be used as a widely wavelength tunable light source.

References

[1] M. G. Young, U. Koren, B. I. Miller, M. Chien, T. L. Koch, D. M. Tennant, F. Feder, K. Dreyer, and G. Raybon, "Six wavelength laser array with integrated amplifier and modulator," Electron. Lett., 31, (21), pp. 1835-1836, 1995.

[2] M. Bouda, M. Matsuda, K. Morito, S. Hara, T. Watanabe, T. Fujii, and Y. Kotaki, "Compact high-power wavelength selectable lasers for WDM applications," Tech. Dig. OFC'2000, TuL1, pp. 178-180.

[3] K. Kudo, K. Yashiki, T. Sasaki, Y. Yokoyama, K. Hamamoto, T. Morimoto, and M. Yamaguchi, "1.55-μm Wavelength-selectable Microarray DFB-LD's with Monolithically Integrated MMI Combiner, SOA, and EA-Modulator," IEEE Photonics Technol. Lett., 2000, 12, (3), pp. 242-244.

[4] H. Oohashi, Y. Shibata, H. Ishii, Y. Kawaguchi, Y. Kondo, Y. Yoshikuni, and Y. Tohmori, "46.9-nm wavelength-selectable arrayed DFB lasers with integrated MMI coupler and SOA," Tech. Dig., IPRM '2001, Nara, FBI-2, pp. 575-578.

[5] T. Kurobe, T. Kimoto, K. Muranushi, Y. Nakagawa, H. Nasu, S. Yoshimi, M. Oike, H. Kambayashi, T. Mukaihara, T. Nomura, and A. Kasukawa, "High fibre coupled output power 37 nm tunable laser module using matrix DFB laser," Electronics Letters, pp. 1125-1126, Vol. 39, July 2003.

Hiromi Oohashi

Senior Research Engineer, Supervisor, Tunable Light Source Development Project, NTT Photonics Laboratories.

She received the B.S. degree in applied physics from Waseda University, Tokyo, in 1985 and the M.S. degree in physical electronics from the Tokyo Institute of Technology, Tokyo, in 1987. After joining NTT Basic Research Laboratories in 1987, she engaged in research on optical nonlinear processes in semiconductor materials. In 1993, she moved to NTT Opto-electronics Laboratories (now NTT Photonics Laboratories) and researched the temperature dependence and reliability of semiconductor lasers. Her current research interests include the development of optical devices for WDM systems. She is a member of IEEE, the Japan Society of Applied Physics (JSAP), and the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan.

Hiroyuki Ishii

Senior Research Engineer, Tunable Light Source Development Project, NTT Photonics Laboratories.

He received the B.E., M.E., and Ph.D. degrees in electronics and communication engineering from Waseda University, Tokyo, in 1988, 1990, and 1999, respectively. In 1990, he joined NTT Opto-electronics Laboratories (now NTT Photonics Laboratories), Kanagawa. Since then, he has been engaged in developmental research on semiconductor lasers and integrated devices for optical communications systems. He is a member of JSAP and IEICE.

Kazuo Kasaya

Senior Research Engineer, Tunable Light Source Development Project, NTT Photonics Laboratories.

He received the B.E. degree in electronic engineering from Yamagata University, Yamagata, in 1985 and the M.S. degree in electronic engineering from Hokkaido University, Hokkaido, in 1987. After joining NTT Electrical Communications Laboratories in 1987, he engaged in research on the characterization of epitaxial InGaAsP/InP heterostructures, butt-joint selective growth techniques, and the fabrication of semiconductor optical waveguide devices. He has focused on the modeling and measurement of semiconductor waveguides. He has also researched optical devices for WDM systems.

Yuichi Tohmori

NTT Electronics Corporation.

He received the B.E., M.E., and Ph.D. degrees in physical electronics from the Tokyo Institute of Technology, Tokyo, in 1981, 1983, and 1986, respectively. During his Ph.D. work, he studied the integration of functional devices, especially for wavelength tunable DBR lasers. In 1986, he joined NTT Opto-electronics Laboratories, where he engaged in research on narrow-linewidth lasers and wavelength-tunable DBR lasers. From 1989 to 1990, he worked on the development of optical switching devices for optical computing systems in the University of Colorado at Boulder, in the USA. From 1991, he engaged in R&D of wide-wavelength-tunable lasers using SSG-DBR lasers. From 1994, he worked in the project to develop spot-size converter integrated lasers for access network applications. During this project, he worked as a member of NEL from 1994 to 1997. From 1998, he engaged in R&D of integrated devices using lasers and semiconductor optical amplifiers. He moved to NTT Electronics Corporation in 2004. He is a member of IEICE, JSAP, and the Optical Society of America and a senior member of IEEE/LEOS.