The Development of a Nano-ITLA for Digital Coherent Datacenter Interconnects

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ABSTRACT In the compact optical transceivers for datacenter interconnects using digital coherent technology, a compact and low power consumption wavelength tunable light source is required.

We have developed a Vernier-type monolithic integrated tunable laser chip, that uses a Distributed Bragg Reflector (DBR) and a ring resonator reflector, also have developed extremely-high-Δ planar lightwave circuit (extremely-high-Δ PLC) wavelength locker. By mounting them on the laser module, we have achieved a compact tunable light source Nano-ITLA with a control circuit which meets such requirements. We confirmed that, at a bit rate of 400 Gb/s, this Nano-ITLA has excellent constellation characteristics, which is an optical output of 17 dBm and a spectral linewidth of 100 kHz or less in the entire C band.

1. INTRODUCTION

The communication traffic continues to increase rapidly due to the spread of mobile devices such as Smartphones and the expansion of services such as the cloud computing, the video distribution, and the Social Networking Service. Therefore, in order to further increase the transmission capacity, a large capacity transmission system of 100 Gb/s per wavelength using a digital coherent communication that provides the coherent detection using a digital signal processing has been introduced to the backbone long distance network. Since the digital coherent technology uses the phase information of the light, the light source is required to have low phase noise, that is, narrow spectral linewidth.

We have been developing the Micro-ITLA, which is a narrow linewidth wavelength tunable light source with a control circuit that meets such requirements[1]). As a wavelength tunable method, a method that combines a Distributed Feedback (DFB) laser array with an excellent wavelength stability and a tunable system adjusted by the temperature has been used. Furthermore, in order to obtain narrow spectral linewidth, linewidth of 100 kHz or less has been achieved with a laser chip that integrates a Distributed Reflector (DR) laser array and an Arrayed Waveguide Grating (AWG) coupler[2)-4)].

In recent years, there has been a direction to introduce a digital coherent communication to the metro / access areas also to datacenter interconnects, which are short distances. There, the compact optical transceivers are mounted at a high density, and therefore, further miniaturization and low power consumption of the light source are required. However, it has been difficult practically to meet such a requirement with a laser array type wavelength tunable laser.

Therefore, this time, we have developed a compact laser module using a newly designed integrated wavelength tunable laser chip and a wavelength locker using the extremely-high-Δ PLC technology. We will report also on the miniaturization of the control circuit and the achievement of a compact and low power consumption Nano-ITLA.

2. DESIGN

2.1 Wavelength Tunable Laser Chip

Figure 1 shows a schematic diagram of the configuration of the developed integrated laser chip. In the laser chip, the laser section is equipped with two different types of the wavelength selective type reflectors before and after the gain region, and in the output end of the laser section, a Semiconductor Optical Amplifier (SOA) that further amplifies the laser light in order to control the light output is integrated. The rear side reflector is composed of a ring resonator and a Multi-Mode Interference (MMI) coupler that splits the light into two. The front side reflector is a DBR. A micro heater is formed on each reflector, and it makes it possible to control the wavelength spectrum of the wavelength selective reflector by local heating.

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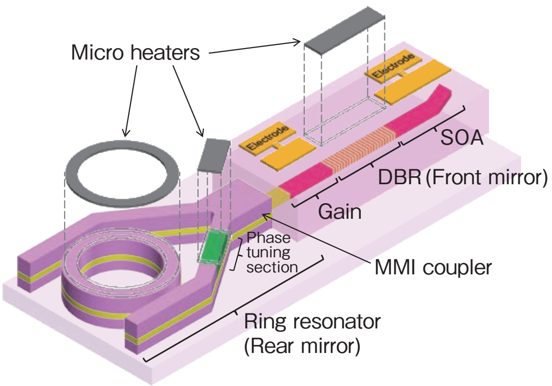


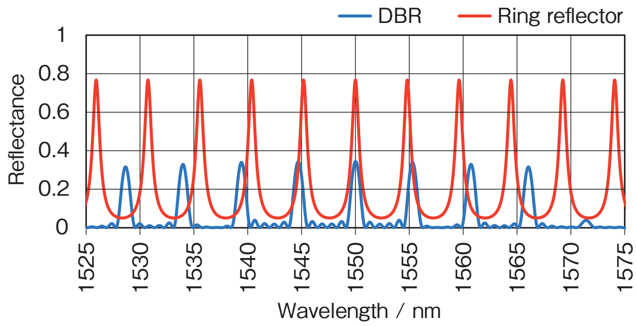
Figure 1 Structure of the wavelength tunable laser chip.

The ring reflector generates periodic reflection peaks determined by the circumferential length of the ring waveguide, and the reflector itself is compact, so that it is suitable for reducing the power consumption of the heater[5]. On the other hand, the phase of the DBR is cyclically modulated and the corresponding periodic reflection peaks are generated. By optimizing the design, a characteristic with eight reflection peaks having almost the same reflectance is obtained. Since the number of peaks is limited, the wavelength tunable range are limited. Since the periods of the reflected peaks of the DBR and the ring reflector are designed to be slightly different, it is possible to select one wavelength in which the reflected peaks overlap each other and oscillate the laser. As well as the previously reported wavelength tunable lasers[6)-8)] using DBRs on both sides, the wideband wavelength tunable operation is possible by the Vernier scale principle, using reflectors having two periodic reflection peaks. Figure 2 (a) shows a calculation example of the reflection spectrum of the DBR and the ring reflector, and Figure 2 (b) shows the reflection spectrum of their overlap. In the example of Figure 2, the laser oscillates at 1550 nm, which has the highest overlap reflectance. By shifting the reflection spectrum of the DBR and the ring reflector to the wavelength direction with their respective micro heaters, the wavelength with the highest overlap reflectance can also be shifted, and the laser oscillation can be performed at the desired wavelength. This DBR / ring laser chip is monolithically integrated on an Indium Phosphide (InP) substrate and is as compact as 3 mm × 0.35 mm. In addition, an optical circuit is built in between the DBR and the SOA to split the light and output it backwards. The output light of this rear monitor port is used as a wavelength locker. We have succeeded in developing the world's first integrated wavelength tunable laser chip of the Vernier type using such a DBR and a ring resonator type reflector.

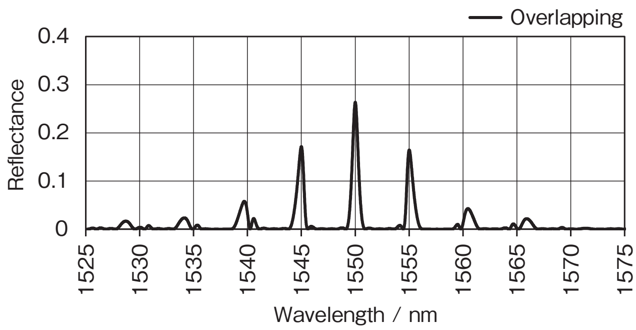
2.2 Laser Module with Integrated PLC Wavelength Locker

Figure 3 shows the configuration of the developed laser module. It consists of a wavelength tunable laser chip, a thermoelectric cooler, a beam splitter, an optical isolator, lenses, photodiodes (PD) and a PLC wavelength locker. In order to reduce the module size, the extremely-high-Δ PLC[9] that we have developed up till now was used for the wavelength locker, instead of the spatial optical subsystem including the etalon filter, which is a bulk optical component. The extremely-high-Δ PLC consists of a SiO_2-ZrO_2 core and has a large specific refractive index difference (Δ) of about 5%, so that we achieved the miniaturized wavelength locker size of 1.7 mm × 2.5 mm.

Figure 4 is an optical circuit diagram of the PLC. The input light is split into three paths and then guided to one power monitor output and two ring resonators. The length of the ring resonators are 2565.0 μm and 2565.3 μm, respectively, and their resonance frequencies differ by 20 GHz.



(a) Calculation example of the reflection spectrum of a DBR and a ring reflector.



(b) Overlapping reflection spectrum

Figure 2 Calculation example of the reflection spectrum.

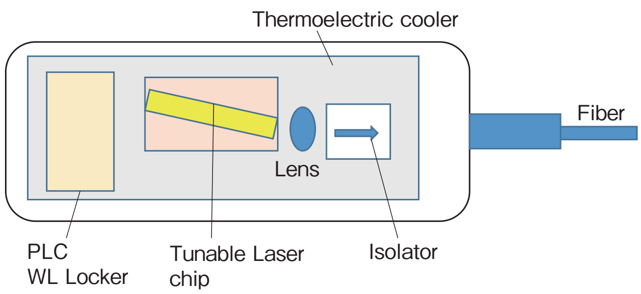


Figure 3 Structure of the laser module.

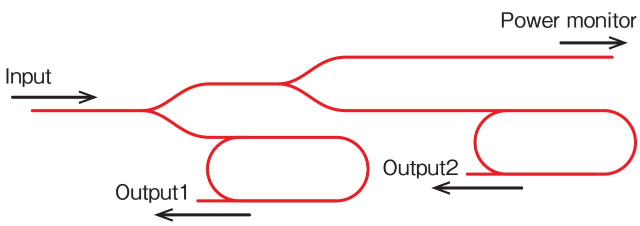


Figure 4 Optical circuit diagram of the PLC.

Figure 5 shows the output characteristics of the PLC. Since the light output intensity depends on the light frequency of the input light, the oscillation wavelength of the laser can be specified from the light receiving intensity of the PD. By selecting two output characteristics and using an appropriate ring resonator as a wavelength locker, the laser output power can be controlled at an arbitrary wavelength with a high accuracy.

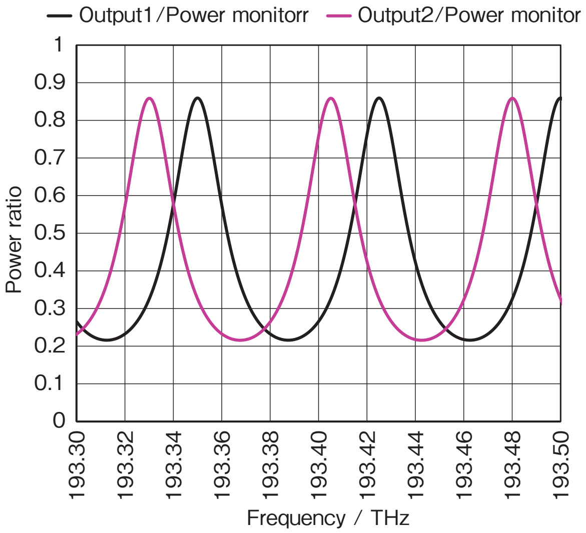


Figure 5 Output characteristics of the PLC.

2.3 Nano-ITLA

Figure 6 shows a picture of the developed Nano-ITLA. In Micro-ITLA, the control circuit is configured by using separate general-purpose parts. Here, the control circuit was downsized by using a new dedicated IC that puts these together, and by combining it with the compact laser module, the Nano-ITLA was miniaturized. The size of Nano-ITLA is 25.1 mm × 15.6 mm × 6.4 mm, and the volume ratio to Micro-ITLA with 37.5 mm × 20.0 mm × 7.5 mm[1] is less than half, thus a significant miniaturization was achieved. It is a size that can be stored in a form factor called QSFP-DD[10] or OSPF[11], which is widely implemented in the compact optical transceivers used for datacenter interconnects.

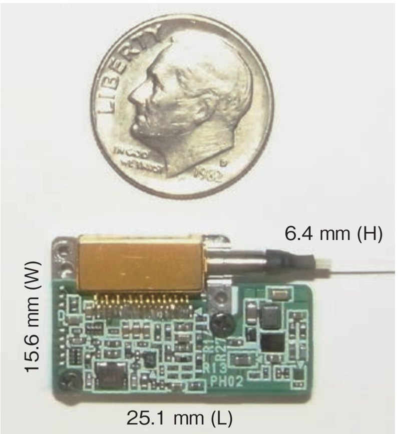


Figure 6 Picture of the developed Nano-ITLA.

3. CHARACTERISTICS

An example of the oscillation spectrum of the manufactured laser module is shown in Figure 7. A wavelength tunable range of 41 nm was achieved with this device. By adjusting the SOA current, the fiber output power was 17 dBm in the entire C band. To fully cover the C-band wavelength, the maximum power consumption of the micro-heater required is 220 mW. Figure 8 shows the spectral linewidth. The phase noise spectrum was measured using a coherent receiver and the linewidth was calculated from the white noise component of the measured phase noise spectrum. As shown in Figure, 8, the narrow linewidth of less than 100 kHz were obtained for all the measured wavelength channels. Figure 9 shows the accuracy of the laser output wavelength when the wavelength is stabilized using a PLC wavelength locker. The accuracy of the laser output wavelength was within

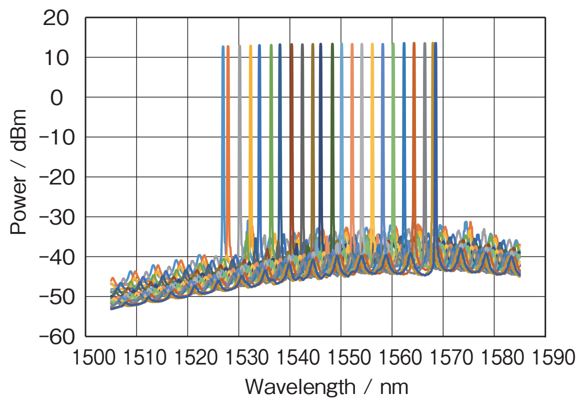


Figure 7 Oscillation spectrum characteristics.

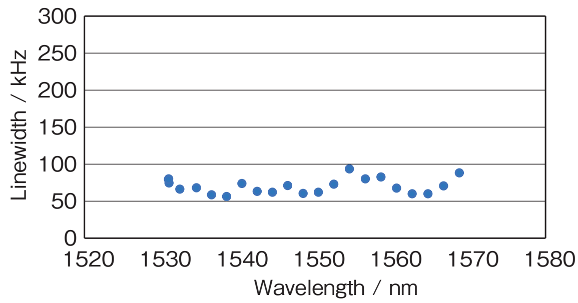


Figure 8 Spectral linewidth characteristics.

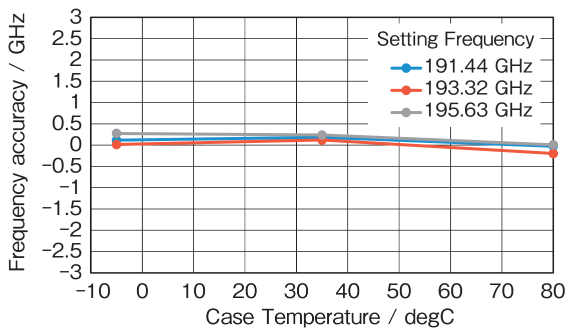


Figure 9 Wavelength locking characteristics.

±0.5 GHz when the case temperature was in the range of –5°C to 80°C. Therefore, it was confirmed that the wavelength could be controlled sufficiently and stably using the PLC wavelength locker.

Figure 10 shows the results of a transmission / reception test of the developed Nano-ITLA in the actual digital coherent communication. The test system for the digital coherent communication is

・Transmitting side: Laser for transmission
+ optical modulator
・Receiving side: Coherent receiver
+ laser for local oscillator
+ Digital Signal Processor (DSP)

The characteristics of a multi-level modulation pattern (called a constellation) were evaluated using a DSP that assumed the transmission at 400 Gb/s. Tests were performed using 16 Quadrature Amplitude Modulation (QAM), 32 QAM, and 64 QAM as the three modulation formats. First, the developed Nano-ITLA was used as a transmission laser, and for comparison, the laser for a local oscillator on the receiving side was tested using an external cavity laser with a spectral linewidth of less than 50 kHz as a reference laser. The results are shown in the upper part of Figure 10. Next, the reference laser and this Nano-ITLA were exchanged, the reference laser was used as the transmission laser, and the evaluation was performed using this Nano-ITLA as the laser for the local oscillator. The results are shown in the lower part of Figure 10. In both top and bottom rows, excellent constellations were detected in all three modulation formats, and there was no difference between the reference laser and this Nano-ITLA. It has been shown that a monolithic integrated wavelength tunable laser chip consisting of a DBR / ring reflector has narrow linewidth characteristics comparable to those of a conventional external cavity laser, and the developed Nano-ITLA can be used for both the signal and the local oscillating lasers at a bit rate of 400 Gb/s.

4. CONCLUSION

We have developed a compact Nano-ITLA that uses a compact wavelength tunable laser module. In order to reduce the size and the power consumption, we have developed a Vernier-type monolithic integrated tunable laser chip, that uses a Distributed Bragg Reflector (DBR) and a ring resonator reflector, also have developed extremely-high-ΔPLC wavelength locker, and these are mounted on the laser module. We confirmed that, at a bit rate of 400 Gb/s, this Nano-ITLA has excellent constellation characteristics, which is an optical output of 17 dBm and a spectral linewidth of 100 kHz or less in the entire C band. Therefore, this Nano-ITLA is useful as a light source for a compact optical transceiver for datacenter interconnects using digital coherent technology.

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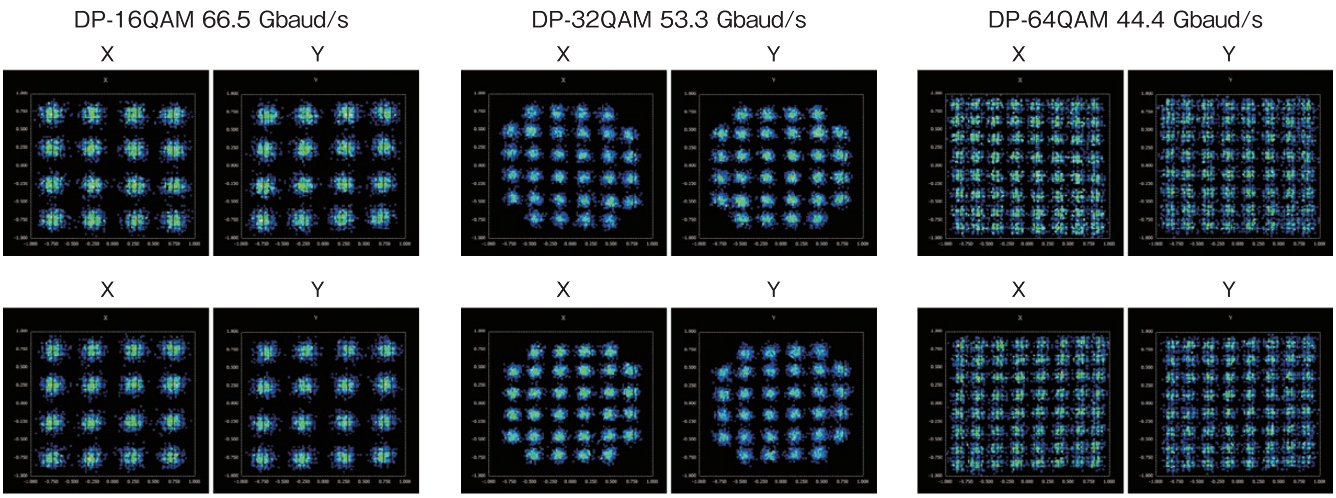

Figure 10 Constellation characteristics.
Top: The Nano-ITLA is in the transmitting side, and the reference laser is in the receiving side.
Bottom: The reference laser is in the transmitting side, the Nano-ITLA is in the receiving side.

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