# Compact Single Wavelength Laser Optical Sub-Assembly Integrated with One-Chip Wavelength Locker for Short Reach Coherent Communication

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**Abstract** *We present a 3.5 mm x 2.0 mm compact single wavelength laser optical sub-assembly with a Si photonics-based wavelength locker chip. The measurement results showed a good agreement with the designed spectrum and 8-GHz bandwidth of target slope > 0.027 GHz$^{-1}$ were successfully obtained.*

## Introduction

In recent years, the network traffic handled by data centers has increased dramatically along with the proliferation of smart devices. To meet the demand for increased transmission capacity, 800G and 1.6T communication configurations have been discussed [1,2]. In the IMDD system, the transmission distance is estimated to be limited by around 10 km due to non-linear effects in optical fiber [3-5].

On the other hand, the application of digital coherent communication to short distances has been considered in recent years, and the Coherent-Lite, which aims to simplify its configuration and reduce power consumption, has been discussed [6,7]. As short-range coherent communication is a peer-to-peer connection, it requires wavelength match between a transmission signal and local oscillator, instead of WDM (Wavelength Division Multiplexing) system used in long-reach communication. In this case, a single wavelength light source module capable of fine wavelength tuning can fulfill the requirements.

When considering the realisation of light source modules for short reach, compactness, low cost and low power consumption are demanded. Such light source modules mainly consist of two elements: a single mode laser and a wavelength locker. Here, a DFB laser is considered to be the simplest light source emitting a single wavelength, but wavelength locker is configured with relatively complicated.

An etalon is generally used for wavelength locker, which has free-space optics and needs well-aligned several bulk components [8,9]. Recently, a demonstration of wavelength locking with a PLC has also been reported [10]. They reduced the size by integrating optical filters on a PLC, but PDs must still be mounted separately.

In order to realize an even simpler and smaller light source module, we have proposed a Si photonics-based one-chip wavelength locker and investigated its system [11]. This configuration provides compact and low-power consumption thanks to the monolithic integration of waveguide filters and PDs on Si substrate. In this paper, we fabricated a single wavelength optical sub-assembly with a one-chip wavelength locker to realize a compact light source module for short-range digital coherent communication.

## Device Concept

Fig. 1 shows our concept of our optical sub-assembly. The Si chip is mounted almost vertically against the laser chip. The rear output from the laser is coupled to a Si waveguide by a grating coupler and divided into two ports. One goes to a power monitor PD (output current: $I_p$), and another to wavelength monitor PD (output current: $I_\lambda$) via a ring resonator filter. A single TEC controls the carrier temperature to tune the lasing

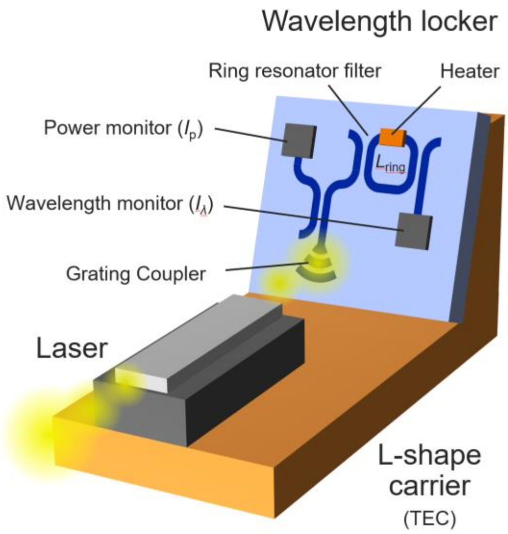


**Fig. 1:** Schematic diagram of laser optical sub-assembly.

wavelength. This configuration allows the wavelength locker operation by a single Si chip, which is expected to result in a more compact and simplified light source module.

Fig. 2 shows the operation principle of our device. Here, the temperature dependence of the lasing wavelength ($\lambda_{LD}$) and Si filter spectrum ($\lambda_{filt}$) are assumed to be $d\lambda_{LD}/dT$ = 90 pm/K and $d\lambda_{filt}/dT$ = 70 pm/K, respectively. In the configuration, when the laser temperature $T_{LD}$ is changed by 1 °C to control lasing wavelength $\lambda_{LD}$, it changes by 90 pm as shown in Fig. 2 (a). At the same time, as the Si chip temperature $T_{Si}$ is also varied by 1 °C, the filter spectrum ($\lambda_{flit}$: $T_{Si}$ = const.) moves by 70 pm as shown in Fig. 2 (b). Although both move simultaneously with temperature change, they move at different speeds, resulting that the dotted line characteristic ($\lambda_{flit}$: $T_{Si}$ = $T_{LD}$) can be obtained. By checking the relation between laser and filter characteristics, we can estimate and control the lasing wavelength.

## Filter design

As the wavelength dependence is different between the Si chip at fixed temperature and our concept operation, it is necessary to design the Si chip while considering their temperature dependence. In the wavelength locker design, we used 0.027 $GHz^{-1}$ as the filter slope target value to meet the desired frequency stability and 0.6 as the transmission coefficient $t$ of the directional coupler to see any slope even at the filter bottom. In addition, this design was based on the measured temperature dependencies of the laser and the Si chip.

Fig. 3 (a) shows the calculation results for $T_{Si}$ = const. and Fig. 3 (b) for $T_{Si}$ = $T_{LD}$. The vertical axis are normalized monitored value $I_\lambda/I_p$, which is correspond to filter output. From the relationship between $d\lambda_{LD}/dT$ and $d\lambda_{filt}/dT$, it can be seen that the FSR of the filter widens from 23 GHz to 90 GHz. Fig. 3 (c) shows the slope characteristics, which is the derivative of Fig. 3 (b) with frequency. From this figure, a bandwidth of 8 GHz can be obtained as the range meets the target slope > 0.027 $GHz^{-1}$. In this range, small wavelength fluctuations can be detected without filter phase adjustment, and the estimated bandwidth is sufficiently wide for our wavelength-locking algorithm.

## Fabrication and Evaluation

Fig. 4 shows a cross-view of the fabricated optical sub-assembly. The laser and the wavelength locker chip are mounted on an L-shape carrier to put them together. Thanks to adopting a one-chip wavelength locker and

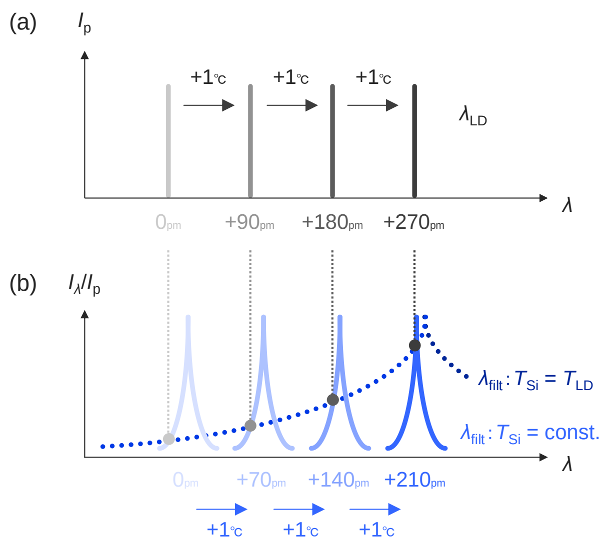


**Fig. 2:** Temperature characteristics of wavelength locker. (a) Lasing characteristics, (b) Filter characteristics.

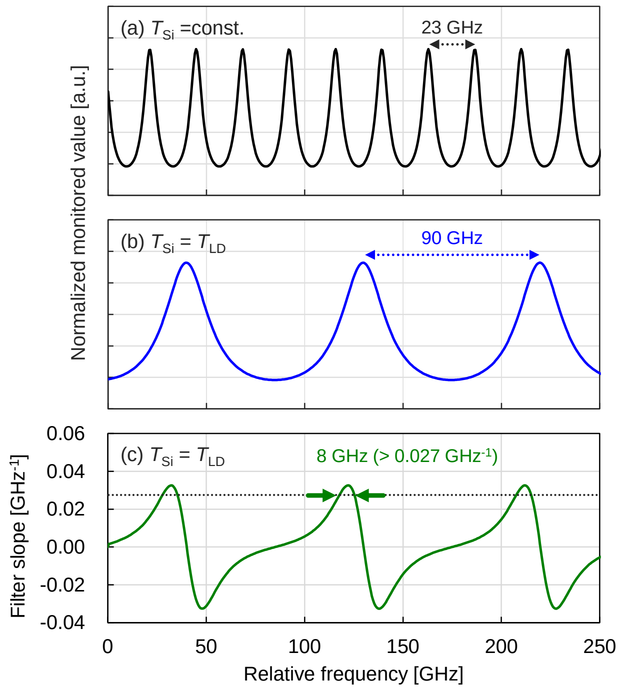


**Fig. 3:** Calculated results of wavelength locker output. (a) $T_{Si}$ = const., (b) $T_{Si}$ = $T_{LD}$, (c) filter slope.

simple configuration, we realize a small size of less than 3.5 mm x 2.0 mm. The rear output of the laser is coupled to a waveguide on the Si chip without any lens. To demonstrate our concept, we have evaluated the wavelength characteristics of this optical sub-assembly.

Fig. 5 (a) shows a block diagram of the measurement system configuration. While controlling the fabricated optical sub-assembly, the front optical output $\lambda_{LD}$ of the laser and photocurrents ($I_p$ and $I_\lambda$) of PDs on the Si chip were measured with a wavelength meter and ammeters, respectively. In this experiment, 110 mA was applied as injection current to the laser, and the reverse bias voltage to the PD was set to 2 V. At the condition, the TEC temperature was varied from 30°C to 60°C.

Fig. 5 (b) shows the measurement results. From the figure, large wavelength dependence of $I_\lambda$ for wavelength monitor and small dependence of $I_p$ for power monitor were successfully observed. The $I_p$ dependence is considered to be caused by both temperature dependences of the laser output and the coupling efficiency of the grating coupler. Besides, an FSR of 90 GHz was obtained, which agreed well with the designed characteristics. From these results, it is confirmed that a laser and wavelength locker configuration reflecting the concept can be integrated.

Fig. 6 shows the slope of the normalized monitored value $I_\lambda/I_p$ which is almost correspond to filter characteristics. The circled plots are the measurement results and the green dashed line is the calculated result. They agreed very well and succeeded in obtaining 8-GHz range with the target slope > 0.027 $GHz^{-1}$ as expected. By using the wavelength characteristics, we can estimate the lasing wavelength and provide stable lasing wavelength at any aimed value.

From the above, it was confirmed that the optical coupling between the laser and the designed Si wavelength rocker chip has been realized, and we have successfully achieved fabricating a compact optical sub-assembly with a single-chip wavelength locker.

## Conclusion

We reported a 3.5 mm x 2.0 mm size small single wavelength optical sub-assembly and its measurement results. Si chip and laser chip were mounted on an L-shape carrier, and they were optically coupled by a grating coupler. The measurement results of the fabricated sub-assembly showed expected values of 90-GHz FSR and 8-GHz bandwidth with target slope. This new laser optical sub-assembly has a good capability for simple configuration for wavelength locking while minimizing the package size. We believe that our device will be a promising device for constructing a compact laser source module for the digital coherent transceivers used in future data center networks.

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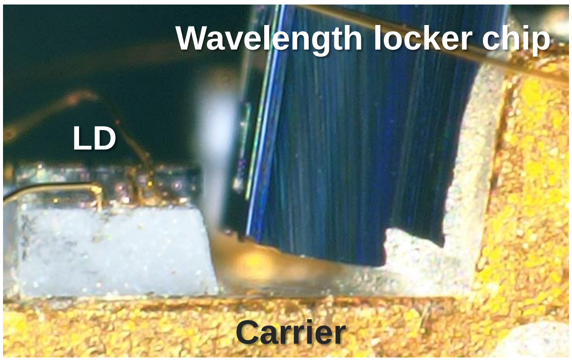


**Fig 4.** Fabricated optical sub-assembly.

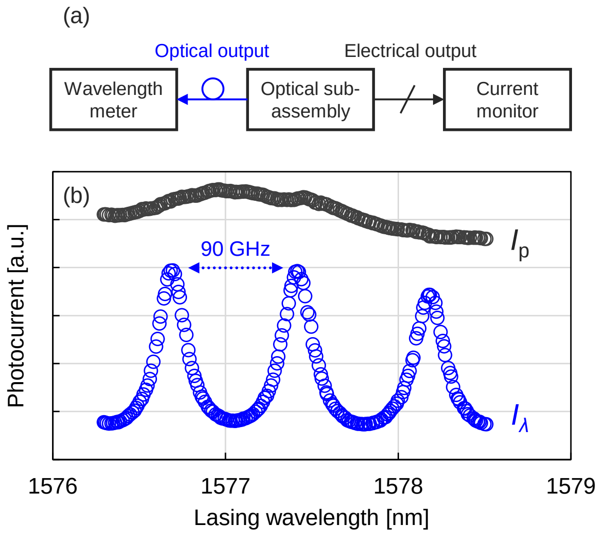


**Fig 5.** Measured characteristics of wavelength locker.

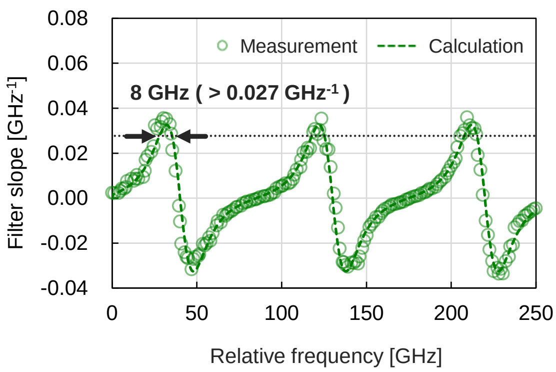


**Fig 6.** Slope characteristics of wavelength locker output.


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