Low Power Consumption 2D Beam Scanner Integrated with Wavelength Tunable Laser Diode

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Abstract *In this paper, we fabricated a 6 × 1.5 mm² 1-chip beam steering device by integrating a laser diode with an OPA that doesn't have any phase shifters. Power consumption for beam steering is 65 mW. Beam steering range is 42.2 ° × 9.54 °.*

Introduction

In recent years, the development of sensing technology for the realization of automated driving has been actively done. Various sensors are required to realize more advanced automated driving, among which LiDAR (Light Detection and Raging) is an important sensor for avoidance actions in emergency situations because of its superiority in detecting obstacles located over long distance. LiDAR illuminates obstacles with a two-dimensionally scanned beam and detects obstacles from the reflected light, so LiDAR consists of beam steering and distance measurement. There is a growing demand for solid-state beam steering that eliminates mechanical moving parts to improve durability and reduce size. The compact OPA (Optical Phased Array) on silicon photonics is a promising candidate for the solid-state beam steering device [1-6].

However, conventional OPA controls the beam emission angle by a phase shifter loaded for each waveguide. Therefore, in a large-scale OPA with a small beam spread angle, the power consumption of the phase shifters increases and their control becomes complicated.

In this paper, a significant reduction in power consumption has been achieved by fabricating an OPA that realizes two-dimensional beam steering only by controlling the light wavelength. In addition, a hybrid wavelength tunable laser diode integrated in OPA to realize more compact beam steering device.

Device Design and Operation Principle

OPA is an optical device that can change the angle of light output by controlling the phase of light passing through waveguide array. In conventional OPAs, each of the waveguides has a phase shifter with TO (Thermo-Optical) or EO (Electro-Optical) effects, all of which are controlled. Therefore, the power consumption of OPA using a phase shifter increases in proportion to the number of waveguide arrays.

Figure 1 shows the fabricated 1-chip beam steering device that integrates a hybrid wavelength tunable laser diode.

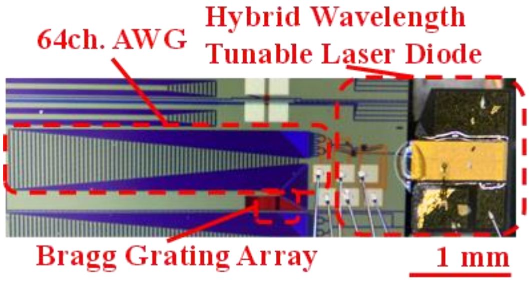

Fig. 1: Fabricated device.

Two-dimensional beam steering is realized by two types of diffraction gratings, AWG (Arrayed Waveguide Grating) and Bragg grating [7]. The lightwave from the hybrid wavelength tunable laser diode is evenly divided into 64 array waveguides by a tree-shaped MMI couplers. As shown in Fig. 2, a phase difference $\Delta\phi_x$ depending on incident light wavelength λ occurs by the 64 ch. AWG with a constant path length difference ΔL between adjacent waveguides. Since light is diffracted to the top surface of the chip by Bragg grating, the emission beam angle in the array direction θ_x is obtained from

$$n_{eff,AWG}\Delta L - d\sin\theta_x = m\lambda \qquad (1)$$

Here, $n_{eff,AWG}$ is effective refractive index of silicon waveguide in AWG, d is the pitch of antenna and m is the diffraction order. As shown in Fig. 3, a phase difference $\Delta\phi_y$ depending on λ occurs by the pitch of Bragg grating Λ, so the emission beam angle in the grating direction θ_y is obtained from

$$n_{eff,gr}\Lambda - \Lambda\sin\theta_y = n\lambda \qquad (2)$$

Here, $n_{eff,gr}$ is effective refractive index of Bragg grating and n is the diffraction order in θ_y angle.

However, the AWG is strongly affected by waveguide manufacturing errors. Manufacturing errors in waveguide core size cause changes in the $n_{eff,AWG}$, resulting in errors in the phase difference between adjacent waveguides. This

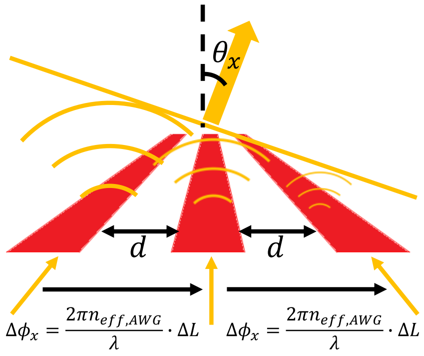

Fig. 2: Operation principle in θ_x angle

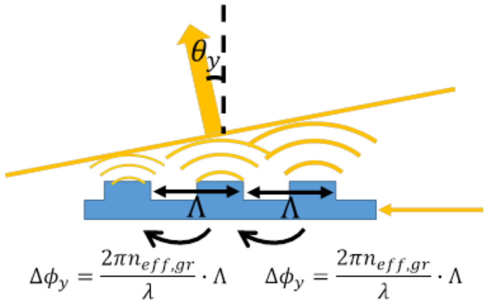

Fig. 3: Operation principle in θ_y angle

causes phase mismatch in θ_x angle. Therefore, in this research, we fabricated the device by ArF immersion lithography, which has a small manufacturing error [8]. In addition, 3.2 μm-width multi-mode waveguides are designed in the straight part of the AWG to further minimize the effects of manufacturing errors by expanding waveguide width. Numerical calculations predict that the phase error caused by manufacturing errors will be reduced to 1/100 by expanding the waveguide width of a single-mode waveguide with a width of 440 nm to 3.2 μm.

Additionally, the hybrid wavelength tunable laser diode as the light source for this OPA was integrated on a single chip by edge-bonding a silicon chip and an SOA (Semiconductor Optical Amplifier) chip [9]. Figure 4 shows the schematic of hybrid wavelength tunable laser diode. The laser cavity structure is formed by the reflection on the edge facet of the SOA with 95 % reflectivity and the loop mirror on the silicon chip with 47.5 % reflectivity. Wavelength filtering by two ring resonator enables laser oscillation at single wavelength. Lasing wavelength can be controlled by TO effect because micro-heaters are installed on ring resonators. The phase of longitudinal mode can also be controlled by a micro-heater installed on a bus waveguide.

Table 1 shows the main design parameters of the device fabricated in this research. Based on the FSRs (Free Spectral Range) of two ring resonators, the maximum wavelength tunable range is expected to be around 108 nm.

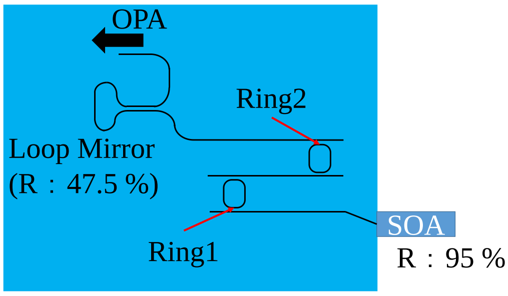

Fig. 4: Schematic of hybrid wavelength tunable laser

Tab. 1: Design parameters of the device

Parameter	value
ΔL (μm)	79.7
d (μm)	2.07
Λ (nm)	900
FSR of Ring1 (nm)	7.46
FSR of Ring2 (nm)	8.01

Experiment

Figure 5 shows the relationship between SOA injection current and the intensity of diffracted light from OPA. It shows that threshold current was 32.5 mA. The maximum light intensity emitted from OPA was 4.68 mW at 100 mA injection. In Fig. 5, light intensity does not increase linearly. This might result from mode hopping.

Figure 6 shows the Ring1 heater power dependence of the lasing wavelength when the injection current to the SOA was set to 100 mA and the Ring2 heater power was varied in the range between 0 mW and 60 mW. The plots in Fig. 6 have SMSR (Side-Mode Suppression-Ratio) of more than 30 dB. Figure 6 shows that the lasing wavelength could be selected in the range of over 60 nm.

Figure 7 shows two-dimensional beam steering by controlling heater power of two ring resonators. The steering range is shown in Fig. 7 and 8. It was 42.2 ° × 9.54 ° (θ_x, θ_y, in that order). The maximum heater power of two ring resonator was 130 mW. Since the heater power consumption during wavelength sweep is time-averaged, the power consumption of the beam steering device was 65 mW. Figure 9 shows FWHM (Full Width at Half Maximum) of the beam from OPA. It was 1.15 ° × 2.52 °. The designed FWHM in θ_x angle was 0.578 °, but measured value was wider than it. This shows that the phase error caused by manufacturing errors in AWG need to be reduced more.

Table 2 shows the performance parameters of this device expected from the design and their measured values. This confirms that the performance as a beam scanner is in good agreement with the design values.

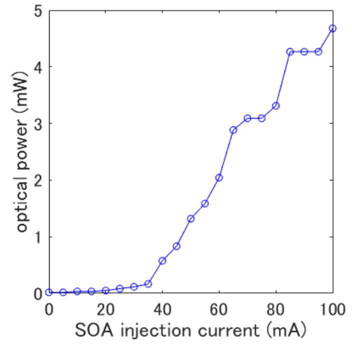

Fig. 5: Relationship between SOA injection current and output power from OPA

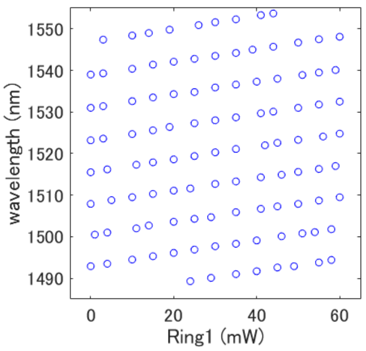

Fig. 6: Change in lasing wavelength

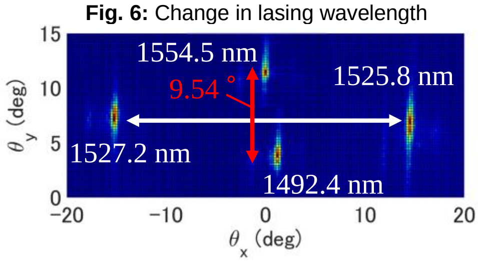

Fig. 7: Two-dimensional beam steering

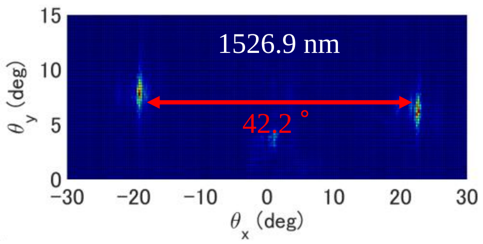

Fig. 8: Far field pattern at 1526.9 nm

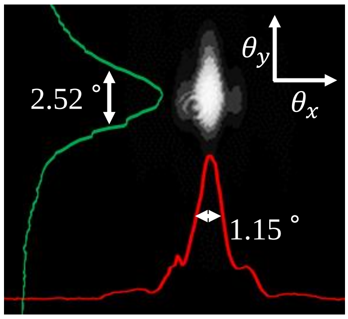

Fig. 9: FWHM of emitted beam

Tab. 2: Performance parameters of the device

Parameter	designed	measured
FSR of AWG (THz)	1.00	0.956
steering range of θ_x (deg)	44.0	42.2
steering efficiency of θ_y (deg/nm)	0.141	0.154

Tab. 3: Comparison with previous research

Research	FOM (mW/ch.)
16ch. TO [1]	215
32ch. EO [3]	160
128ch. TO [4]	80
50ch. TO [5]	12
This work	1.02

Table 3 shows comparisons with previous research. FOM is defined as the ratio of the number of channels in OPA to the total power consumption required for beam steering (mW/ch.). Thus, it is possible to control a large scale OPA with low power consumption when FOM is small. Compared to the previous research, the FOM was reduced by an order of magnitude in this research. In addition, total power consumption of the OPA in this research does not depend on number of channels because it needs only three heaters in the hybrid wavelength tunable laser diode. Therefore, the contrast of power consumption is more remarkable in a large-scale OPA. For example, when the OPA in [5] is expanded to 128 ch., the total power consumption is 1536 mW, whereas the wavelength sweep OPA in this research consumes 65 mW for the wavelength tuning. Furthermore, the edge-bonding a silicon chip and SOA chip enabled integration of the two-dimensional beam scanner function into an area 6 × 1.5 mm^2.

Conclusion

In this paper, we designed an optical phased array that enables two-dimensional beam steering by only changing the wavelength of the incident light and integrated a wavelength tunable laser on the same chip by edge-bonding. This has reduced the power consumption required for beam steering control to approximately 1 mW per channel. In addition, the entire structure as a two-dimensional beam scanner is integrated in an area of 6 × 1.5 mm^2.

This compact and low-power-consumption two-dimensional beam scanner will be a key device for the realization of automated driving cars and other applications.

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