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Tapered Hollow Waveguide Multiplexer for Multi-wavelength VCSEL array

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Abstract: A tapered hollow waveguide multiplexer is proposed to combine the output of a GaInAs/GaAs multi-wavelength VCSEL array. We demonstrated multiplexing of 4-channel output of a VCSEL array formed on a patterned substrate for coupling into a multi-mode fiber.

I. INTRODUCTION

Multi-wavelength vertical cavity surface emitting laser (VCSEL) array is a good candidate for wavelength division multiplexing (WDM) short reach systems to increase the data capacity of local area networks (LAN), optical interconnects and so on. We realized a multi-wavelength VCSEL array exhibiting a wavelength span of 190nm using MOCVD on patterned substrates [1]. In order to realize WDM transceivers based on multi-wavelength VCSEL arrays, however, a low-cost and compact multiplexer of each VCSEL output is necessary. We have developed hollow waveguide optical devices exhibiting various unique features of temperature insensitivity and large tunability and so on [2]. In this paper, we propose and demonstrate a tapered hollow waveguide multiplexer for coupling multi-wavelength VCSEL array output into a multi-mode fiber.

II. DEVICE STRUCTURE

Our proposed tapered hollow waveguide multiplexer is shown in Fig. 1. The structure consists of two high-reflectivity mirror. The core is air and a VCSEL array is integrated on the bottom mirror in the figure. Each output from VCSEL is radiated vertically from the bottom mirror side. An upper mirror and bottom mirror are placed with a taper angle A. After multiple reflections, the reflection angle of the output is simply changed as

$$\theta_{reflection} = n \times A,$$

where $\theta_{\text{reflection}}$ is reflection angle, n is the number of reflections. Therefore the propagation direction of the output from each VCSEL is converted to a horizontal direction. The output from the tapered hollow waveguide multiplexer can be coupled to a multi-mode fiber and simple and low-cost multiplexer can be realized without losing the advantages of small foot print of VCSEL arrays.

We fabricated the proposed multiplexer using multi-wavelength 7-ch VCSEL array on the patterned substrate [3]. VCSEL array was fabricated using MOCVD on a patterned substrate, consisting of 22pair-$Al_{0.85}Ga_{0.15}As/GaAs$ p-DBR for the output mirror, 35.5pair-$Al_{0.85}Ga_{0.15}As/GaAs$ n-DBR for the bottom mirror, an active region of 8nm-thick $Ga_{0.67}In_{0.33}As/GaAs$ 3 quantum wells (QWs) with 30nm-thick GaAs barriers. In order to use a VCSEL array substrate as a bottom mirror for a slab hollow waveguide, Au was deposited except a 10 μm square output window. An upper mirror was also prepared by depositing a Au on a GaAs substrate and the length is 2mm. A four channel multi-mode VCSEL array was used for an experiment. Figure 2 shows the I-L characteristics of the array. Au was deposited on the surface of the device and thus all the VCSEL was driven simultaneously at 8.6mA per device.

Ⅲ. RESULT

The air core thickness at an output side and tapered angle was precisely controlled by a PZT actuator and a micro rotation stage. Figure 3 shows the near field pattern of a tapered hollow waveguide multiplexer output when the output air core is 50μm and the taper angle is 1.4 degree. With this condition, the combined output from the VCSEL array was directly coupled with a 50μm-core multi-mode fiber. Figure 4 shows the spectra of multiplexed four channel output coupled into a fiber. The insertion loss was 35dB. This large insertion loss is primarily due to poor reflectivity of the bottom mirror and lateral diffraction in the slab hollow waveguide. We estimated the average reflectivity of the used mirror surface by ray trace and found that it would be deteriorated from a theoretical Au reflectivity of 98% to 80% as shown in Fig. 5. We believe this is due to rough polyimide surface between each VCSEL and mesa steps. By introducing the trench structure for each VCSEL mesa and a highly reflective DBR, of which theoretical reflectivity is over 99.9% for a hollow waveguide, the insertion loss will be reduced below 1 dB.

Figure 6 shows the calculated output angle of ray-trace propagation depending on the VCSEL position in the multiplexer. The output air-core size is assumed to be 50μm for coupling with a multi-mode fiber. The opposite side of the upper mirror is connected to the bottom mirror and the mirror length L is changed. The position is defined as the distance of each VCSEL channel from the output end of the hollow waveguide multiplexer. For a 2500µm-long multiplexer, the output from VCSELs placed in 1000µm-long area of the tapered multiplexer can be coupled in a multi-mode fiber so that the output from the multiplexer is within the NA of a 50µm-core multi-mode fiber.

Ⅳ. CONCLUSION

We proposed a compact tapered hollow waveguide muti-mode multiplexer to combine the output from a multi-wavelength VCSEL array and demonstrated multiplexing of four channel VCSEL output into a multi-mode fiber. The present large insertion loss of the experiment will be dramatically improved by increasing the mirror reflectivity of the hollow waveguide. The proposed hollow waveguide multiplexer is helpful for realizing compact, simple and low-cost WDM transceiver for short reach applications.

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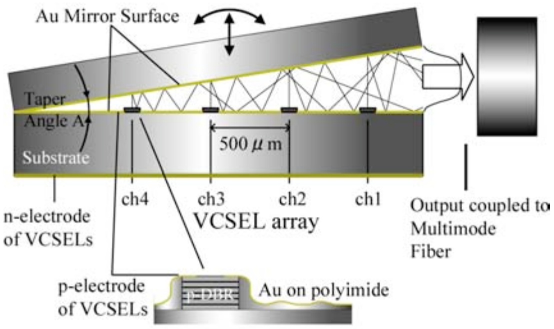

Figure 1 Schematic structure of a tapered hollow waveguide multiplexer for multi-wavelength VCSEL array.

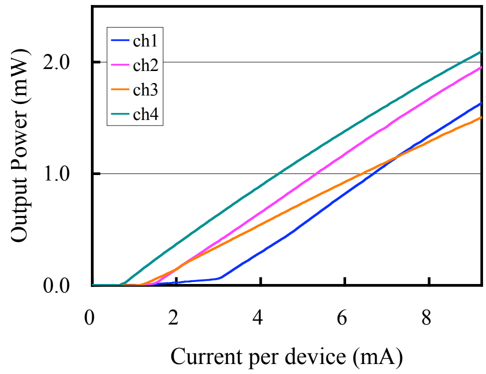

Figure 2 I-L characteristics of 4-ch VCSEL array.

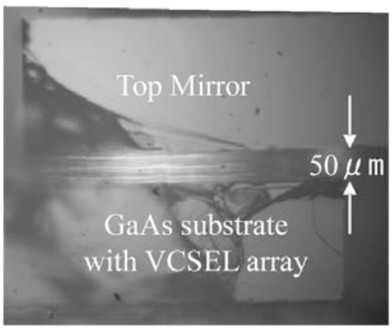

Figure 3 Near field pattern of multiplexer output.

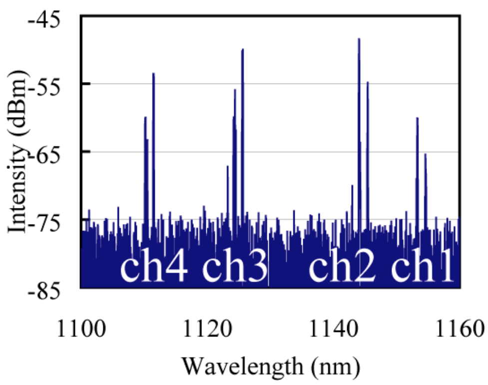

Figure 4 Spectra of the multiplexed four channel VCSEL output coupled into a multi-mode fiber.

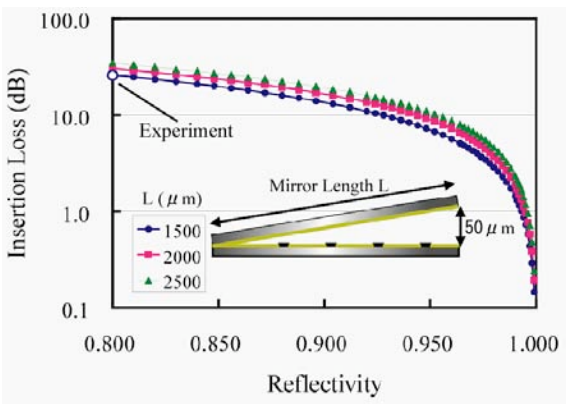

Figure 5 Insertion loss versus the mirror reflectivity.

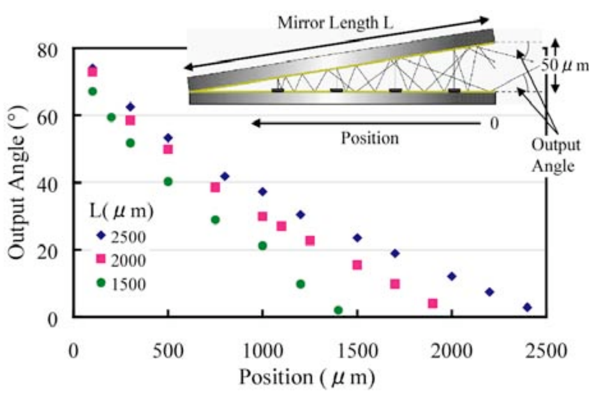

Figure 6 Calculated output angle of ray-trace propagation as a function of VCSEL position.