Monolithic Directly-Modulated Multi-Wavelength-Channel GaInAsP/InP Micro-Ring Laser Array

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Abstract. *Two directly-modulated GaInAsP/InP micro-rings with different radii vertically-coupled on a common bus are assessed for both independent and simultaneous operation. A device area <0.12mm^2 per microring allows the generation of 2λx1Gb/s WDM signals with 6nm wavelength separation. These show successful transmission over 25km of single-mode-fibre with < 0.2dB power penalty.*

Introduction

There is an increasing need for ultracompact direct modulated wavelength multiplexed sources in power efficient data transceivers. Microring laser arrays, vertically coupled to a single passive waveguide bus offer a highly scalable route to integration with a minimum of photonic components and chip footprint. The vertical coupling approach further allows an independent optimisation of epitaxy and waveguide fabrication for close proximity active and passive photonic devices.

Ring resonator lasers have been considered for some time as highly attractive sources in integrated photonics [1]. The coupling of ring lasers has been explored to enhance output power to 6.5mW and spectral purity with high side mode suppression ratio of >40 dB. Multiple coupled cavities have also enabled digital wavelength tuning [2]. Progress in reducing the dimensions for microring lasers has more recently enabled array scaling of active microrings for multiwavelength sources [3] and modulator based demultiplexer arrays [4]. The direct modulation bandwidth of vertically coupled microring laser array has further been demonstrated for 7Gb/s data modulation [5].

In this work we present a directly modulated monolithic microring laser array. The performance of individual channel operation is compared directly with wavelength multiplexed performance at a data rate of 1Gb/s. Transmission over 25km is further shown in system level assessments.

Fabrication

Figure 1(a) shows a schematic of the device structure. A conventional multiple quantum well ridge waveguide laser structure designed to target an emission wavelength of 1.55µm is grown on top of a passive bus waveguide on a 2" InP substrate in a single epitaxial step. The lasers are fabricated first and the p-metalisation is performed. The passive bus is defined between the substrate and the laser epitaxy. The wafer is subsequently transferred epitaxial side down onto a GaAs carrier wafer to which it is bonded by means of a BCB intermediate layer for mechanical support. The substrate and buffer layers are then removed in order to allow the subsequent definition of the bus waveguide. The bus waveguide layer also serves as an etch-stop layer for the wafer thinning. The p-contact is accessed at the ring using a via hole whilst the outside-lying n-contact is split into two parts to avoid additional metal induced losses in the passive bus waveguide. Both parts are connected with an air bridge to allow a homogeneous current injection to the ring resonator.

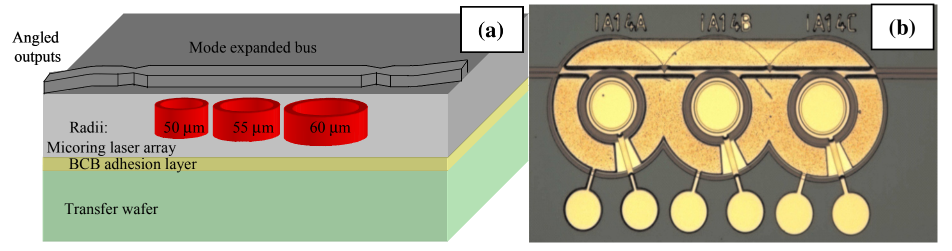

Fig. 1. (a) Schematic diagram for the bus coupled microring laser array showing micro-rings with three distinct radii and the mode expanded bus design. The 60µm and 55µm radius rings emit at 1561nm and 1567nm respectively (b) Photograph of the microring laser array

The ring waveguide width is 1.8µm. The passive bus is 2.5µm where the ring and bus waveguides are in close proximity to relax alignment tolerance. Microring radii of 60, 55 and 50µm are defined for the three bus coupled lasers. Away from the microring, the bus tapers to 1.8µm width over a length of 50µm for mode filtering before rebroadening back to 2.5µm [6]. Waveguides are angled at 7° towards the outputs to reduce reflections from the uncoated cleaved facets. Figure 1(b) shows a photograph of the completed photonic integrated circuit (PIC).

Device Characterisation and Fibre Transmission

In the experiment, the two larger radius lasers are directly probed with broadband coplanar probes contacting the n and p bond pads. The schematic of the experimental setup is shown in Fig. 2.

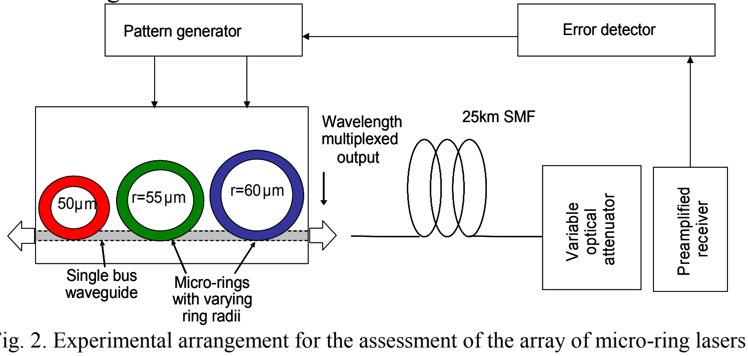

Fig. 2. Experimental arrangement for the assessment of the array of micro-ring lasers

DC measurements indicate threshold currents of 20mA and 22mA and series resistances of 28 and 24Ω for the 60µm and 55µm micro-ring radii respectively. The light is collected from both facets using lensed fibre. Under modulation with a 350mV peak to peak voltage at a 1Gb/s data rate, the optical spectrum is near identical for emission from both facets and comparable side mode suppression ratios of -28.1dB for the 1561nm channel and -25.4dB for the 1567nm channel are observed at applied DC currents of 42.2mA and 37mA, respectively. The submount is held at a temperature of 20°C.

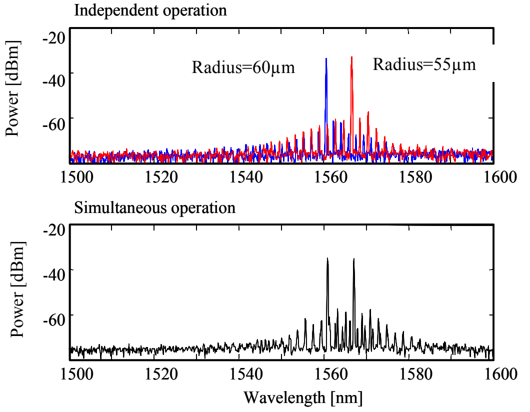

Fig. 3. Spectral characteristics for the directly modulated microring lasers for independent operation (top – overlaid spectra) and simultaneous operation (bottom)

Fig. 3. shows the spectra for both the independent and simultaneous operation of the microring lasers under data modulation. For the case of independent operation, the spectra are overlaid. A comparison of the modal structure indicates very similar spectral performance both as individual data transmitters and as wavelength multiplexed transmitters, indicating consistent behaviour and good immunity to electrical and thermal cross talk between the to lasers.

Transmission tests over 25km of single mode fibre have been carried out. After transmission, a mean received power of over 10µW is injected into an Erbium doped preamplifier at the receiver. Channels are selected with a 1nm bandwidth optical filter. A 933MHz low pass electrical filter is implemented after the photo-receiver. The optically preamplified receiver exhibits a -26dBm sensitivity.

As the longer wavelength channel is outside the gain bandwidth of the receiver, the signal to noise ratio for that channel is severely degraded. Received powers after the Erbium preamplifier are measured to be -1dBm and -18.6dBm for the two channels due to the wavelength dependent amplifier gain. Due to this relatively low received power from the 1567nm channel, BER measurements are carried out only on the 1561nm channel at the output of the bus waveguide. This is used as a reference for power penalty measurements and data are denoted by open square symbols in Fig. 4. In addition, BER measurements after the 25km transmission, where data are denoted by solid square symbols in Fig. 4, exhibit a negligible power penalty of 0.2dB. It should be noted that the modulation performance is sensitive to the bias conditions. At bias points near to a mode hops, closed eyes are found under modulation, even if the stationary starting point showed good single mode operation. However, for the correct bias points, good quality eyes are observed as shown in the inset of fig. 4.

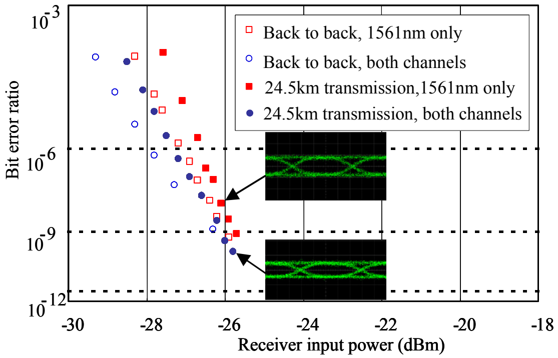

Fig. 4. Bit error rate performance for individual and wavelength multiplexed operation for 0km (back to back: open symbols) and 25km fibre transmission (filled symbols). Single wavelength operation is denoted by squares and wavelength multiplexed operation by circles. Insets show eye diagrams over 25km for independent and simultaneous operations.

The addition of the 1567nm channel is observed to only slightly affect the error rate performance of the 1561nm channel under wavelength multiplexed operation. For back to back multiplexed operation, a slight improvement is even observed and the transmission penalty is low. The observed low power penalties are indicative that the two lasers do not appear to influence each other greatly.

Conclusion

Simultaneous data modulation of monolithically integrated microring laser arrays vertically coupled to a single passive bus waveguide is demonstrated. 2λx1Gb/s WDM transmission assessment over 25km of single-mode-fibre is demonstrated with low 0.2dB multiplexed power penalty. The comparable performance of individual and multiplexed operation is indicative of low interference between the laser channels, suggesting a potential solution for small size integrated wavelength multiplexed laser arrays. Further resonator integration may extend the number of WDM sources as well as the aggregate data rate.

References

[1] A.S.-H. Liao and S. Wang, "Semiconductor injection lasers with a circular resonator", Applied Physics Letters, Vol. 36, No. 10, pp. 801-803, 1980.

[2] S. J. Choi, Z. Peng, Q. Yang, E. H. Hwang, P. D. Dapkus. "A semiconductor tunable laser using a wavelength selective reflector based on ring resonators". Proc. OFC/NFOEC, 2005,

[3] S.J. Choi, Z. Peng, Q. Yang, S.J. Choi and P.D. Dapkus, "An eight-channel demultiplexing switch array using vertically coupled active semiconductor microdisk resonators", IEEE Photonics Technology Letters, 16, 11, pp. 2517-2519, 2004

[4] S.J. Choi, Z. Peng, Q. Yang, S.J. Choi and P.D. Dapkus, "Eight-channel microdisk CW laser arrays vertically coupled to common output bus waveguides", IEEE Photonics Technology Letters, 16, 2, pp. 356-358, 2004

[5] A. Kapsalis, U. Troppenz, M. Hamacher, H. Heidrich, D. Syvridis, "7 Gb/s direct modulation of vertically coupled microring lasers", Proc. OFC/NFOEC 2008

[6] C.W. Tee, K.A. Williams, R.V. Penty, I.H. White, "Fabrication-tolerant active-passive integration scheme for vertically coupled microring resonator," IEEE Journal of Selected Topics in Quantum Electronics, 12, 1, pp. 108-116, 2006