Multi-wavelength channel 1.5 μm and 10 Gb/s EMBH DFB-LD array module using SAG technology

O.K. Kwon✉, S.H. Oh, K.S. Kim, C.W. Lee, Y.A. Leem and E.S. Nam

A multi-wavelength channel distributed feedback laser diode array (DFB-LDA) for the low-cost and low-power consumption applications of WDM-based datacentre networks is reported. The gain spectrum and lasing wavelength of each channel are controlled by using selective area growth and E-beam lithography techniques, respectively. To reduce the operation current and parasitic capacitance of the proposed array, an etched mesa buried hetero-structure (EMBH) is introduced. From this study, it was found that an eight-channel 300 μm long $\lambda/4$-shifted DFB-LDA has a threshold current of 10 ± 1.5 mA and a side mode suppression ratio of over 50 dB at a current of 50 mA for all channels. A transmission test for this LDA showed a clear eye opening with a dynamic extinction ratio of over 4.5 dB at 10 Gb/s after a 2 km transmission.

Introduction: A multi-wavelength channel laser diode array is an attractive component as a light source for a datacentre communication network [1]. In particular, since low- power consumption is one of the most important requirements within the datacentre, the array should be implemented with high energy efficiency and good channel uniformity. Specifications for a datacentre network were recently proposed and revised for a 100 Gb/s transmission of Ethernet signals over single mode fibre (SMF) with a distance of 2, 10, or 40 km [2]. We previously developed a ten-channel 10 Gb/s distributed feedback laser diode array (DFB-LDA) satisfying the above specifications by using selective area growth (SAG), E-beam lithography, and reverse-mesa ridge waveguide (RM-RWG) LD processing techniques [3, 4]. However, for the fabricated LDA, the threshold current was shown to be 13–28 mA and the bias current appeared to be as high as 80–100 mA. As a result, an array with a higher energy efficiency and better channel uniformity with static and dynamic properties needs to be developed.

A laser diode is usually fabricated into one of the two types of waveguides: an RWG or a buried hetero-structure (BH). A BH type has many advantages over an RWG, such as a lower power consumption (i.e. lower threshold current and lower thermal resistance) and a better output beam quality (i.e. a more circular and stable spatial mode) owing to a tight confinement of carriers and photons to an active region achieved using current blocking layers in a strongly index-guided LD. In spite of showing an excellent current blocking property, one critical problem exists, i.e. a low-modulation bandwidth from the large parasitic capacitance of the blocking structure. Recently, such a problem can be overcome by the use of an etched mesa (EM) structure, where the region containing the active region and current blocking structures was etched into a mesa form [5]. In this Letter, we describe the implementation of a multi-channel 1.5 μm and 10 Gb/s EMBH DFB-LDA. In addition, we tested their static and dynamic properties using mesa widths of about 8 μm. Finally, for this optimised structure, a 2 km transmission test was conducted.

Device structure: Fig. 1 shows a photograph of an optical sub-assembly module for an eight-channel DFB-LDA [where a ten-channel LDA was designed but there was an error in the grating pattern of two outermost channels (i.e. one and ten) during the E-beam lithography process, and the results of these channels were removed in this Letter]. The module contains an eight-channel $\lambda/4$-shifted DFB-LDA, 45 Ω surface-mountable device resistors, a ten-channel flexible printed circuit board, and a thermistor on a copper-tungsten metal optical bench. The cavity length of the DFB LDA was 300 μm and the wavelength interval of each channel was designed to be 8 nm. The $\lambda/4$-shifted DFB LDA was fabricated through a six-step metal organic chemical vapor deposition growth procedure. In the first growth step, an n-InP buffer layer, a grating layer (InGaAsP) with a bandgap wavelength of 1.3 μm (i.e. $\lambda_{bg} = 1.3$ μm), and an n-InP cap layer were grown in sequence. The grating patterns were fabricated to have a channel spacing of about 8 nm for all channels by changing the grating period according to the Bragg condition. In the second growth step, an n-InP spacer layer was grown in the grating region. For the SAG process, the mask patterns were designed into bilaterally symmetric shapes with a unit cell period of 500 μm [3]. After the mask patterning, the InGaAsP SAG layers (i.e. a SCH layer, seven-pair QWs, and a SCH layer) were grown during the third growth step. After the removal of the SAG mask, a p-InP cap layer was grown in sequence during the fourth growth step. For the formation of current blocking, a mesa structure was formed though a reactive ion etchinges (RIE) and a wet etching processes using 1.5 μm wide SiN_x mask stripes lined up along the <011> direction. After the formation of the active mesa structure, the fifth growth step for current blocking was conducted. The last growth step was for a p-InP clad layer and a p-InGaAs ohmic layer. The outer part of the EMBH region was etched out to reduce the parasitic capacitance of the DFB lasers and the width and depth of the EM were fabricated to be about 8 and 5 μm, respectively.

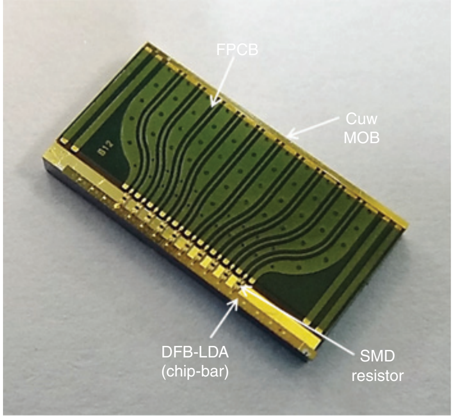

Fig. 1 *Photograph of sub-assembly module of eight-channel DFB-LDA*

Results of eight-channel 10 Gb/s DMLA: The fabricated eight-channel $\lambda/4$-shifted DFB-LDA were measured at an operating temperature of 25°C, and Fig. 2 shows the typical *L–I* curves and lasing spectra at a current of 50 mA. The threshold currents of the DFB-LDAs are within the range of 8.5–11 mA, which is 4.5–17 mA lower than 13–28 mA of the RWG structure described in [3]. The variations of the threshold current are 2.5 mA for all channels, which is one by sixth of the 15 mA found in [3], which is a very excellent performance owing to a low-threshold current of ∼10 mA and a very low variation of about ±1.5 mA for all channels. From this result, we confirmed that the degradations of various material and structural parameters related to the threshold current in a DFB-LDA employing an SAG layer are significantly decreased by adopting a BH structure. In contrast, the slope efficiency (SE) is from 0.114 to 0.141 W/A at an injection current of 50 mA, which is about 0.02 W/A lower than 0.143–0.165 W/A of an RWG type described in [3]; however, the variation of SE was 0.027 W/A, which is similar to 0.022 W/A in [3]. The superimposed CW spectra of the eight channels are spaced at about 8 nm within 55.6 nm from 1528.4 to 1584 nm. The side mode suppression ratio of the DFB-LDA was larger than 50 dB for all channels.

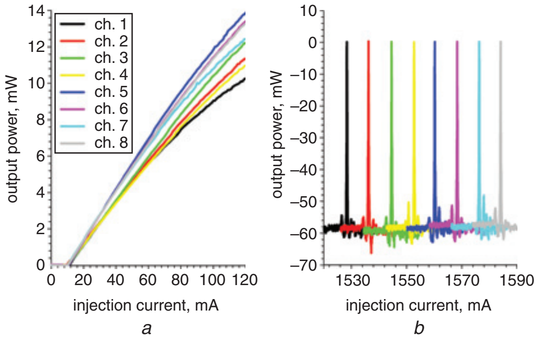

Fig. 2 *Measured static properties of the fabricated eight-channel DFB-LDA*

a Typical *L–I* curves
b Lasing spectra injection current of 50 mA for all channels

Fig. 3 shows the electro-optic (EO) responses of an eight-channel DFB-LDA module at a bias current of 50 mA. Nearly flattened responses are shown and −3 dB modulation bandwidths appear to be >8 GHz for all channels. The DFB-LD is directly modulated for

10 Gb/s with a pseudo random bit sequence of $2^{31}-1$ non-return to zero with a bias current of 50 mA and a modulation current of 40 mA (±20 mA). Fig. 4 shows the measured eye diagrams at a 10 Gb/s direct modulation of the module at the back to back (BTB, without a filter in the receiver module) and after a 2 km standard single-mode fibre transmission (with the filter) for all channels. The eye patterns are clearly opened with extinction ratios (ERs) of more than 5 and 4.52 dB for the BTB and 2 km transmission, respectively. For this result, the value of ER is similar to that in [3], but the operating current of 50 mA is 30 mA lower than 80 mA of the RWG in this reference.

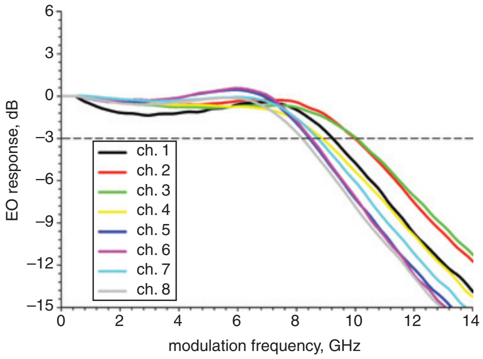

Fig. 3 *Measured EO responses of eight-channel DFB-LDA module. Measurement was performed individually for all channels. Bias currents were 50 mA for all channels*

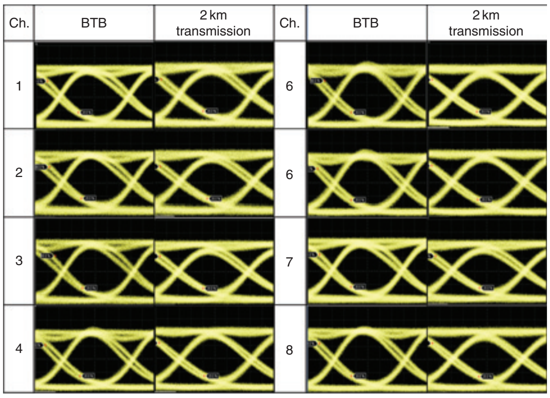

Fig. 4 *Measured 10 Gb/s eye patterns at BTB (without a filter in the receiver module) and after 2 km transmission (with filter). Bias currents were 50 mA for all channels*

Conclusion: We developed an eight-channel 10 Gb/s DFB-LDA having a wavelength spacing of 8 nm using the SAG technique, E-beam lithography, and re-growth technique. The waveguide of the DFB-LDA was fabricated using an EMBH structure for an uniform operating performance and a 10 Gb/s operation. The threshold currents of the fabricated LDs were 10 mA, ±1.5 mA, for all channels. The module shows clear eye patterns before and after a 2 km transmission with an ER of over 4.5 dB at a low operating current of 50 mA for all channels.

These results confirm that the performance uniformity in each channel was significantly improved using an EMBH structure. As a result, we concluded that our DFB-LD is capable of operating at a data rate of 10 Gb/s, and can be used as a low-cost light source for a datacentre communication network.

Acknowledgments: This work was supported by the ‘Next Generation Optical and Electrical Module Technology for Smart Data Center’ IT Convergence Device R&D project (no. B0101-15-0132).

Submitted: *25 August 2015* E-first: *8 October 2015*
doi: 10.1049/el.2015.3000
One or more of the Figures in this Letter are available in colour online.

O.K. Kwon, S.H. Oh, K.S. Kim, C.W. Lee, Y.A. Leem and E.S. Nam (*Photonic-Wireless Convergence Components Research Department, Components & Materials Research Laboratory, Electronics and Telecommunications Research Institute, 138 Gajeong-no, Yuseong-gu, Daejeon, Republic of Korea*)

✉ E-mail: okkwon@etri.re.kr

References

1 IEEE 802.3ba 40 Gb/s and 100 Gb/s Ethernet Task Force public area, June 2010
2 10 × 10 Low cost 100 Gb/s pluggable optical transceiver [Online]. Available at: http://www.10×10msa.org/documents.htm, accessed August 2, 2012
3 Kwon, O.K.: ‘A 10×10 Gb/s DFB laser diode array fabricated using a SAG technique’, *Opt. Express*, 2014, **22**, (8), pp. 9073–9079
4 Kwon, O.K.: ‘A 10 × 10 Gb/s DFB-LD array integrated with PLC-based AWG for 100 Gb/s transmission’, *IEEE Photonics Technol. Lett.*, 2014, **26** (21), pp. 2177–2180
5 Kwon, O.K.: ‘1.5 μm and 10 Gb/s etched mesa buried hetero-structure DFB-LD for datacenter networks’, *Semicond. Sci. Technol.*, 2015, **30**, (10), pp. 105010–105017