A Four-Channel Laser Array with Four 10 Gbps Monolithic EAMs Each Integrated with a DBR Laser

Jae-Sik Sim, Sung-Bock Kim, Yong-Hwan Kwon, Yong-Soon Baek, and Sang-Wan Ryu

ABSTRACT— A distributed Bragg reflector (DBR) laser and a high speed electroabsorption modulator (EAM) are integrated on the basis of the selective area growth technique. The typical threshold current is 4 to 6 mA, and the side mode suppression ratio is over 40 dB with single mode operation at 1550 nm. The DBR laser exhibits 2.5 to 3.3 mW fiber output power at a laser gain current of 100 mA, and a modulator bias voltage of 0 V. The 3 dB bandwidth is 13 GHz. A 10 Gbps non-return to zero operation with 12 dB extinction ratio is obtained. A four-channel laser array with 100 GHz wavelength spacing was fabricated and its operation at the designed wavelength was confirmed.

Keywords—Distributed Bragg reflector (DBR) laser, electro-absorption modulator (EAM), selective area growth (SAG).

I. Introduction

A dense wavelength division multiplexing (DWDM) system operating at a high bit rate requires stable low chirp transmitters with multiple channel wavelengths. Integration of a WDM transmitter into a single chip or a single package has been studied for the application to metropolitan area networks and access networks because it can allow us to construct low-cost optics modules [1]. There are several reports on integrated transmitters in which distributed feedback (DFB) lasers have been used dominantly [2], [3]. However, it is very difficult to vary the period of Bragg reflectors of constituent DFB lasers across an array. So, very complicated approaches have been used to fabricate multi-wavelength DFB laser arrays [4]-[6].

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Jae-Sik Sim (phone: +82 42 860 5909, email: jssim@etri.re.kr), Sung-Bock Kim (email: sbk@etri.re.kr), Yong-Hwan Kwon (email: yhkwon@etri.re.kr), and Yong-Soon Baek (email: yongb@etri.re.kr) are with IT Convergence & Components Laboratory, ETRI, Daejeon, Korea.

Sang-Wan Ryu (email: sangwan@chonnam.ac.kr) is with the Division of Physics & Chemistry, Chonnam National University, Gwangju, Korea.

A distributed Bragg reflector (DBR) laser is a promising candidate for integrated dense WDM transmitters because of its inherent wavelength tunability [7]. By controlling the tuning current in the DBR section, the wavelength of the laser can be tuned over a range of 5 nm [8]. For a high-speed transmission system, monolithic integration of an electroabsorption modulator (EAM) in front of a DBR laser is highly recommended because of its low wavelength chirp [9].

In this letter, we report on the fabrication and characterization of a four-channel laser array associated with a DBR laser integrated with an EAM. The channel spacing was designed to be 100 GHz (0.8 nm). A clearly open eye diagram with a dynamic extinction ratio over 12 dB has been achieved under 10 Gbps non-return to zero (NRZ) modulation.

II. Device Structure and Fabrication

A four-channel laser array was constructed with four monolithic EAMs each integrated with a DBR laser. Figure 1 is a schematic diagram of an EAM integrated monolithically with a DBR laser. The DBR laser consists of a 400 μm long gain section, a 150 μm long phase control section, and a 200 μm long DBR section, while the EAM has a length of 120 μm. The DBR laser and EAM are electrically isolated with a 20 μm long isolation trench. An isolation resistance of 10 kΩ was acquired.

At the DBR laser section, a laser diode was formed in the planar buried heterostructure, so current leakage was effectively blocked. Then, the active waveguide was laterally tapered in the spot-size converter (SSC) region. The passive waveguide core was very thin and was laterally confined by the ridge structure. The optical power was gradually transferred to

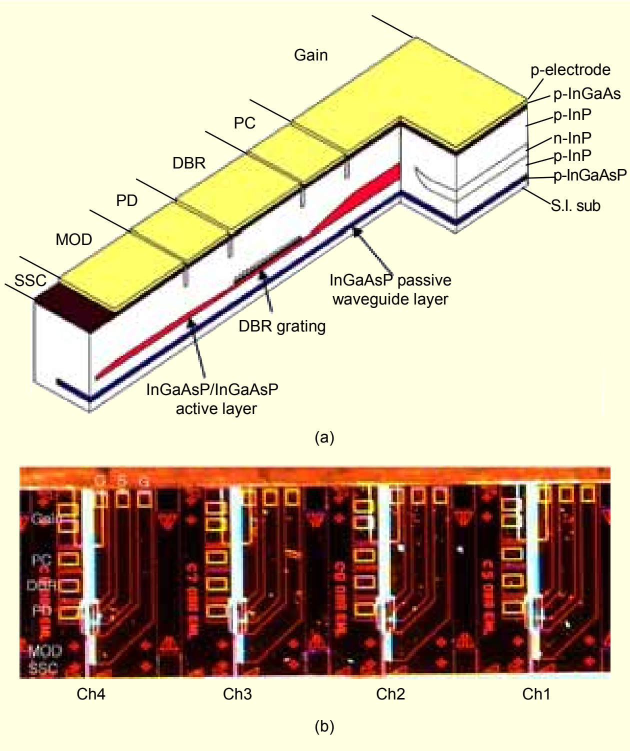

Fig. 1. (a) A schematic diagram of an EAM integrated with a DBR laser and (b) top view of a four-channel laser array.

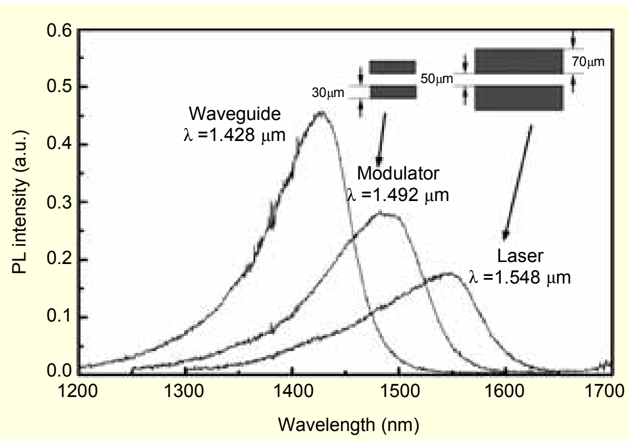

Fig. 2. PL spectra from laser, modulator, and flat regions.

the passive waveguide as the width of the active waveguide was decreased in the SSC section. Since the active waveguide was totally gone at the facet end, the far field pattern was determined only by the thin passive waveguide. Though the width of the taper tip was needed to be zero at the SSC end, it was easily achieved both by normal photolithography and by an undercut etching [10], [11].

The bandgap energies of the active regions were different from each other in their selective area growths. A specially designed SiN_x mask pattern was used to adjust the photoluminescence peak wavelengths of an active layer in the laser, modulator, and Bragg grating regions to 1.548, 1.492, and 1.428 μm, respectively.

The inset in Fig. 2 shows the SAG oxide pattern, which provides all laser, modulator, and passive waveguide materials in one primary growth. The grown material photoluminescence (PL) is shown in Fig. 2.

The samples were grown by low-pressure metal-organic vapor phase epitaxy (LP-MOCVD), which was also used in the SAG steps.

An n-InP buffer layer, a 50 nm thick n-type 1.08 μm bandgap InGaAsP quaternary (Q) lower waveguide layer, and a 450 nm thick n-InP spacer layer were grown sequentially. In the second epitaxial growth, two SiN_x pads were patterned on the n-InP spacer layer. In the unmasked region, the multi-quantum well undoped core layer consisting of seven 6 nm thick lattice-matched InGaAsP wells (λ_{PL}= 1.58 μm) and seven 10 nm thick tensile strained (–0.6%) InGaAsP barriers (λ_{PL}= 1.20 μm) was grown and embedded between two 100 nm thick compressive-strained InGaAsP confinement layers (λ_{PL}= 1.20 μm, λ_{PL}= 1.10 μm). The thickness of the core layer in the tuning region is 300 nm. The transition energy in the gain regions corresponds to the wavelength of 1.548 μm, while the wavelength detuning between the gain and the tuning regions is 120 nm.

In the third step we grew a p-InP buffer layer and a high-bandgap p-InGaAsP layer in which the Bragg grating was inscribed by optical holography and reactive ion etching. Optical lithography, chemical wet etching to form a mesa type of waveguide, was then followed by the fourth growth step. The chemical, $HBr:H_2O_2:H_2O$, was used for the wet etching to form not only the mesa waveguide but also a submicron taper tip of the SSC. The width of the buried mesa was 1.2 μm. We found that a sharp taper tip less than 0.2 μm at the SSC was easily achieved by normal photolithography combined with the undercut wet etching. Expensive and time-consuming e-beam lithography was not needed here to form a submicron pattern of SSC.

After the waveguide was formed, a p-n-p current blocking layer was regrown. A 1.5 μm-thick p-InP cladding layer and a 0.1 μm-thick p^+-InGaAs contact layer were overgrown successively. The passive waveguide in the modulator region was defined by both dry and wet etchings to have the shape of a deep ridge 8 μm in width. Polyimide was used for planarization of the deep ridge structure and electrical isolation between lasers. Finally, n- and p-metal contact electrodes were deposited.

The facet of the SSC is antireflection-coated with TiO_2/SiO_2. Reflectivity (R) of less than 1% is obtained with an optimized condition, and the bandwidth where $R < 1\%$ is 40 nm at 1.55 μm. The rear facet is HR coated (R is approximately 90%) with three pairs of SiO_2/TiO_2.

III. Results

Figure 3 shows the output power when the four-channel laser array was operated with a 60 mA constant current. The threshold currents of the DBR laser were between 4 mA and 8 mA. The fiber coupled output power was about 2.5 to 3.3 mW at an injection current of 60 mA and 0 V modulator bias voltages. The fiber coupling efficiency was about 30%. In this four-channel array, no degradation of a spectral quality was observed in the curves.

Figure 4 shows typical lasing spectra at the operation current of 60 mA. The observed spectra exhibited that the lasing wavelength was well managed as designed. The wavelengths were 1550.4 nm, 1551.2 nm, 1552.0 nm, and 1552.8 nm, so the deviation of channel spacing was less than 0.8 nm for the four channels. All the lasers revealed a good SMSR of over 40 dB.

The tuning characteristics of the DBR laser are shown in Fig. 5. The total tuning range is 3.3 nm and the SMSR is greater than 35 dB on each step. The frequency response was measured at a current of 50 mA.

The electrical-to-optical (E/O) frequency response was

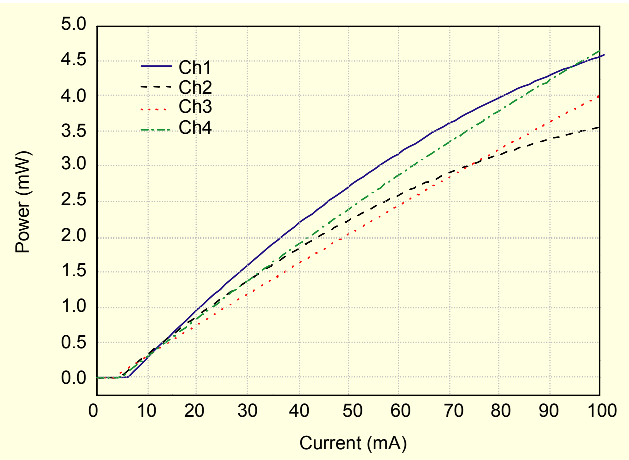

Fig. 3. Light-current characteristics of individual channels of the four-channel laser array.

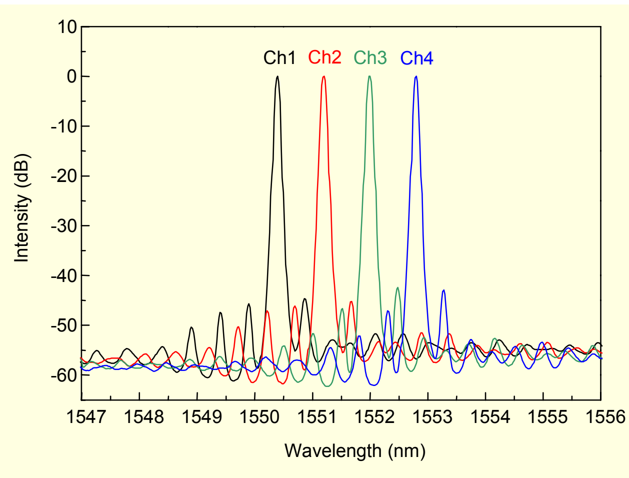

Fig. 4. Lasing spectra of the four channels measured at 60 mA.

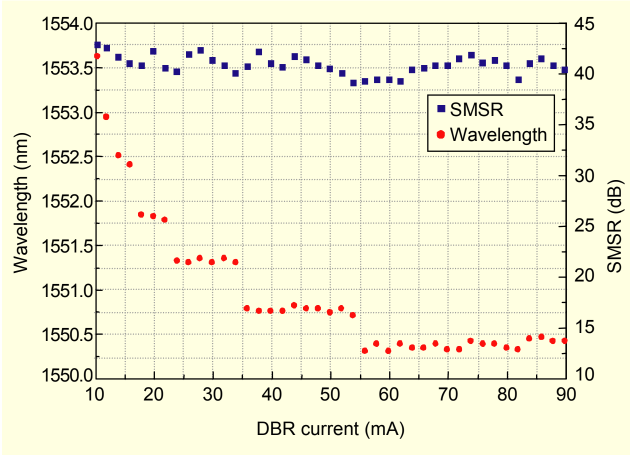

Fig. 5. DBR wavelength and SMSR as a function of tuning current I_{gain} = 50 mA, T = 25°C.

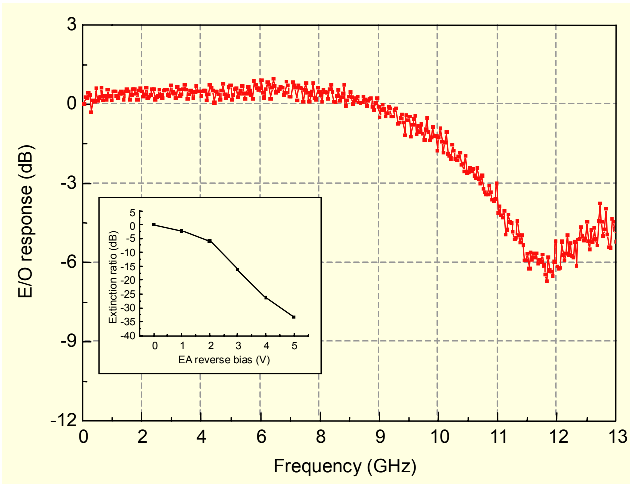

Fig. 6. The measured small-signal frequency response of the EAM integrated with DBR laser.

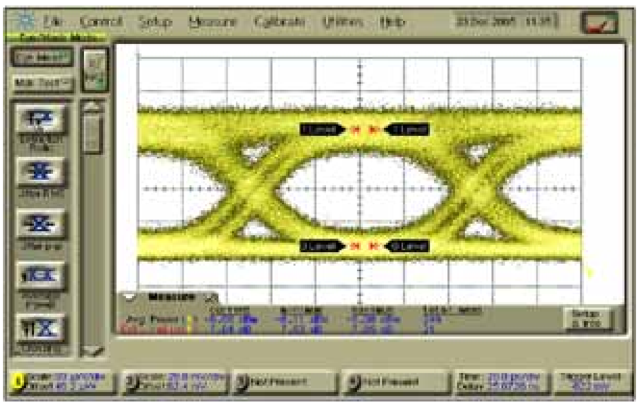

Fig. 7. 10 Gbps NRZ eye diagram.

measured using an HP 8703 lightwave component analyzer. The response in Fig. 6 shows a 3 dB small signal bandwidth of 13 GHz. The DC extinction ratio, shown as an inset in the figure, of the EAM was 12 dB at –2.5V.

Back-to-back transmission experiments at 10 Gbps NRZ modulation were carried out. A 10 Gbps NRZ electrical signal came from a pulse pattern generator, and the pseudorandom binary sequence was 2^{31}-1. A driving signal with 2 V peak-to-peak voltage was applied to the light-source module. The modulated light from the module was directly detected with an oscilloscope. Figure 7 shows the corresponding optical output, with a laser current of 60 mA and EAM static bias of –2.5 V. A clearly open eye diagram was observed.

IV. Conclusion

A four-channel laser array was constructed with four monolithic EAMs each integrated with a DBR laser. The monolithic integration of a fast tunable DBR laser with an EAM has been achieved with use of the selective area growth. Optimization of the quantum well stack led to the fabrication of integrated components having high fiber-coupled output power, a tuning range larger than 3.3 nm, and good static and dynamic modulation characteristics. Four-channel laser arrays with very promising performances, including a low threshold current of 4 to 6 mA, a low voltage swing of 2.5 V for a 12 dB extinction ratio, a 3 dB cut-off frequency exceeding 13 GHz, and 10 Gbps NRZ modulation characteristics are very attractive for high-speed data transmission applications.

The lasing wavelength was effectively controlled by adjusting the DBR current and phase control. The fabricated device showed uniform laser performance and a high SMSR of over 40 dB.

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