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A wavelength-tunable short-cavity DBR laser with active distributed Bragg reflector

Hideo Arimoto,[1,2a)] **Hiroshi Sato,**[1] **Takeshi Kitatani,**[1,2]
Tomonobu Tsuchiya,[1,2] **Kazunori Shinoda,**[1] **Aki Takei,**[1,2]
Hiroyuki Uchiyama,[1,2] **Masahiro Aoki,**[1] **and Shinji Tsuji**[1,2]
[1] *Central Research Laboratory, Hitachi, Ltd., 1–280 Higashi-Koigakubo Kokubunji, Tokyo, 185–8601 Japan*
[2] *Optoelectronic Industry and Technology Development Association (OITDA), 20–10, Sekiguchi 1-Chome, Bunkyo-ku, Tokyo 112–0014*
a) *ari-hide@crl.hitachi.co.jp*

Abstract: The incorporation of an active single-quantum well in the tuning layer of a DBR laser is proposed as a way of compensating for optical loss and achieving stable single-mode operation during wavelength tuning. Experimental results demonstrate that the structure achieves these goals while maintaining the efficiency of tuning. In application to a short-cavity DBR laser with a gain region 35-μm long, continuous wavelength gtuning over a broad 4.8 nm is achieved with stable lasing properties (more than 40 dB of side-mode suppression). Fast wavelength switching less than 10 ns to cross a wavelength spacing of 2 nm is also confirmed.

Keywords: Short-cavity DBR laser, Active DBR structure, Wavelength tunable laser
Classification: Photonics devices, circuits, and systems

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1 Introduction

Tunable lasers with fast wavelength (λ) switching will be essential for next-generation photonic networks. Distributed Bragg reflector (DBR) lasers inherently realize fast tuning, of the several-nanosecond order, because the tuning time is limited by the carrier lifetime [1]. However, conventional DBR lasers, such as the sampled grating (SG) DBR laser [2], super-structure-grating (SSG) DBR laser [3], and vertical-grating-assisted codirectional coupler laser with rear-sampled grating reflector (GCSR) laser [4], require delicate current adjustment. The associated complexity of circuit control can significantly slow the actual rate of λ switching.

The short-cavity DBR (SC-DBR) laser has been proposed [5] as a way around the shortcomings of existing devices, and exhibits continuous λ tuning over a range ($\Delta\lambda_{\mathrm{con}}$) of 6.0 nm [6]. Tuning control is via a single electrode. However, injecting current for λ tuning into the DBR region raises the levels of optical loss due to free carriers and inter-valence-band absorption, leading to a deterioration of the lasing properties [2]. Sakano et al. have proposed an active DBR structure, in which an active layer within the tuning layer of the DBR region compensates for the optical loss, and have demonstrated that this structure provides improved output power and narrower spectral lines [7]. In this device, however, the variability of refractive index in the tuning layer is lowered by the consumption of carriers in the active layer, so $\Delta\lambda_{\mathrm{con}}$ is limited to 1 nm.

In this paper, we propose a new active DBR structure in which the active layer is a quantum well. This allows a moderate amount of gain without degradation of the tuning characteristics. Next, we measure the variation in refractive index and optical loss of this active DBR structure with the injection of tuning current, and compare the results with those for a conventional DBR structure, i.e. a DBR without the active layer. We then fabricate

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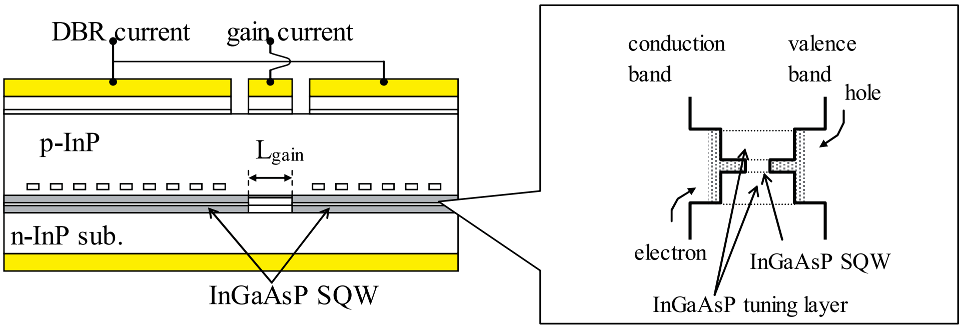
an SC-DBR laser that incorporates the active DBR structure; we call this a short-cavity active DBR laser (SC-ADBR laser). After that, we measure the wavelength-tuning properties of the SC-ADBR laser with a gain-region length, L_{gain} of 35 μm, and show that the device achieves $\Delta\lambda_{con}$ of 4.8 nm with stable lasing properties, i.e. a side-mode-suppression-ratio (SMSR) higher then 40 dB. Finally, we measure the wavelength-switching properties of the device and show that it achieves fast switching, taking much less than 10 ns to cross a wavelength spacing of 2 nm.

2 Device structure

Figure 1 (a) is a cross-sectional view of the SC-ADBR laser. It consists of a short gain region and DBR mirrors. The DBR layer consists of a bulk InGaAsP tuning layer with a bandgap of 0.88 eV, in which an InGaAsP SQW is inserted to produce optical gain. Figure 1 (b) is a sketch of the energy bands in the active DBR. A small amount of injected current makes electrons and holes flow into the SQW and produce optical gain. Larger amounts of injected current cause carriers to flow out of the SQW and accumulate in the bulk tuning layers; this changes the refractive index n_{eq} and tunes the lasing wavelength.

The device was fabricated with three dry-etching processes and four stages of metal-organic vapor-phase epitaxy (MOVPE). Firstly, we grew the InGaAsP/InGaAsP multi-quantum-well active layer. Most of this layer was then etched away by metal-organic reactive ion etching (MORIE), leaving an active layer 35-μm long. This was followed by growth of the core layers of the two (rear and front) DBR regions, each consisting of bulk InGaAsP and an SQW. After growth, these regions, with respective lengths of 300 and 200 μm, were butt-jointed to either end of the gain region. Electron-beam lithography was then used to form the grating pattern as a corrugation above the core layers in the DBR region. The coupling coefficient of the corrugation was controlled to be 90 cm^{-1} by MORIE. Bulk p-type InP was then grown on both the gain and DBR layers, after which a mesa structure was fabricated by MORIE and then buried in Fe-doped InP. The two DBR regions were electrically connected for unified electrical control. For direct comparison,



(a) (b)

Fig. 1. Cross-sectional view of the SC-ADBR laser and (b) energy-band diagram for the active-DBR.

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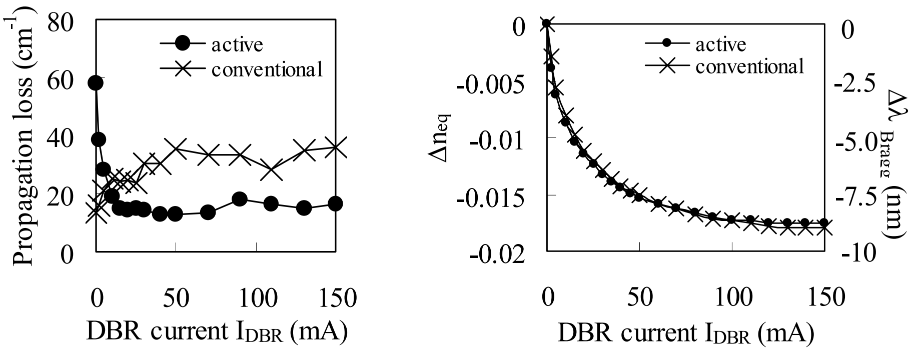
we also fabricated a conventional-DBR laser, i.e. a structure differing only in the omission of the active layer.

3 Experimental results

We started by measuring the basic properties of the DBR region. Figure 2 (a) shows the dependence of the optical loss on the DBR current (I_{DBR}) in the DBR region, as measured by the contrast-fringe method [8]. In the conventional DBR structure, the optical loss increases with I_{DBR} because of free-carrier and inter-valence band absorption. In the active DBR structure, however, the optical loss only remains large as long as the injected current is less than 10 mA. As I_{DBR} increases above this level, the propagation loss decreases sharply to about 15 cm^{-1}, and then remains almost constant for I_{DBR} up to at least 150 mA. The optical loss is around 20 cm^{-1} less than that for the conventional DBR structure. Figure 2 (b) shows the dependence of n_{eq} in the DBR region on I_{DBR}, relative to the value for $I_{DBR} = 0$ mA; which was measured from the sub-threshold spontaneous emission spectra of the gain region as observed through the DBR region. The change of Bragg wavelength, $\Delta\lambda_{Bragg}$, is plotted on the right axis. n_{eq} decreases as I_{DBR} is increased, but this effect starts to enter saturation at around $I_{DBR} = 100$ mA. We found no difference between the changes in index, Δn_{eq}, for active and conventional DBR structures. That is, the loss compensation is attained without sacrificing the efficiency of tuning.



(a) (b)

Fig. 2. Dependence of (a) optical loss and (b) Δn_{eq} and the variation in Bragg wavelength $\Delta\lambda_{Bragg}$ on IDBR.

Plots of λ and SMSR as functions of I_{DBR} in the conventional and active DBR lasers are given as Fig. 3. The gain current I_{gain} is fixed at 20 mA. In the conventional DBR laser, the SMSR falls rapidly with tuning, and the laser oscillation stops when $I_{DBR} > 30$ mA. This is due to the increase in optical loss shown in Fig. 2 (a); by decreasing the reflectivity of the DBR mirror, the increased mirror loss suppresses laser oscillation. The continuous tuning range, $\Delta\lambda_{con}$, is thus limited to less than 2 nm. In the active DBR

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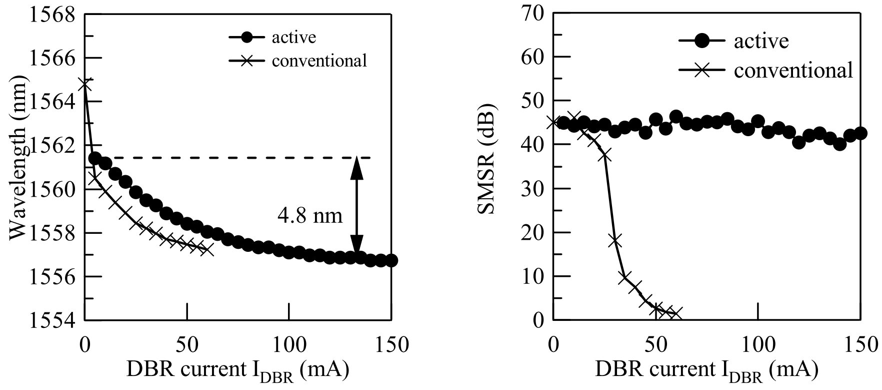

(a) (b)

Fig. 3. Dependence of (a) λ and (b) SMSR in the conventional and the active-DBR lasers on I_{DBR}. I_{gain} is fixed at 20 mA.

laser, on the other hand, the SMSR remains above 40 dB over the whole range of I_{DBR} shown in Fig. 3 (b), leading to a large $\Delta\lambda_{con}$ of at least 4.8 nm. The active DBR structure has a superior tuning characteristic because the loss remains low across a much wider range of tuning current.

Figure 4 shows the wavelength-switching characteristic of the active DBR driven by a rectangular 36 mA peak-to-peak injection current at a frequency of 10 MHz. I_{gain} is again fixed at 20 mA. The wavelength is switched from 1561.7 nm to 1559.7 nm. Crossing the 2-nm wavelength spacing takes less than 10 ns, which is almost the same as the time seen in an SC-DBR laser based on a conventional DBR [9]. This result indicates that including an active layer within the DBR layer has no negative effect on the switching characteristics. The results in general indicate that the SC-ADBR laser is one of the most promising candidates for future commercial application as a tunable laser that provides fast wavelength switching.

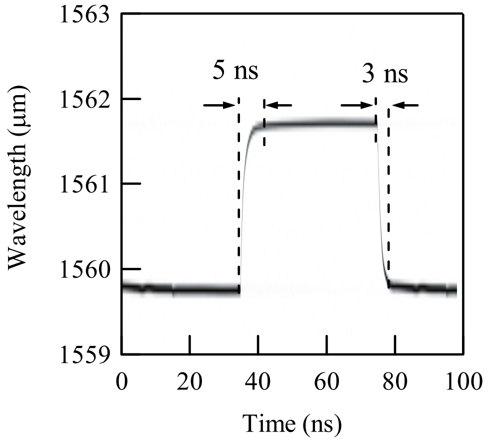

Fig. 4. Wavelength-switching characteristics of the laser when driven by a 36-mA peak-to-peak rectangular DBR current at a frequency of 10 MHz. I_{gain} is again fixed at 20 mA.

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4 Conclusion

We have described the inclusion of an SQW in the DBR region of an SC-DBR laser as a way of compensating for optical loss during tuning operations. We showed that the new structure provides loss compensation while maintaining efficiency of tuning. In application to a short-cavity DBR laser ($L_{\text{gain}} = 35\,\mu\text{m}$), the structure provided continuous wavelength tuning over the large range, $\Delta\lambda_{\text{con}}$, of 4.8 nm. We also demonstrated the superior and stable lasing properties of the device, with SMSR remaining higher than 40 dB throughout the above range. Wavelength switching across 2 nm within 10 ns was also demonstrated. These results indicate that the SC-ADBR laser holds great promise as a practical technology for tunable lasers that provide fast wavelength switching. Moreover, our active DBR concept should be applicable to any type of DBR-based laser in which increases in optical loss impose strict limits on lasing performance.

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