Dual-Wavelength InGaAs–GaAs Ridge Waveguide Distributed Bragg Reflector Lasers with Tunable Mode Separation

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***Abstract*—The design and operation of integrated dual-wavelength sources are reported. These InGaAs–GaAs ridge waveguide (RW) distributed Bragg reflector (DBR) lasers consist of a common gain section and two, separate DBR sections. Multiple current injection is not necessary for these lasers to operate in dual-wavelength. Dual-wavelength operation is easily achieved by simply biasing the gain section. A relatively low coupling coefficient κ in the front grating reduces the added cavity loss for the back grating mode. Therefore, the back grating mode reaches threshold easily. Also, the addition of a spacing section lowers the current induced thermal interaction between the two uniform grating sections, significantly reducing the inadvertent wavelength drift. As a result, biasing the front DBR section results in tunable mode pair separations ($\Delta\lambda$) as small as 0.3 nm and as large as 6.9 nm.**

***Index Terms*—Distributed Bragg reflector lasers, gratings, quantum-well lasers, ridge waveguides, semiconductor lasers.**

I. Introduction

MULTIWAVELENGTH optical sources are important components in applications such as wavelength division multiplexing, optical remote sensing, and optical data processing. While a common approach to achieve multiple wavelengths from a single output is to integrate the outputs from multiple, discrete lasers [1]–[3], this can lead to large and complex chip design. Recently, research on integrated, multiwavelength sources with single emission aperture has gathered great interest. Cascaded, strongly gain coupled DFB lasers have been demonstrated as an integrated multiwavelength source [4], [5]. Periodic phase shifted gratings, sampled grating DBRs, and multiwavelength grating (MWG) distributed feedback (DFB) were utilized to achieve dual-wavelength operation [6]–[8]. These approaches rely on the reflectivity comb from the integrated multiwavelength feedback mechanisms for their operation. However, because of the integrated design of the multiwavelength feedback, it is very difficult to select and tune a wavelength while leaving other wavelength(s) unaffected.

We reported the design and operation of dual-wavelength asymmetric cladding InGaAs–GaAs RW-DBR lasers utilizing two separate uniform gratings operation with fixed mode separations [9]. The different periods of the gratings defined the wavelength separation between the mode pairs. Recently, we also reported the design and operation of a RW-DBR laser that can be operated in both a single-wavelength mode and a stable, dual-wavelength mode [10]. In this device, uniform gratings with an identical period were used, and current injection into the tuning DBR defined the wavelength separation between the mode pairs. The laser operates in a single-wavelength mode with no current applied to the tuning DBR pad, and dual-wavelength operation is achieved when current is applied to the tuning DBR pad. Tunable mode pair separations were $13 \sim 17$ nm depending on the tuning conditions. This rather large mode pair separation is the result of significant current injection (therefore, heating) into the tuning pad necessary for the second mode to achieve lasing. Also, tuning one wavelength resulted in an inadvertent drift in the other wavelength because of current induced thermal interaction between the two closely spaced DBR pads.

In this letter, we report a new design for an integrated, dual-wavelength source that requires no additional current for dual-wavelength operation. With this design, the control over the wavelength tuning is greatly improved. As a result, the InGaAs–GaAs asymmetric cladding RW-DBR lasers reported here operate in a dual-wavelength mode with tunable mode pair separations as small as 0.3 nm and as large as 6.9 nm.

II. Device Design

The epitaxial layers for the asymmetric cladding separate confinement heterostructure (SCH) were grown by atmospheric pressure metalorganic chemical vapor deposition (MOCVD) in a vertical reactor on a (100) $\mathrm{GaAs:n^+}$ substrate. Direct-write electron beam lithography was used to write first-order, uniform in PMMA. The details of the lasers epitaxial structure and subsequent processing are reported in [9]. No coatings are applied to the facets. Fig. 1 shows a schematic diagram of the tunable dual-wavelength InGaAs–GaAs RW-DBR laser. The dual-wavelength asymmetric cladding RW-DBR laser consists of a common gain section with two DBR sections. These DBRs utilize uniform gratings with the same Bragg period. The metal liftoff was aligned over the gratings to provide electrical isolation for the common gain section and the two DBR sections. The two DBR sections are physically separated in order to reduce the inadvertent heating mentioned above. Three different device dimensions were investigated. Table I is

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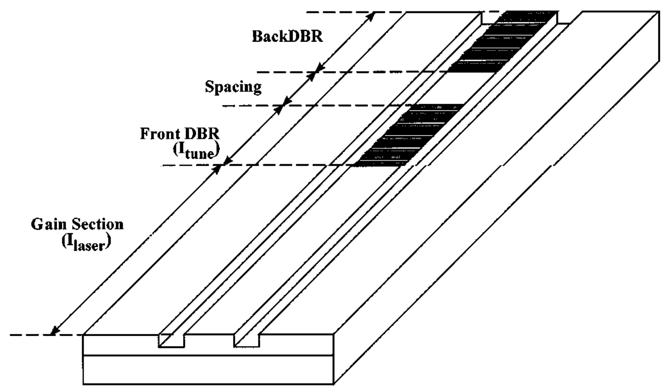

Fig. 1. A schematic diagram of the tunable dual-wavelength InGaAs–GaAs RW-DBR laser. The dual-wavelength asymmetric cladding RW-DBR laser consists of a common gain section with two DBR sections.

a summary of physical dimensions of these devices. The ridge heights and ridge widths for all three devices are 0.15 μm and 3.5 μm, respectively. All DBRs consist of uniform grating with a period of 166.0 nm.

III. Results and Discussion

Testing was performed continuous wave (CW) with a heat sink temperature maintained by a thermoelectric (TE) cooler. Only the gain section is biased to achieve lasing. Shown in Fig. 2 are the threshold currents for the three different devices in Table I measured at different temperatures. At 20 °C, the threshold currents for devices (a), (b), and (c) are 12 mA, 28 mA, and 32 mA, respectively, and the uniform grating period of 166.0 nm results in a single nominal lasing wavelength of 1077.4 nm. As expected, device (a), with the shorter gain section and the longer front DBR section (i.e., stronger reflectivity), exhibits the lowest threshold current for all temperatures. Fig. 2 also shows that the threshold currents decrease for all three devices as the TE cooler temperature is increased from 20 °C to 60 °C. Threshold currents for devices (a), (b), and (c) are as low as 7.1 mA, 18 mA, and 18.5 mA, respectively. This trend can be accounted for by the Bragg condition being red-shifted with respect to the gain peak. As the temperature of the device increases, the gain peak tunes toward the Bragg condition, leading to a lower threshold current. As expected, no lasing is observed when only the tuning DBR pad is biased.

Dual-wavelength operation occurs in devices (b) and (c) when the lasers are biased high enough to support two lasing modes ($2 \times I_{th}$). Both devices exhibit similar trends in their performance. Unlike previous devices reported in [9], no additional current is required for dual-wavelength operation. The coupling coefficient, κ, of the DBR is estimated to be ~80 cm^{-1}, significantly lower than the previously reported κ, ~135 cm^{-1}, for the RW-DBR device that required an additional 40 mA in the DBR section for dual-wavelength operation [9]. This lower value of κ is believed to be an important feature that contributes to the dual-wavelength operation of these devices. For devices with deeply etched surface gratings, a higher threshold condition for the second lasing mode for the back DBR (λ_{back}) results from the added cavity loss caused by scattering in the front grating. By reducing this loss, λ_{back}

TABLE I
Summary of Dimensions (All Units in μm)

Device	(a)	(b)	(c)
L_{gain}	500	525	550
$L_{front\ DBR}$	100	75	50
L_{space}	100	75	50
$L_{back\ DBR}$	100	100	100

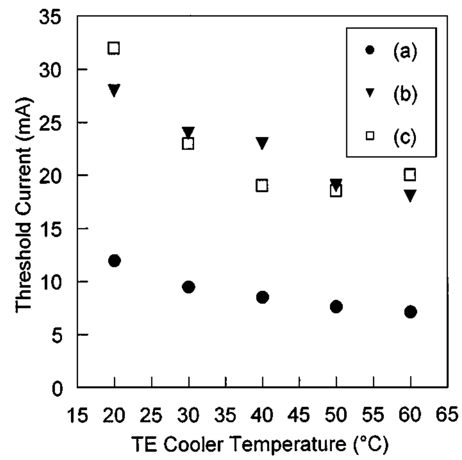

Fig. 2. Threshold currents for devices (a), (b), and (c) measured at different temperatures from 20 to 60 °C.

reaches threshold more easily. While device (a) exhibits the lowest threshold current, it does not exhibit dual-wavelength operation. This is because the added loss for λ_{back} in device (a) with the longest front grating (L_f) and the spacing (L_s) sections. Therefore, a low κL product for the front grating is an important factor determining the threshold condition of λ_{back} (i.e., dual-wavelength operation). However, κ for the front grating still needs to be sufficiently high in order for the front grating to act as a good wavelength-selective reflector. Minimizing cavity loss for the back grating section should be carefully balanced with sufficient reflection for λ_{front}.

Once dual-wavelength operation is achieved by biasing the gain section, injection of current into the front DBR section results in wavelength tuning. Fig. 3 shows the longitudinal mode spectra of device (c) measured at different tuning currents from 0 mA to 35 mA with the laser current fixed at 50 mA at 60 °C. As noted earlier, the gain peak of the material overlaps better with the Bragg condition at elevated operating temperatures, facilitating dual-wavelength operation and therefore, tuning. Because of thermal coupling between the gain section and the front DBR, the wavelength of λ_{front} is slightly longer than that of λ_{back}. The difference in relative intensity of the two modes increases as the mode pair separation ($\Delta\lambda$) becomes larger because the gain for λ_{back} decreases as it tunes away from the peak gain. This can be avoided by initially designing the Bragg wavelength to be blue-shifted with respect to the peak gain. Fig. 4 shows the peak wavelengths for the RW-DBR laser presented in Fig. 3. Closed circles represent the front DBR mode (λ_{front}), and open circles represent the back DBR mode (λ_{back}). As the tuning current increases, both modes shift toward longer wavelengths, with the tunable wavelength shifting further. When the

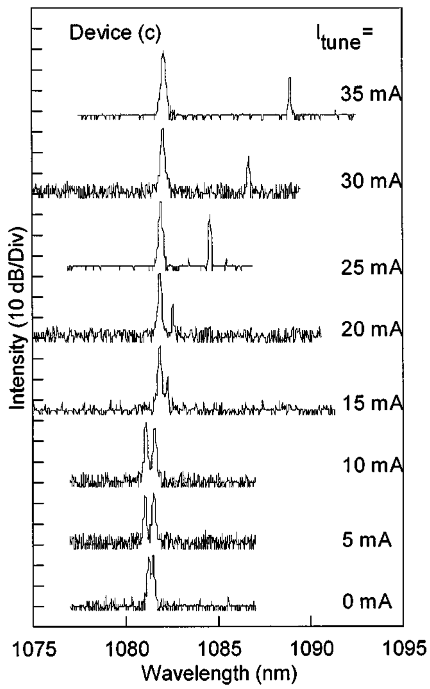

Fig. 3. Longitudinal mode spectra of device (c) measured at different tuning currents ($I_{\rm tune}$) in the front DBR section from 0 to 35 mA with the laser current ($I_{\rm laser}$) fixed at 50 mA ($\sim 2 \times I_{th}$) at 60 °C.

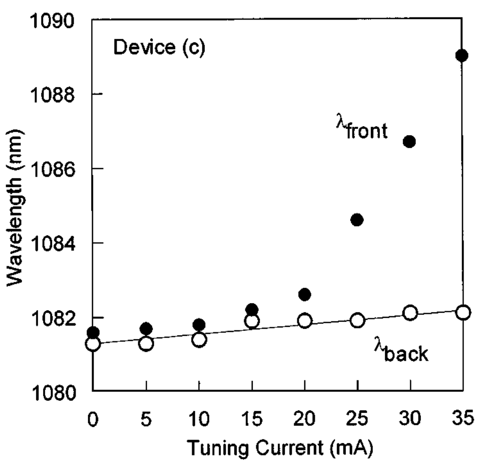

Fig. 4. Peak wavelengths the RW-DBR laser presented in Fig. 3. Closed circles represent the front DBR mode ($\lambda_{\rm front}$), and open circles represent the back DBR mode ($\lambda_{\rm back}$). $\Delta\lambda$ is tunable from 0.3 to 6.9 nm over this tuning current range.

tuning current is increased from 0 mA to 35 mA, the wavelength of $\lambda_{\rm front}$ increases by 7.4 nm, tuning continuously from 1081.6 nm to 1089.0 nm. Therefore, the RW-DBR laser exhibits a tunable $\Delta\lambda$ as small as 0.3 nm and as large as 6.9 nm. At higher currents $\lambda_{\rm front}$ jumps a lower wavelength that is more favorable for lasing. Device (b) also exhibits similar trends. Fig. 4 also illustrates the effect of inserting a 50-μm spacing section between the two DBR sections to reduce the inadvertent drifting of $\lambda_{\rm back}$. When the tuning current is increased from 0 mA to 40 mA, the wavelength of $\lambda_{\rm back}$ increases by only 0.9 nm, from 1081.3 nm to 1082.2 nm (0.025 nm/mA). Compared to that observed in previous results with no spacing section (0.038 nm/mA) [9], the rate of wavelength drift is reduced by 35%. For device (b), which has a longer spacing section (75 μm), the drift in $\lambda_{\rm back}$ is further reduced to $\sim$0.015 nm/mA.

IV. Conclusion

The design and operation of integrated dual-wavelength sources are reported. By simply biasing the gain section, these InGaAs–GaAs RW-DBR lasers operate in dual-wavelength. Lower coupling coefficient, κ, in the front grating reduces the added cavity loss for the back DBR mode ($\lambda_{\rm back}$), and therefore, $\lambda_{\rm back}$ reaches threshold more easily. Also, the addition of a spacing section reduces the current induced thermal interaction between the two uniform grating sections, significantly reducing the inadvertent wavelength drift. As a result, a tunable mode pair separations ($\Delta\lambda$) as small as 0.3 nm and as large as 6.9 nm can be achieved.

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