Wavelength and Mode Stabilization of Widely Tunable SG-DBR and SSG-DBR Lasers

G. Sarlet, *Student Member, IEEE*, G. Morthier, *Member, IEEE*, and R. Baets, *Senior Member, IEEE*

***Abstract*—A novel mode stabilization scheme for widely tunable SG-DBR and SSG-DBR lasers is demonstrated. It is shown that a minimum in active section voltage is obtained when a cavity mode and a reflection peak of each DBR mirror are aligned. Locking the laser to such a local minimum in active section voltage therefore ensures stable single-mode operation.**

***Index Terms*—Distributed Bragg reflector lasers, laser stability, laser tuning, semiconductor lasers, wavelength-division multiplexing.**

I. INTRODUCTION

WAVELENGTH-division multiplexing (WDM) is considered to be the key technology to upgrade existing fiber-optic networks to higher transmission capacities. An increase in demand for data-carrying capacity can be accommodated by increasing the number of wavelength channels on a single fiber. Since the total bandwidth that can be used is currently limited by the bandwidth of the erbium-doped fiber amplifier, this comes down to decreasing the channel spacing. The current ITU specification is set to a 100-GHz channel spacing, but a move toward 50 GHz or even 25 GHz is expected in the near future.

In present WDM systems, mostly wavelength-selected DFB lasers are used, yet they are not the ideal sources if the number of channels keeps increasing. Widely tunable lasers, like the sampled grating (SG) DBR [1], the super-structure grating (SSG) DBR [2], and the grating coupler sampled reflector (GCSR) [3] laser, on the other hand, are capable of addressing any wavelength over a range of 30–60 nm. Application of these devices in a dense WDM system requires a precise control of the wavelength and mode stability, especially when the channel spacing continues to be reduced. The basic operation of these lasers is similar to that of ordinary three-section DBR lasers. To obtain the wide tuning range, the simple DBR has to be replaced by a combination of two filter sections: two periodically modulated Bragg reflectors (SG or SSG) with a comb-shaped reflectivity spectrum or a concatenation of a coupler section (broadly tunable, but poorly selective) and a sampled grating. For stable single-mode operation, a peak of each of the filters and a cavity mode have to be aligned at the desired wavelength. Adjusting the phase current allows fine-tuning of the wavelength within a limited range. In order to avoid mode jumps, the currents through the two intracavity filters have to be suitably adjusted so as to track the cavity mode.

For simple three-section DBR lasers, a correlation was observed between the side-mode suppression ratio (SMSR) and the variation of output power with tuning current. This has been used to develop a control loop that ensures high SMSR [4]. Analogous observations were made for (S)SG-DBR lasers by Ishii *et al.* [5]: a saddle point in the output power is expected as a function of front and rear reflector currents at the point where a peak of each reflector and a cavity mode coincide [Fig. 1(b)]. Unfortunately, due to the carrier-induced losses in the DBR sections, these saddle points do generally not appear across the entire tuning range. In this letter, we propose a scheme that uses the active section voltage as a feedback signal and solves this problem.

II. VOLTAGE FEEDBACK SCHEME

When the output power of a SG-DBR or SSG-DBR laser is measured as a function of both reflector currents, saddle points are observed at certain locations: a minimum with respect to the front DBR current coincides with a maximum with respect to the rear DBR current. In the absence of carrier-induced absorption losses in the reflectors, such a saddle point would occur at the points where a peak of each reflector is exactly aligned with the same cavity mode, i.e., in the center of the regions with high SMSR [Fig. 1(a)]. The increase with current of the losses in the reflectors causes the saddle points to shift toward lower rear and higher front DBR currents. For high currents, the saddle points even disappear. The effect is largest for the front DBR section, since the output light has to pass through this section [Fig. 1(b)]. This severely limits the application range of the feedback loop described in [5]. One might consider adding some sort of correction, but this does not seem very practical, especially since there is no guarantee that the needed correction will not vary over time.

This leads us to the question of whether there are other signals that are easy to measure and also provide a measure for the alignment of the reflector peaks with a cavity mode, but that are less sensitive to the carrier-induced absorption losses. From the above discussion, it is clear that such a signal should come from the active section of the cavity.

The perfect alignment of the reflector peaks with a cavity mode corresponds to a (local) minimum in threshold gain and carrier density [5], since moving one of the reflectors out of alignment will increase the threshold gain and the carrier density. As the active section voltage (at fixed bias current) depends on the carrier density, it will also increase. If the

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The authors are with the Department of Information Technology, University of Gent-IMEC, B-9000 Gent, Belgium. G. Sarlet is a Research Assistant with the Fund for Scientific Research—Flanders, Belgium (F.W.O.).

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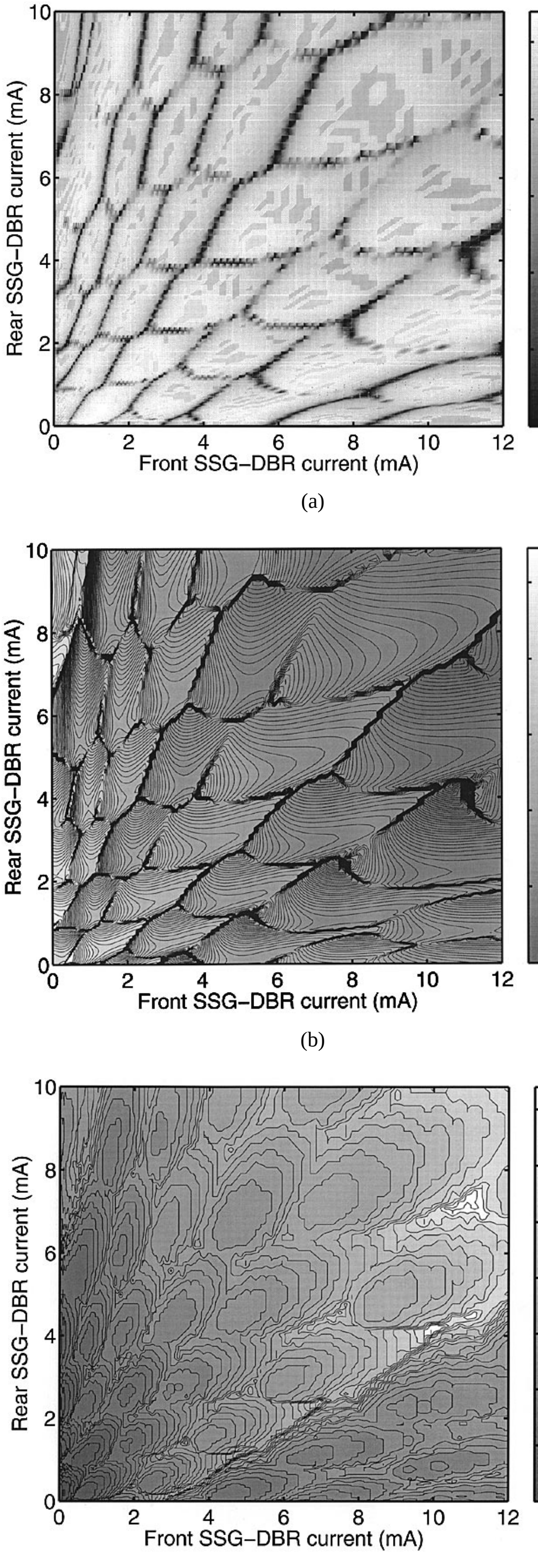

(a)

(b)

(c)

Fig. 1. Maps of (a) SMSR, (b) output power, and (c) active section voltage variation as function of front and rear SSG-DBR currents.

absorption losses are taken into account, the local minimum in voltage will shift slightly to lower currents, but, as Fig. 1(c) shows, the minima are all well within the mode boundaries and minima appear even for modes where there is no saddle point in the output power.

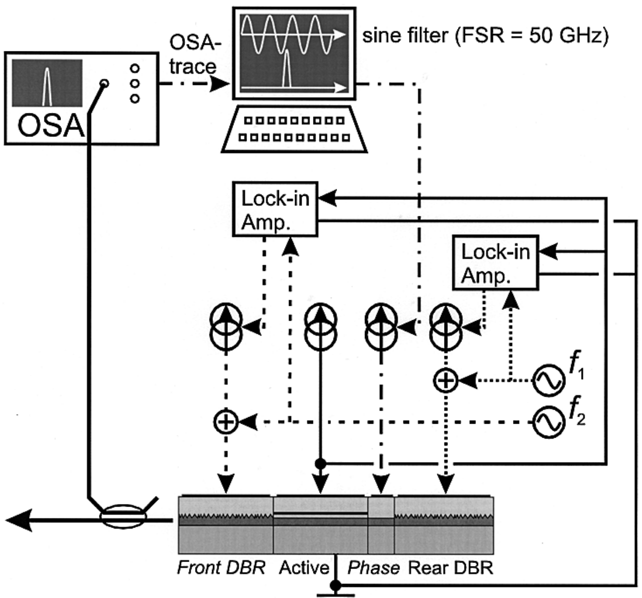

Fig. 2. Schematic of an SSG-DBR laser with wavelength and mode stabilization circuit.

Fig. 2 shows the wavelength stabilization circuit that was built. Small sinusoidal signals (5 μA) at two different frequencies ($f_1 = 1.1$ kHz, $f_2 = 2.9$ kHz) are added to the front and rear DBR currents. Using two lock-in amplifiers, the modulation components ΔV_1 and ΔV_2 of the active section voltage at the frequencies f_1 and f_2 are measured. The results are read out by a PC, which updates the drive currents for the front and rear DBR sections using a simple proportional feedback scheme. The wavelength is controlled by using a reference optical filter, which generates an error signal that is fed back to the phase current. Examples of such filters are: a Fabry–Perot etalon or a fiber Bragg grating, both requiring a reference power measurement, or an arrayed waveguide grating, as was used in [5]. In our case, the operation of such a filter is simulated by reading out a trace from the optical spectrum analyzer with the PC and filtering it through a sinusoidal filter with a free spectral range (FSR) of 50 GHz.

III. PERFORMANCE OF THE FEEDBACK SYSTEM

In order to test the feedback circuit, some wavelength drift of the laser had to be instigated. This was done by changing the temperature of the laser submount between 20 °C and 30 °C. During the temperature sweep, wavelength and SMSR were continuously monitored. Fig. 3 shows the variation of the laser frequency with temperature under different feedback conditions for a nominal laser frequency of 193.9 THz (reference point at 25 °C). With only feedback from the active section voltage, the wavelength increases with a slope of 0.091 nm/°C, while the SMSR remains above 40 dB. The measured change in wavelength is consistent with the temperature coefficient of the refractive index in the InP–InGaAsP material system. With feedback from the wavelength locker only, the laser remains locked to the desired channel in the temperature range from 23.4 °C to 25.8 °C. Beyond this range, the SMSR decreases drastically and the wavelength starts to hop back and forth

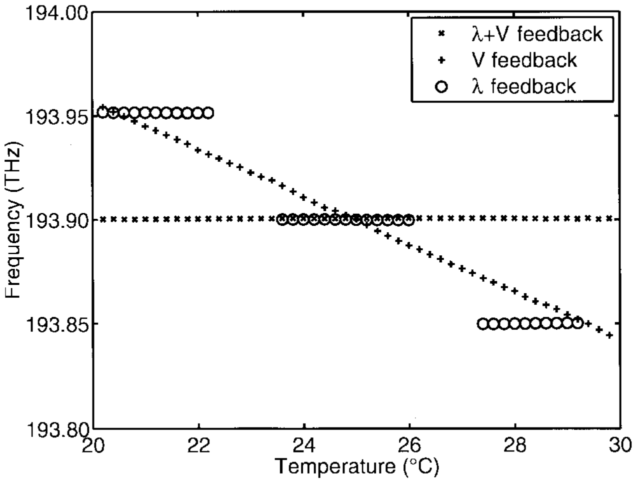

Fig. 3. Variation of laser frequency with temperature under different feedback conditions: (×): feedback from wavelength locker and active section voltage; (+): feedback from active section voltage only; (∘): feedback from wavelength locker (FSR = 50 GHz) only.

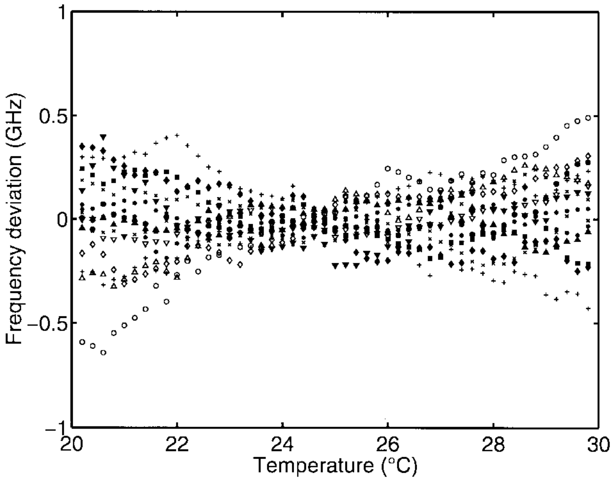

Fig. 4. Frequency deviations as a function of temperature for 16 ITU channels with frequency and mode stabilization (nominal frequencies from 192.3 to 195.3 THz in 200-GHz increments).

between adjacent channels of the wavelength locker, until stable operation is again obtained at the adjacent channel, i.e., 50 GHz away from the original channel. With both feedback loops combined, frequency deviations are within ±1 GHz from the center frequency, and the SMSR remains above 40 dB across the entire temperature range. The experiment was repeated for 16 ITU channels at 200-GHz spacing, from 192.3 to 195.3 THz. As Fig. 4 shows, stable operation was obtained for all 16 channels, with similar frequency deviations and SMSR values across the temperature range.

A possible disadvantage of the control circuit is the fact that small sinusoidal signals (5 μA) are added to the front and rear reflector currents. Since the average tuning efficiency of the reflector peaks of the DBR sections is 25 GHz/mA, the modulation of the reflector peaks is approximately 125 MHz. The corresponding variation of the laser frequency, or, in other words, the variation of the cavity mode frequency, is, however, only a fraction of this value, typically 0.2 [5]. With current modulation on both reflectors, this gives a total frequency modulation on the order of 50 MHz. At the same time, a slight power modulation is added. Measurements have shown, however, that relative power variations are very small, on the order of 10^{-10}–10^{-9}. It also has to be noted that these frequency and power fluctuations are much slower than typical data rates, so the variation during a single bit period will be negligible.

IV. CONCLUSION

A novel mode stabilization scheme for widely tunable SG-DBR and SSG-DBR lasers has been demonstrated. It uses the fact that a minimum in active section voltage is expected as a function of the reflector currents at the point where a peak of each reflector is aligned with the same cavity mode. A feedback circuit was built which locks the laser to such a local minimum in the active section voltage for mode stabilization and uses a periodical filter for wavelength stabilization. Stability of the feedback circuit has been confirmed by changing the laser submount temperature from 20 °C to 30 °C and monitoring the frequency and SMSR. Frequency deviations remained within ±1 GHz, and the SMSR was always above 40 dB.

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REFERENCES

[1] V. Jayaraman, Z. M. Chuang, and L. A. Coldren, “Theory, design and performance of extended tuning range semiconductor lasers with sampled gratings,” *IEEE J. Quantum Electron.*, vol. 29, pp. 1824–1834, June 1993.

[2] H. Ishii, H. Tanobe, F. Kano, Y. Tohmori, Y. Kondo, and Y. Yoshikuni, “Quasicontinuous wavelength tuning in super-structure-grating (SSG) DBR lasers,” *IEEE J. Quantum Electron.*, vol. 32, pp. 433–440, Mar. 1996.

[3] M. Öberg, S. Nilsson, K. Streubel, L. Bäckbom, and T. Klinga, “74 nm wavelength tuning range of an InGaAsP/InP vertical grating assisted codirectional coupler laser with rear sampled grating reflector,” *IEEE Photon. Technol. Lett.*, vol. 5, pp. 735–738, July 1993.

[4] S.L. Woodward, T.L. Koch, and U. Koren, “A control loop which ensures high side-mode-suppression ratio in a tunable DBR laser,” *IEEE Photon. Technol. Lett.*, vol. 4, pp. 417–419, May 1992.

[5] H. Ishii, F. Kano, Y. Yoshikuni, and H. Yasaka, “Mode stabilization method for superstructure-grating DBR lasers,” *J. Lightwave Technol.*, vol. 16, pp. 433–442, Mar. 1998.