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Cite as: Appl. Phys. Lett. **82**, 4236 (2003); <https://doi.org/10.1063/1.1584521>

Submitted: 06 December 2002 . Accepted: 21 April 2003 . Published Online: 10 June 2003

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Impact Factor:
12.894

Gain switching of an external cavity grating-coupled surface emitting laser with wide tunability

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(Received 6 December 2002; accepted 21 April 2003)

Gain-switched, single frequency operation of an external cavity grating-coupled surface emitting laser with a wavelength tuning range of 100 nm is presented. A short pulse duration of 41 ps and a high peak power of 0.88 W have been obtained. © 2003 American Institute of Physics.
[DOI: 10.1063/1.1584521]

The grating-coupled surface emitting laser (GCSEL) is a type of laser where the radiation output is provided by an incorporated diffraction grating.^{1–3} The grating can be designed in a way that minimizes the reflection feedback into the cavity. Exceptionally good suppression of parasitic feedback from the grating and from the grating–air interface can be achieved. GCSELs are therefore extremely well suited for system configurations based on an external cavity. At the same time, it is possible to use the same grating for broadband spectral control. Indeed, broadband, continuous tuning in the continuous-wave regime over a range of 115 nm has been demonstrated.²

One aspect of particular interest is to employ GCSELs as the gain medium for compact, tunable sources of ultrashort optical pulses. In a preliminary study, gain-switched operation of a GCSEL was demonstrated with a tuning range of 60 nm³ and relatively long 160 ps pulses were generated.³ Here, we present a detailed study of the operation of a gain-switched GCSEL in an optimized external cavity. In particular, a tuning span in excess of 100 nm and a pulsewidth in range of 40–100 ps are reported.

The laser used in the experiments had a single quantum well, graded-index InGaAs structure. The waveguide was 100 μm wide with electrical confinement provided by SiO₂ stripes. The lengths of the active region and the grating section were 500 μm and 850 μm , respectively, and the grating period was 340 nm. Bragg resonance at 180° angle was not achieved within the grating for any frequencies inside the gain band, therefore, practically no signal was reflected back into the laser from the grating. Instead, the light in the grating section was coupled out of the laser at a specific angle to the surface of the device.

The external cavity was formed by a small ($\sim 1\text{ mm} \times 1\text{ mm}$), 100% reflecting flat aluminum mirror, placed in the vicinity of the grating section, as shown in Fig. 1. It was possible to vary the distance d and the angle θ between the surfaces of mirror and the grating by moving the mirror. The

laser output was taken from the cleaved facet of the active region.

The laser was driven by an avalanche pulse generator with a repetition rate of 10 kHz and a maximum current of 5 A. No dc bias was applied. The electrical pulses had a rise time of 150 ps and a fall time of 650 ps.

Within the driving current range, lasing in the device only occurred when the external cavity was properly aligned. The output power increased as the mirror was moved closer to the laser. Tuning of the signal wavelength was provided by the adjustment of the mirror angle θ . The mirror separation d did not affect the spectral bandwidth of the laser output. We, therefore, kept the length of the external cavity very short, $\sim 800\ \mu\text{m}$, in order to provide strong optical feedback. The corresponding longitudinal mode spacing of the compound cavity was in range of 0.15–0.2 nm.

The tuning curves, showing the peak power and the pulse duration as a function of wavelength, are presented in Fig. 2. When the mirror angle θ was turned from 15.9° to 35.0°, the output wavelength changed by 100 nm, from 902 nm to 1002 nm. The pulse duration remained in the range of 40–100 ps across the tuning range, substantially increasing only at the edges of the range, where the gain of the medium is lower. A pulse duration shorter than 100 ps was observed within a 70 nm wide spectral window between 920 nm and 990 nm. The shortest pulse duration of 41 ps was obtained at a wavelength of 938 nm with the corresponding peak power

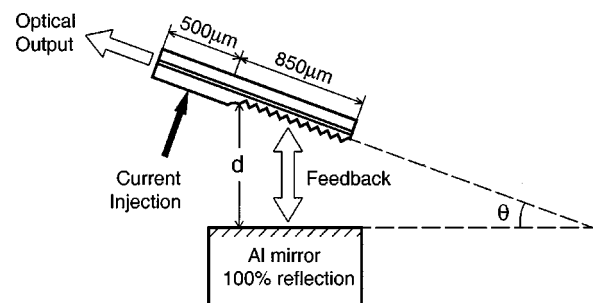


FIG. 1. External cavity configuration.

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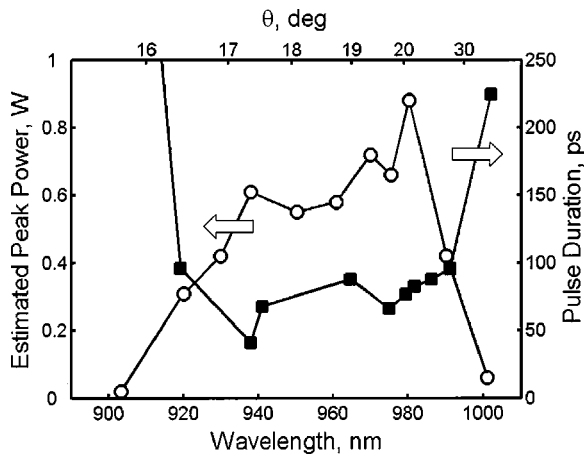


FIG. 2. Tuning curves of the external cavity laser showing the peak power and the pulse duration.

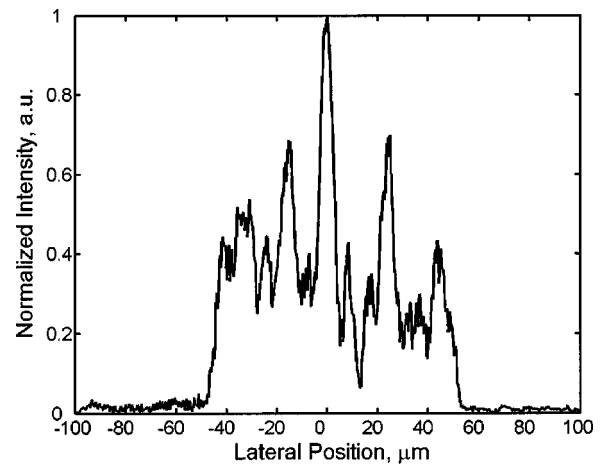


FIG. 5. Lateral near-field profile of the laser output.

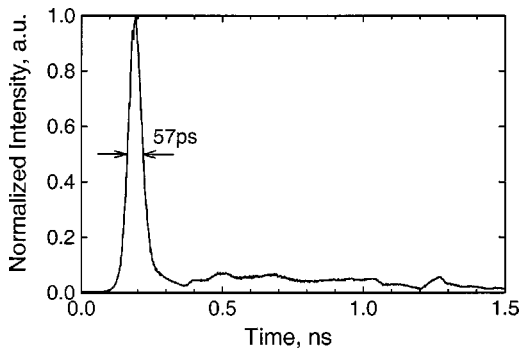


FIG. 3. Gain-switched pulse produced at the point corresponding to the maximum peak power. Corresponding pulse duration is 57 ps.

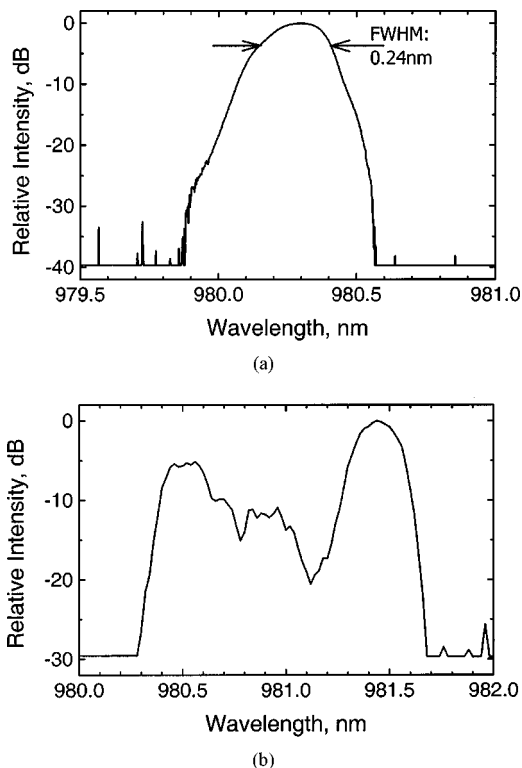


FIG. 4. Typical spectra corresponding to (a) single frequency operation and (b) multimode operation.

of 0.64 W. The maximum peak power of 0.88 W was obtained at a wavelength of 980 nm. A 57 ps long pulse accompanied by a low-energy tail was observed at this point (Fig. 3).

Figure 4 shows the spectral characteristics obtained using an optical spectrum analyzer with a resolution of 0.06 nm. As the laser was tuned, the spectra changed in a periodic manner, switching between the single frequency operation and multimode operation with a period of 1.18 nm. A possible explanation for this phenomenon is the etalon effect in the grating substrate. An estimated free spectral range of the substrate etalon approximately matches the spectral features discussed herein. In the single frequency state, an exceptionally good spectral side-band suppression ratio of 40 dB and full width at half maximum linewidth around 0.2 nm were observed. In the multimode regime, three to six laser modes were generated. At the edges of the tuning range, multimode operation did not occur. Instead, dark zones with no lasing were observed between the adjacent single frequency points, indicating that the multimode operation occurs in the minima of the substrate etalon reflection.

The near-field lateral intensity profile at the output facet was measured with a charge coupled device camera and is presented in Fig. 5. The breakup of the laser beam into a number of filaments is evident in Fig. 5. The laser, therefore, produces a spatially multimode output. However, the spectral and the temporal profiles of the emission in different filaments proved to be identical. The near-field mode pattern changed substantially when tuning the laser. A specially designed external cavity may be required for improved lateral mode.

In conclusion, the generation of picosecond optical pulses with a tunability of 100 nm has been demonstrated using a GCSEL in an optimized external cavity. The pulses obtained had a duration in the range of 40–100 ps, maximum peak power of 0.88 W, and spectral side-band suppression ratio in excess of 40 dB.

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