# TUNABLE EXTERNAL-CAVITY QUANTUM-WELL LASER USING GRATING COUPLER INTEGRATED IN SELECTIVELY DISORDERED WAVEGUIDE

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## *Introduction*

High-power semiconductor lasers with a diffraction limited output beam are attractive for many applications, such as free-space communications, and pumping of fiber amplifiers, solid-state lasers and nonlinear-optic devices. Monolithically integrated high-power lasers with tapered gain regions have been demonstrated [1],[2]. For several applications including optical communications and nonlinear optics, precise wavelength control is also required, and tunable high-power lasers have been reported [3]. However, the output from such edge-emitting lasers diverges elliptically and widely, and an external lens system is required for beam collimation. A tunable external-cavity laser (TECL) using a monolithically integrated tapered amplifier (TA) and grating coupler (GC) in an InGaAs quantum well (QW) waveguide has been proposed and demonstrated [4]. The GC, which couples out a collimated output beam, eliminates the need of the lens system, and simultaneously enables wavelength tuning through its wavelength dispersion.

To obtain high output power and good beam collimation, high coupling efficiency and large effective aperture of the GC are required. Absorption loss in the GC limits the coupling efficiency and the effective aperture. Loss reduction would lead to improvements of the output power, the beam collimation and the tuning range.

Disordering of QWs [5] permits postgrowth widening of the effective band gap. By disordering the QW only within the passive area of the monolithically integrated device, the absorption loss at the lasing wavelength can be reduced significantly. Impurity-free vacancy diffusion by rapid thermal annealing (RTA) is an effective way for disordering. We have reported selective QW disordering technique using $SiO_2$ caps of different thicknesses and RTA, and substantial loss reduction was achieved [6]. In this work, we demonstrate a tunable external-cavity QW laser using a grating coupler integrated in a selectively disordered waveguide.

## *Device Description and Design*

The TECL using a monolithically integrated device and an external half-mirror (HM) is schematically shown in Fig. 1. The semiconductor device is constructed with a narrow channel (NC), the TA and the GC, and is fabricated using an InGaAs-AlGaAs strained-layer single-QW GRIN-SCH waveguide. The QW is selectively disordered in the GC area to accomplish low absorption loss. The laser-cavity consists of a facet mirror, NC, TA, GC and the external HM. The ridge NC with a width of 2.0 μm is adopted for lateral single-mode guiding. The GC couples a guided wave into air as a collimated beam. Due to the wavelength dispersion of the GC, the beam exit angle depends upon the wavelength. Therefore, by rotating the semiconductor device with respect to the HM, as shown in Fig. 1, the lasing wavelength can be tuned. A collimated output beam is obtained through the HM.

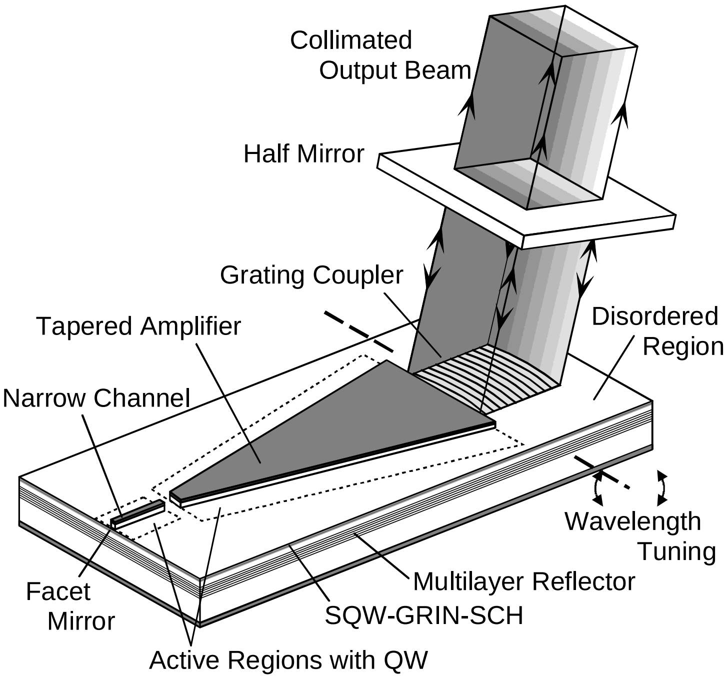

Fig. 1 Schematic of the tunable external-cavity laser.

In order to design the TA, theoretical simulation was performed based on the beam propagation method [7]. The TA electrode configuration was optimized for high output power and minimum wavefront aberration. The simulation showed that, by designing the GC with compensation for wavefront distortion produced in the TA, a well-collimated output beam can be obtained even for high injection.

The GC of 400 × 400 $\mu m^2$ aperture in the disordered waveguide was designed to couple the guided wave at a wavelength of 995 nm into air as a collimated beam at an exit angle of 15°. Our selective QW disordering technique using $SiO_2$ caps of different thickness and RTA can reduce the passive waveguide loss, $\alpha_p$, to 3 $cm^{-1}$ within the passive area [6]. To obtain both of high coupling efficiency and small beam divergence, the groove depth was determined as 60 nm and the corresponding radiation decay factor was calculated as 61 $cm^{-1}$. For $\alpha_p$ of 3 $cm^{-1}$, the outcoupling efficiency and the effective aperture length (1/e decay length of the field amplitude) were estimated as 81% and 310 μm, respectively.

Table I  Specifications of the fabricated device.

| | |
|---|---|
| Narrow Channel | Width 2.0 μm  Length 300 μm |
| Tapered Amplifier | Narrow/Wide end width 20 μm / 600 μm  Length 2000 μm |
| Grating Coupler | Aperture $400 \times 400$ μm$^2$  Exit angle 15°  Focal length 2262 μm (int.), ∞ (ext.)<br>Grating period 330 nm  Depth 60 nm<br>Radiation factor 61 cm$^{-1}$  Directionality into air 92 % |
| Chip Size | $1.0 \times 3.5$ mm$^2$ |

## *Device Fabrication*

The specifications of the fabricated device are summarized in Table I. The compensation for the wavefront distortion was incorporated in the design of the GC.

As a disordering cap, a $SiO_2$ cap of 300-nm thickness was deposited by PCVD at a substrate temperature of 150 °C. After removing the $SiO_2$ cap in the NC and TA areas by reactive ion etching (RIE), a $SiO_2$ cap of 30-nm thickness was deposited at 400 °C for a suppressing cap. RTA was performed at 920 °C for 15 s, and then both $SiO_2$ caps were removed by buffer etching. After fabrication of *p*-electrodes for the NC and the TA, the ridge structures were formed by RIE using the electrodes as masks. The GC was fabricated by a curved-line scanning of electron beam and two-step RIE. Bonding electrodes were formed, the wafer was thinned to 100 μm, and then an *n*-electrode was evaporated on the backside. After cleaving for facet formation, the device was mounted on a heat sink.

## *Experimental Results*

The device was mounted on a rotary stage, and the HM with a 50-% reflectivity was aligned at a distance of 10 mm from the GC. For all measurement, the heat-sink temperature was fixed at 15 °C. Figure 2 shows the dependence of the output power through the HM on the TA injection current measured for the CW lasing at an exit angle of 13.5° at $I_{NC}$ = 3 mA. The lasing threshold in terms of $I_{TA}$ was ~1.5 A, and the maximum output power of 105 mW was obtained. The inset shows the lasing spectrum at $I_{TA}$ = 1.8 A. The lasing wavelength was 1003.9 nm, and the linewidth was within the measurement resolution of 0.08 nm.

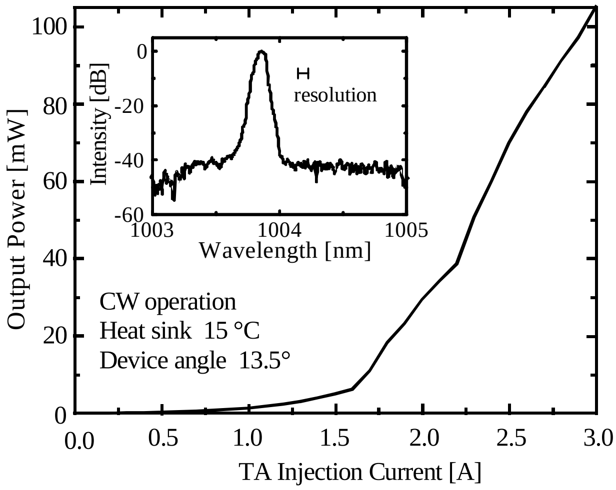


Fig. 2 Dependence of the output power on the TA injection current. The inset shows the lasing spectrum at $I_{TA}$ = 1.8 A.

The far-field pattern of the collimated output beam is shown in Fig. 3. The full divergence angles at half maximum of 0.16° × 0.18°, close to the diffraction-limited values of 0.13° × 0.14°, were obtained at $I_{TA}$ = 2.5 A. As a result of the loss reduction and the compensation for the wavefront distortion, a well-collimated output beam with a nearly circular profile was maintained up to $I_{TA}$ = 3.0 A.

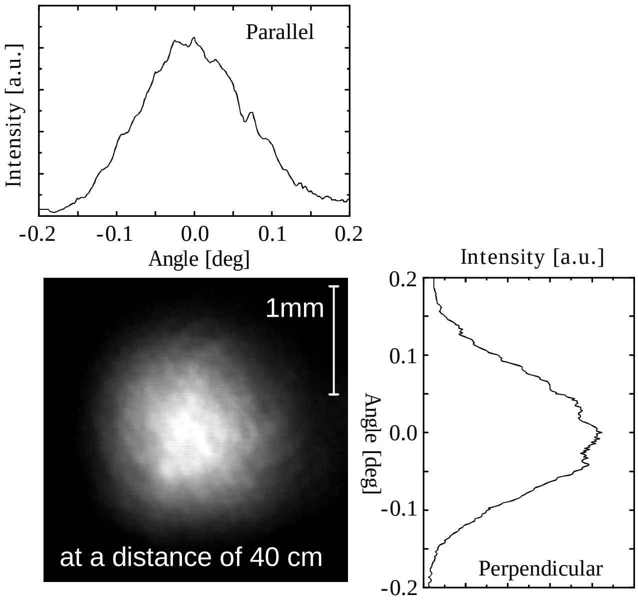


Fig. 3 Far-field pattern and the intensity profiles of the collimated output beam at $I_{TA}$ = 2.5 A.

Wavelength tuning characteristics were examined by rotating the device as shown in Fig. 1. Figure 4 shows the dependence of the lasing wavelength and the output power on the device angle for $I_{TA}$ = 1.8 A and $I_{NC}$ = 3 mA. By varying the device angle from 13.0° to 17.5°, linear and continuous wavelength tuning over a wide range of 21.1 nm, from 985.2 to 1006.3 nm, was achieved.

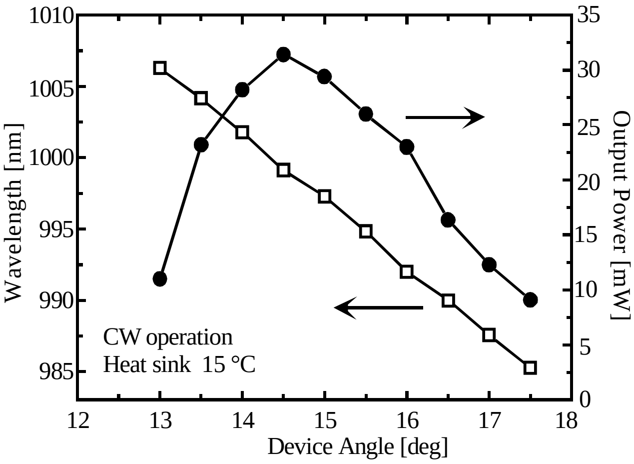


Fig. 4 Dependence of the lasing wavelength and the output power on the device angle for $I_{TA}$ = 1.8 A and $I_{NC}$ = 3 mA.

## Conclusion

A tunable lensless external-cavity quantum-well laser using a grating coupler integrated in a selectively disordered waveguide has been demonstrated. The reduction of the passive waveguide loss by the selective QW disordering lead to significant improvements of the output power, the beam collimation and the wavelength tuning range.

## References

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