Single Frequency 1550-nm AlGaInAs–InP Tapered High-Power Laser With a Distributed Bragg Reflector

S. R. Šelmić, *Student Member, IEEE*, G. A. Evans, *Fellow, IEEE*, T. M. Chou, *Member, IEEE*, J. B. Kirk, J. N. Walpole, *Fellow, IEEE*, J. P. Donnelly, *Fellow, IEEE*, C. T. Harris, and L. J. Missaggia

***Abstract*—A strained-layer multiple-quantum-well tapered laser with single-frequency operation near 1550 nm and with 20-dB sidemode suppression, for continuous-wave power levels up to 0.6 W is reported. At a power level of 0.5 W, 80% of the power from this device remains in the central lobe of the far-field. Increased lateral mode stabilization was observed in devices having both a Gaussian-patterned contact and a distributed Bragg reflector (DBR) compared to those without a DBR. An increase by a factor of five in the power level obtainable, with at least 80% of that power in the central lobe of the far-field pattern, was obtained using the DBR reflector.**

***Index Terms*—Distributed Bragg reflector lasers, high-power lasers, quantum-well lasers, semiconductor lasers.**

I. Introduction

A LARGE gain volume is required to achieve high optical power in a semiconductor laser. Simply increasing the width of a single-lateral-mode laser results in a large increase in the number of photons, but because of filamentation and operation in numerous modes, the brightness or useable optical power is significantly reduced. Recent approaches to achieving coherent, high power from semiconductor lasers include tapered lasers [1], angled-grating distributed feedback lasers [2], master oscillator power amplifiers (MOPAs) [3], and arrays of antiguiding lasers [4].

Single-frequency semiconductor lasers operating near the 1-W level at "eye-safe" wavelengths near 1550 nm are needed not only for pumping applications, but for free-space communication, laser radar, and night vision as well. Recently, high-power InGaAsP–InP tapered lasers [5]–[7] were obtained at this wavelength with a single lateral mode, but with numerous longitudinal modes.

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S. R. Šelmić, G. A. Evans, T. M. Chou, and J. B. Kirk are with the Department of Electrical Engineering, School of Engineering and Applied Science, Southern Methodist University, Dallas, TX 75275-0338 USA (e-mail: sandraz@engr.smu.edu).

J. N. Walpole, J. P. Donnelly, C. T. Harris, and L. J. Missaggia are with the Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, MA 02173 USA.

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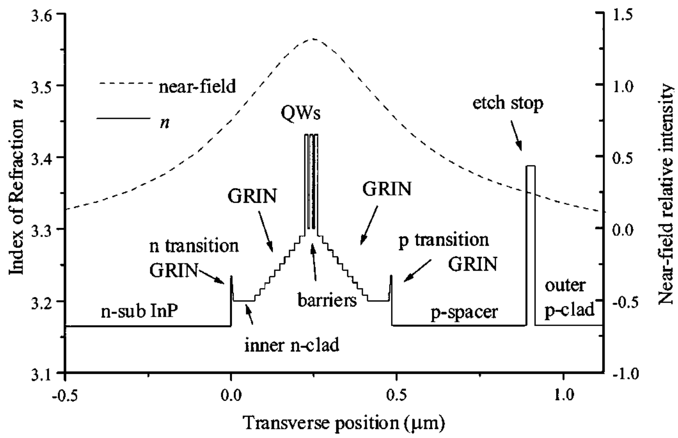

Fig. 1. The vertical index of refraction and calculated vertical mode intensity profiles in epitaxial structure.

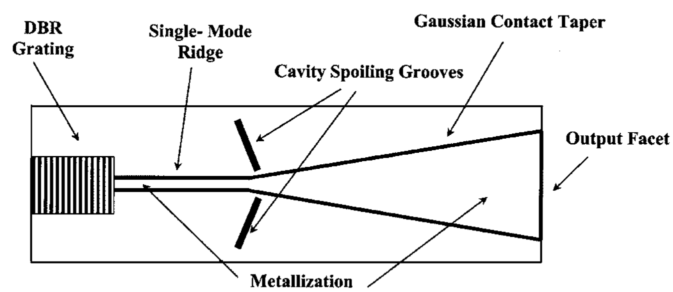

Fig. 2. Schematic illustration of DBR tapered laser.

Here, we report on an AlGaInAs–InP tapered laser with a distributed Bragg reflector (DBR). The AlGaInAs material system is used to reduce carrier leakage from the quantum-well (QW) region compared to the conventional InGaAsP material system under high temperature operation [8].

II. Laser Structure and Fabrication

The 1550-nm AlGaInAs–InP material was grown by metal–organic chemical vapor deposition. The multiple active region consists of three 10-nm-thick QWs with 5-nm-thick barriers. A compressive strain of 0.65% is incorporated in the QW. The index of refraction of the epitaxial structure, layer thicknesses and the calculated near-field intensity profile is shown are Fig. 1.

The tapered laser, shown schematically in Fig. 2, contains a ridge waveguide, a tapered region and a grating region. The ridge waveguide allows only one lateral mode, while the DBR structure provides single frequency operation. An InGaAsP etch stop layer is incorporated into the InP p-doped cladding of the epitaxial structure to locate the position of the grating and to provide the lateral index step for the ridge guide.

Nonuniform lateral injection-current profiles have been used to reduce filamentation in wide stripe lasers [9], [10]. We use a Gaussian patterned contact [7] over the tapered region to achieve a Gaussian-like distribution of the lateral current to match the lateral optical profile and reduce self-focusing and beam instability effects.

Cavity-spoiling elements (as shown in Fig. 2) consist of grooves etched down through the active region and angled with respect both to the axis of symmetry of the tapered structure and to the plane of the active gain region. The grooves are angled to deflect and scatter unwanted radiation away from the tapered region and prevent a direct feedback path between the front and rear facets outside the narrow ridge region.

The ridge-guide and DBR regions are defined by etching away the p-cap and p-cladding layer down to the etch stop layer (Fig. 1). A standard holographic lithography process is used to define a photoresist grating with a 0.2452-μm period in the DBR region. Ion beam etching is used to replicate the photoresist grating into the etch stop and p-spacer layers. The resulting grating has a depth of about 90 nm and is covered by 150 nm of silicon oxide. The coupling coefficient of the DBR grating is about 35 cm^{-1}.

A Gaussian-patterned contact was fabricated as previously described [7]. A single nonsegmented metallization was applied over a patterned oxide to provide electrical contact to the ridge and tapered regions. The wafer is thinned and a backside contact applied to the n^+-InP substrate. The devices are then cleaved and mounted junction-side down using indium solder on a copper heatsink. The output facet is coated with a 1% antireflection coating.

III. Experimental Results and Discussion

The continuous-wave (CW) output power versus injected current obtained on tapered lasers with (solid curve) and without (dashed curve) the DBR grating at a temperature of 20 °C, are shown in Fig. 3. In both of these devices, the ridge section is 800 μm long, the taper section is 2000 μm long, and the output aperture is 225 μm. The DBR grating section is 220 μm. The laser with the grating has a threshold current of 1.3 A, an output power of 453 mW at 3.0 A, and an external differential quantum efficiency, just above threshold of 52%. The laser without the grating region has a threshold current of 1.4 A, an output power of 310 mW at 3.0 A, and an external quantum efficiency of 38%. The DBR and Fabry–Pérot tapered lasers both have cleaved uncoated back facets.

The spectrum of the tapered laser structure at a drive current of 3 A shows a single longitudinal mode at 1576.47 nm (Fig. 4). The spectrometer resolution is 0.05 nm and the measured linewidth is instrument resolution limited. The sidemode suppression ratio was typically between 15 and 20 dB over the maximum tested current of 4 A, and the spacing between the side lobes is about 0.125 nm, nearly exactly what is predicted for the longitudinal modes of the overall 2800-μm-long cavity.

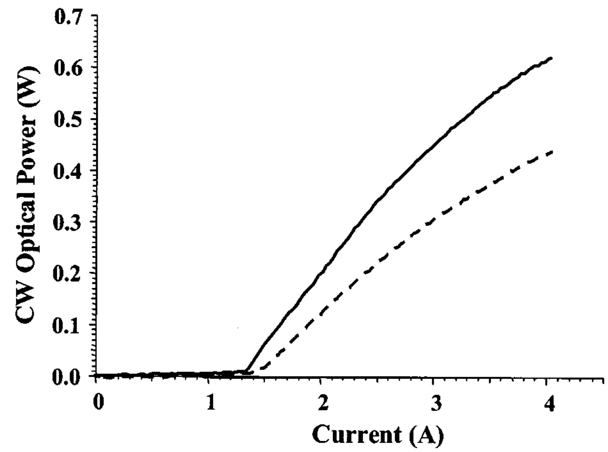

Fig. 3. L–I CW characteristics for tapered lasers with (solid curve) and without (dashed curve) the DBR grating.

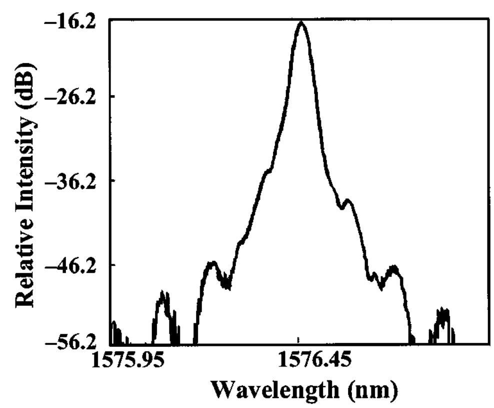

Fig. 4. Wavelength spectrum for the DBR tapered laser at 3 A. The spectrometer resolution is 0.05 nm.

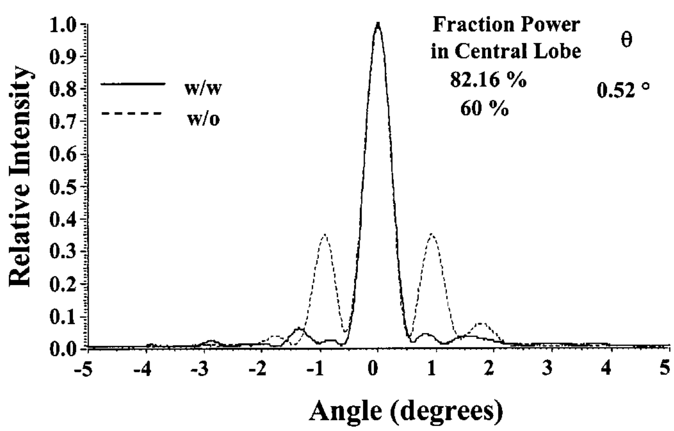

Fig. 5. Far-field distribution of the taper amplifier with and without the grating for $I = 3$ A.

The comparison between the normalized far-fields of the tapered lasers with and without the grating at about 3 A is illustrated in Fig. 5. The side lobes are much stronger for the device without the DBR grating. Approximately 82% of the output power at 3.0 A is in the near-diffraction-limited central lobe of the far-field pattern for the DBR tapered laser, in comparison to only 60% of the power in the central lobe for the tapered laser without the DBR region. The addition of a DBR section to the device not only appears to stabilize the wavelength, but also significantly improves the power in the central far-field lobe

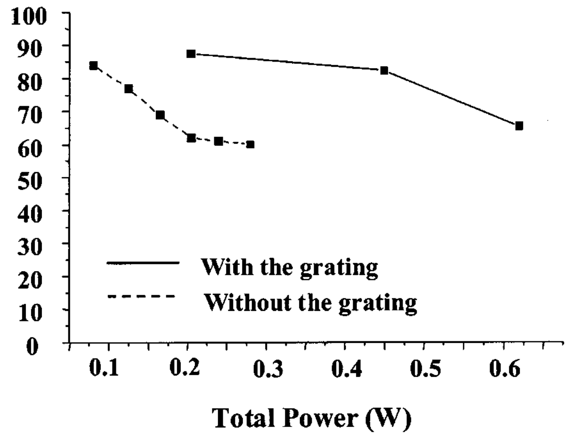

Fig. 6. Central lobe power versus total optical power for tapered lasers with and without a DBR grating.

and lowers the tendency toward filamentation at higher drive currents.

Fig. 6 shows the power in the central lobe of the far-field as a function of total output power for tapered lasers with and without a DBR region. The addition of the DBR region allows a fivefold increase in the total output power at which 80% of the power remains in the central lobe. We speculate that the single-frequency operation of DBR tapered lasers may eliminate temporal instabilities due to frequency shifts that can occur in the highly multimode broad spectrum ($\Delta\lambda > 10$ nm) of regular tapered lasers.

IV. Conclusion

We have reported strained-layer multiple-QW AlGaInAs–InP tapered lasers emitting a single frequency near 1550 nm. A CW output power of 0.6 W in a single longitudinal mode with 20-dB sidemode suppression was achieved at an injection current of 4 A. 80% of the power from this device remains in the central lobe of the far-field at a power level of 0.5 W. The DBR section, along with a Gaussian-patterned contact, appears to increase the lateral mode stability. The power level at which 80% of the far-field remained in the central lobe, was increased by a factor of five for a device having the DBR section compared to one without.

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