Widely Tunable High-Power Tapered Diode Laser at 1060 nm

Jensen, Ole Bjarlin; Sumpf, Bernd; Erbert, Götz; Petersen, Paul Michael

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Widely Tunable High Power Tapered Diode Laser at 1060 nm

Ole Bjarlin Jensen, Bernd Sumpf, Götz Erbert, Member, IEEE, and Paul Michael Petersen

Abstract—We report a large tuning range from 1018 nm to 1093 nm from a InGaAs single quantum well 1060 nm external cavity tapered diode laser. More than 2.5 W output power has been achieved. The tuning range is to our knowledge the widest obtained from a high power InGaAs single quantum well tapered laser operating around 1060 nm. The light emitted by the laser has a nearly diffraction limited beam quality and a narrow line width of less than 6 pm everywhere in the tuning range.

Index Terms—Semiconductor lasers, quantum well lasers, tapered lasers, laser tuning.

I. INTRODUCTION

High power narrow line width diode lasers in the 1060 nm spectral region are of interest for many applications including spectroscopy and frequency conversion to the green spectral range [1]. The tapered diode lasers are currently attracting an increasing amount of interest as they combine high output power with good beam quality [2].

High power near diffraction limited tapered diode lasers have been realized at many operating wavelengths with a main focus on the red to near infrared spectral range [3,4]. For many applications narrow line width operation is required and various techniques have been investigated to achieve this. Different external cavity approaches including the use of diffraction gratings [5] and Bragg gratings [6,7] have been investigated as well as injection seeding using a low power narrow line width seed laser [8].

Recently, DBR tapered diode lasers have shown high output power and narrow line width operation and the simplicity and robustness makes this approach very attractive [9,10]. For some applications, however, tuning of the output wavelength is required and injection seeding or external cavity techniques can be used. In the 1000-1100 nm wavelength range, tunable, near diffraction limited external cavity tapered diode lasers have been developed with high output power of 4 W [7] and also large tuning ranges of up to 65 nm have been obtained [11]. An injection seeded tapered diode laser with an output power of up to 7.4 W at 1083 nm has been demonstrated [8].

II. EXPERIMENTAL SETUP

The tapered amplifier used in the experiments has a total length of 4 mm divided between a 1 mm long index guided single-mode ridge waveguide section and a 3 mm long gain guided tapered amplifier section. The taper angle for the amplifier is 4° resulting in an output aperture width of 210 μm.

The tapered amplifier is grown by metal-organic vapor phase epitaxy (MOVPE). The active region of the amplifier consists of a single 7 nm thick In0.25Ga0.75As quantum well (SQW). The active region is embedded in a 3.6 µm thick Al0.25Ga0.75As waveguide and 500 nm thick Al0.5Ga0.5As cladding layers. The layer sequence is completed by a highly doped GaAs contact layer. The layer structure is shown in the inset of Fig. 1. The vertical far field angle of this super large optical cavity structure (SLOC) [12] is about 22° (FWHM). The slow axis far field angle from the back facet is smaller than 20º (1/e²).

Here, we present the operation of a tunable, near diffraction limited external cavity tapered diode laser with an output power of up to more than 2.5 W and a wide tuning range of 75 nm centered around 1060 nm. To our knowledge this is the widest tuning range for an external cavity tapered diode laser in this wavelength region. Narrow line width operation is obtained over the entire tuning range.

Fig. 1. Free running spectrum for the tapered amplifier at 2 A drive current and a temperature of 25ºC. The inset shows the layer structure of the amplifier.

The facets of the device were passivated [13] and after this optically coated. The rear facet of the amplifier is
antireflection coated with a reflectivity below 0.1 % while the
front facet is coated to a reflectivity of 2 %.

The device was mounted p-side down on a CuW submount
using AuSn solder and soldered on a standard C-mount.
The emission spectrum of the free running tapered amplifier,
I.e. without external grating feedback, at 2 A drive current and
25°C temperature is given in Fig. 1. The center of the emission
is at 1059 nm and 99% of the emission is originated from a
spectral width of 85 nm.

The tapered amplifier described above has been operated
in an external cavity. A simplified sketch of the external cavity
is given in Fig. 2. The beam emitted from the back facet of the
tapered amplifier is collimated in both the fast and slow axes
using an aspherical lens with a focal length of 3.1 mm and a
numerical aperture (NA) of 0.68. The diffraction grating is
ruled with 1200 grooves/mm and is blazed for 1000 nm. A
half wave plate is inserted before the diffraction grating in
order to rotate the polarization by 90º for maximum diffraction
efficiency of the grating, which is about 85%. The grating is
operated in the Littrow configuration and the grating lines are
parallel to the active region of the amplifier in order to achieve
better frequency discrimination. The output from the external
cavity laser is collimated in the fast axis using a 3.1 mm focal
length aspherical lens with a NA of 0.68. A cylindrical lens
with a focal length of 40 mm is used to collimate the slow axis
beam and simultaneously compensate for astigmatism.

The power characteristics for the external cavity laser are
shown in Fig. 3, at an operating temperature of 20°C and at
different wavelengths.

The maximum achieved output power is 2.63 W at 6 A
drive current at a wavelength of 1060 nm limited by the
available current from the power supply and by thermal roll
over. At low currents, the slope efficiency of the laser is in
the range between 0.59 W/A and 0.64 W/A depending on the
wavelengths. For the wavelength close to the maximum of the
free running spectrum (see Fig. 1), the threshold is about 1.5
A. This value increases to 2.5 A for the wavelengths in the
wings of the spectrum. Moreover, measurements of the
amplified spontaneous emission for this material show that the
spectral position and width of the gain curve is independent
from the excitation current. This is due to the compensation
between the blue shift caused by the strong band filling and
the red shift caused by the thermal heating with increasing
current.

The beam quality of the external cavity tapered diode laser
in the slow axis is determined by measuring the beam quality
parameter M\(^2\) at different output powers. A spherical lens
with a focal length of 80 mm is used to focus the output beam. The
beam diameter (1/e\(^2\)) is measured at various distances along
the optical axis. The M\(^2\) value is obtained by fitting the
measured values to a hyperbola. The measurement is
performed at different driving currents and wavelengths to
evaluate the change in beam quality with output power and the
result is given in Fig. 4 at wavelengths of 1035 nm, 1060 nm,
1070 nm and 1080 nm. The M\(^2\) values did not change
significantly within the tuning range.

The M\(^2\) of the external cavity tapered laser at wavelengths
around the gain maximum stays below 1.7 up to 2.2 W output
power and increases to 2.15 at maximum output power. At 2.2
W output power, approximately 80% of the power is contained
in the central lobe of the beam. For this working point, the
beam quality data using the 1/e\(^2\) method and the second
moments were determined. The M\(^2\)(1/e\(^2\)) was 1.7 and the
M\(^2\)(4\(\sigma\)) was determined to 2.1. This compares favorably to the
beam quality of M\(^2\) < 1.4 at 1 W output power reported by

III. EXPERIMENTAL RESULTS

![Fig. 4. Measured beam quality parameter M\(^2\) at different driving currents for the external cavity tapered laser. The inset shows the measured beam width at an output power of 2.2 W at 1060 nm.](image)

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Kelemen et al. [11]. The increase at maximum output power is caused by higher order modes beginning to oscillate and thus increasing the focus size. During the measurements, the position of the cylindrical lens is shifted along the optical axis to account for the change in astigmatism occurring when the current of the laser is increased. The inset of Fig. 4 shows the measured beam width for the laser at 2.2 W output power at a wavelength of 1060 nm.

Wavelength tuning of the external cavity tapered diode laser is realized by rotating the diffraction grating. In Fig. 5 the tuning characteristics of the laser are given. In the experiments, the temperature is kept constant at 20°C and the current is 5 A.

The full tuning range of the external cavity tapered laser ranges from 1018 – 1093 nm while the FWHM tuning range is 1027 – 1086 nm with an output power of more than 1 W.

At maximum output power the spectral width increases and is in the range 30 – 100 pm with the largest line width measured at the long wavelengths of the tuning range. This could possibly be attributed to higher thermal load, less gain for the longest wavelengths or a possible slight misalignment of the external cavity.

IV. CONCLUSION

We have demonstrated a widely tunable external cavity tapered diode laser system around 1060 nm. More than 2.5 W of output power in a nearly diffraction limited output beam has been achieved. A wide tuning range of 75 nm has been demonstrated from 1018 nm to 1093 nm. This is to our knowledge the widest tuning range obtained from an external cavity tapered diode laser system in this wavelength range.

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