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# Tunable High-Power Narrow-Linewidth Semiconductor Laser Based on an External-Cavity Tapered Amplifier at 670 nm

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**Abstract:** A narrow-linewidth laser system based on a tapered semiconductor optical amplifier in external cavity is demonstrated. 800 mW output power is obtained, and the laser system is tunable from 655 to 679 nm.

**Keywords:** Semiconductor tapered amplifier, external-cavity

## 1. INTRODUCTION

Diffraction-limited high-power narrow-linewidth red diode lasers are attractive in a number of key applications, such as high-resolution spectroscopy, laser cooling, and second harmonic generation toward UV light. High-power, diffraction-limited diode lasers can be realized by the introduction of the technology of lasers with a tapered gain-region [1]. More than 1 W output power around 670 nm from a Fabry-Perot tapered diode laser was obtained with a beam propagation factor of 1.7, and the spectral width was smaller than 0.2 nm [2]. Around 670 nm, narrow-linewidth diffraction-limited output was also achieved from master oscillator power amplifier system [3, 4]. In pulse operation mode, 5 W peak power was obtained from a micro-external cavity tapered laser with the beam propagation factor of 10, and the spectral width below 150 pm [5]. External cavity based on a bulk diffraction grating in a Littrow configuration is a useful technique to get a tunable narrow-linewidth, high-power, and diffraction-limited tapered diode laser system [6]. Here, we present the experimental results of a tapered diode laser system based on a Littrow external cavity. 800 mW output power is obtained. The laser system is tunable from 655 to 679 nm with linewidth less than 100 pm.

## 2. EXPERIMENTAL SETUP

The laser structure of the 670 nm tapered amplifier was grown using metal organic vapor phase epitaxy. As active layer a 5 nm thick compressively strained single InGaP quantum well was used, which was embedded in AlGaInP waveguide layers. On the n-side the cladding layer was made of AlInP whereas the p-side cladding consists of AlGaAs. The processed tapered gain media had a total length of 2 mm, a 0.75 mm long index guided ridge-waveguide section and a 1.25 mm long flared section. The tapered angle is 4°, and the output aperture is 95 μm. The rare facet was anti-reflection coated with a reflectivity of  $5 \times 10^{-4}$ , whereas the front facet had a reflectivity of 1%. The external cavity configuration

employed is depicted in Fig. 1. An aspherical lens of 3.1-mm focal length with a N.A. of 0.68 is used to collimate the beam from the back facet in both fast and slow axes. The bulk grating is ruled with 1200 grooves/mm and has a blazed wavelength of 750 nm. The grating is mounted in the Littrow configuration and oriented with the lines in the grating parallel to the active region of the amplifier. The laser cavity is formed between the diffraction grating and the front facet of the tapered amplifier. Another aspherical lens of 3.1-mm focal length with a N.A. of 0.68 is used to collimate the beam from the output facet in the fast axis. Together with a cylindrical lens of 65-mm focal length, these two lenses collimate the output beam in the slow axis and compensate the astigmatism simultaneously. All the lenses are antireflection coated for the red wavelength. A beam splitter behind the cylindrical lens is used to reflect part of the output beam of the tapered diode laser system as the diagnostic beam, the beam quality factor  $M^2$  is measured in this beam.

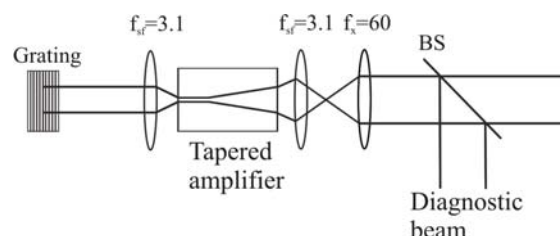


Fig. 1. Experimental set-up of the tapered diode laser system using a bulk diffraction grating external cavity. BS: beam splitter, (the units are in mm).

## 3. EXPERIMENTAL RESULTS

The laser is TE-polarized, i.e., linearly polarized along the slow axis. The temperature of the amplifier is controlled with a Peltier element and it is operated at 15°C in the experiment. The emission wavelength of the laser system is tuned by rotating the diffraction grating. The output power is measured behind the aspherical lens. The power/current characteristics for the laser system is shown in Fig. 2. The threshold current is around 0.3 A, and the slope efficiency is around 0.62 W/A. More than 800 mW output power is obtained with the operating current of 1.7 A. The output power at different wavelength is shown in Fig. 3 at an operating current of 1.7 A. The laser system is tuned over a 24 nm range centered at 667 nm. As high as 810 mW output

power is obtained at the wavelength of 668.36 nm, and an output power above 400 mW is achieved from 656 to 678 nm.

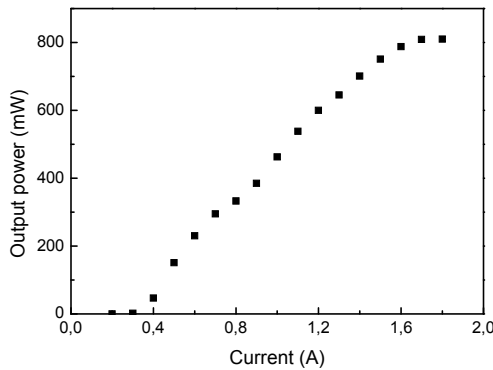


Fig. 2. The power/current characteristics for the tapered diode laser system.

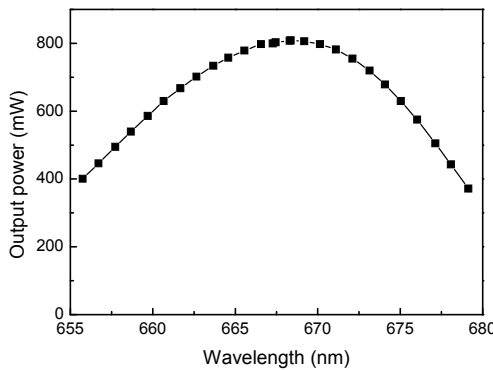


Fig. 3. Tuning curve of the tapered diode laser system at an operating current of 1.7 A.

The beam quality of the output beam along the slow axis is estimated by measuring the beam quality factor  $M^2$  for the external cavity laser system. A spherical lens with a 100-mm focal length is used to focus the diagnostic beam. Then the beam width,  $W$  ( $1/e^2$ ), is measured at various recorded positions along the optical axis – on both sides of the beam waist. The value of  $M^2$  is obtained by fitting the measured data with a hyperbola. Fig. 4 shows the measured beam widths and the fitted curves with the output power of 295 mW and 606 mW. The estimated  $M^2$  values are  $1.35 \pm 0.07$  with 295 mW output power and  $3.39 \pm 0.07$  with 606 mW output power. So the beam quality is diffraction-limited when the output power is less than 300 mW. The beam quality deteriorates at high output power, and the reason may be the heating effect and/or higher current density [5].

The optical spectrum characteristic of the output beam from the tapered diode laser system is measured using a spectrum analyzer (Advantest Corp. Q8347). A typical result measured at 665.83 nm with the output power of 210 mW is shown in Fig. 5. The linewidth (FWHM) is 0.007 nm, and the amplified spontaneous emission intensity is around 20 dB suppressed. We find the linewidth is below 0.01 nm when the output power is less than 300 mW, and the linewidth is below 0.1 nm with the output power of 810 mW.

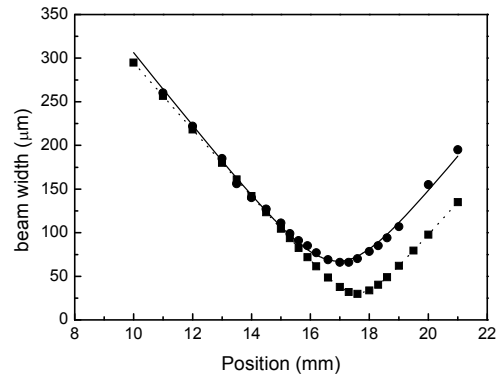


Fig. 4. Beam width of the output beam from the tapered diode laser system for the slow axis with the output power of 295 mW (squares and dot line), and 606 mW (circles and solid line). The curves represent hyperbola fits to the measured data.

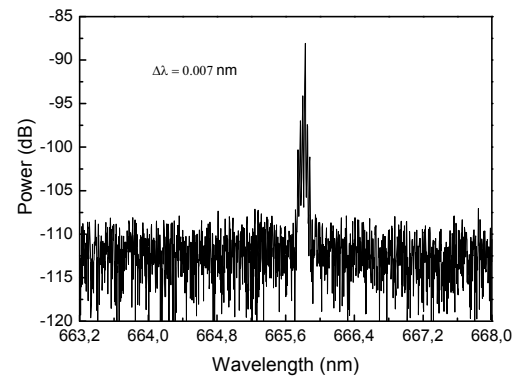


Fig. 5. The optical spectrum of the output beam from the tapered diode laser system with the output power of 210 mW.

## CONCLUSION

A diode laser system based on a tapered semiconductor optical amplifier in external cavity is demonstrated. More than 800 mW output power is obtained, and the laser system is tunable from 655 to 679 nm. The linewidth is less than 0.1 nm.

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