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Published in:
Optics Letters

Link to article, DOI:
10.1364/OL.36.002626

Publication date:
2011

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Chi, M., Jensen, O. B., & Petersen, P. M. (2011). High-power dual-wavelength external-Cavity diode laser based on tapered amplifier with tunable terahertz frequency difference. *Optics Letters*, *36*(14), 2626-2628. https://doi.org/10.1364/OL.36.002626

High-power dual-wavelength external-cavity diode laser based on tapered amplifier with tunable terahertz frequency difference

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Received March 30, 2011; revised June 8, 2011; accepted June 11, 2011;
posted June 13, 2011 (Doc. ID 145091); published July 11, 2011

Tunable dual-wavelength operation of a diode laser system based on a tapered diode amplifier with double-Littrow external-cavity feedback is demonstrated around 800 nm. The two wavelengths can be tuned individually, and the frequency difference of the two wavelengths is tunable from 0.5 to 5.0 THz. An output power of 1.54 W is achieved with a frequency difference of 0.86 THz, the output power is higher than 1.3 W in the 5.0 THz range of frequency difference, and the amplified spontaneous emission intensity is more than 20 dB suppressed in the range of frequency difference. To our knowledge, this is the highest output power from a dual-wavelength diode laser system operating with tunable terahertz frequency difference.

OCIS codes: 140.0140, 140.5960, 140.3280.

Dual-wavelength diode laser systems are attractive for many applications such as dual-wavelength interferometry, optical switching, terahertz (THz) radiation generation and THz imaging [1–5]. Different techniques have been developed to achieve dual-wavelength operation from a diode laser system, and they mainly can be classified into two categories: (1) monolithic dual-wavelength diode lasers [6–9] and (2) diode laser systems based on different external-cavity feedback techniques [10–16]. The monolithic dual-wavelength diode lasers show stable dual-wavelength operation, but the tuning range of the frequency difference of the two wavelengths is limited, and the output power is normally less than 500 mW [8]. Different frequency-selective elements have been used in external-cavity feedback techniques, such as bulk diffractive gratings for the double-Littman and double-Littrow external-cavity techniques [10,11,14], dual-fiber Bragg grating [12], dual-period holographic element [13], and single-wavelength volume Bragg gratings or monolithic multiplexed Bragg grating [15,16]. The gain medium in the external-cavity dual-wavelength diode laser system is usually a single-mode ridge-waveguide diode laser, so the output power from these laser systems is normally a few hundred milliwatts. In a few cases, broad-area diode lasers are used as a gain medium, and more than 1.7 W output power has been achieved with fixed frequency difference [15,16]. Because of the broad emitting aperture of broad-area diode lasers in the slow axis, these dual-wavelength diode laser systems suffer from poor beam quality in the slow axis.

In this Letter, a tunable dual-wavelength diode laser system with double-Littrow external-cavity feedback is demonstrated. To our knowledge, this is the first tunable dual-wavelength diode laser system based on a tapered diode amplifier. The tapered diode amplifier was chosen as gain medium in the dual-wavelength laser system based on the fact that it can produce relatively high output power (a few watts) and has good beam quality (with beam quality factor M^2 less than five normally) [17]. Compared with dual-wavelength broad-area diode laser systems [15,16], this is very important for applications, for instance as pump source for THz generation through difference frequency generation in a nonlinear crystal. The use of a double-Littrow external cavity makes the laser system tunable.

When single-Littrow external-cavity feedback is applied, an output power of 2.15 W is obtained at a wavelength of 801.43 nm, and the laser system is tunable from 786 to 813 nm with output power higher than 1.02 W, and the amplified spontaneous emission is more than 35 dB suppressed. When double-Littrow external-cavity feedback is applied, the frequency difference of the two wavelengths is tuned from 0.5 to 5.0 THz. More than 1.5 W output power is achieved with a frequency difference around 1.0 THz, the output power is higher than 1.3 W during the 5.0 THz tuning range of frequency difference, and the amplified spontaneous emission is more than 20 dB suppressed in the 5.0 THz tuning range.

The laser structure of the 800 nm tapered amplifier used in the experiment was grown using metal organic vapor phase epitaxy. As an active layer, a tensile-strained single GaAsP quantum well was used, which was embedded in an AlGaAs waveguide. The processed tapered gain device had a total length of 4 mm, a 1 mm long index-guided ridge-waveguide section, and a 3 mm long flared section. The tapered angle was 4°, and the output aperture was 210 μm. The rear facet was antireflection coated with a reflectivity of 0.05%, while the front facet had a reflectivity of 0.5%.

The double-Littrow external-cavity configuration employed is depicted in Fig. 1. An aspherical lens (L_1) of 3.1 mm focal length with a NA of 0.68 is used to collimate the beam from the back facet in both fast and slow axes. The collimated beam is split into two beams by a cube 50/50 beam splitter (BS_1). Each beam is incident on a bulk diffraction grating, which is ruled with 1200 grooves/mm and has a blazed wavelength of 750 nm. The gratings are mounted in the Littrow configuration and oriented with the lines in the grating parallel to the active region of the amplifier. The laser cavities are

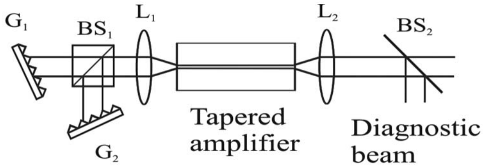

Fig. 1. Experimental setup of the dual-wavelength diode laser system based on a tapered diode amplifier with double-Littrow external-cavity feedback; L_1, L_2, aspherical lenses; BS_1, BS_2, beam splitters; G_1, G_2, diffraction gratings.

formed between the gratings and the front facet of the tapered amplifier. A second aspherical lens (L_2) of 3.1 mm focal length with a NA of 0.68 is used to collimate the beam from the output facet in the fast axis. Together with the aspherical lens, an additional cylindrical lens can be used to collimate the beam in the slow axis and compensate for astigmatism in the tapered amplifier. A beam splitter (BS_2) is used to reflect part of the output beam of the diode laser system as the diagnostic beam; the spectrum of the output beam is measured in this beam. The output power of the laser system is measured behind the second aspherical lens. All the lenses and beam splitters are antireflection coated for the near-IR wavelength.

The laser is TM polarized, i.e., linearly polarized along the fast axis and perpendicular to the grating rulings; thus, the high *s*-polarization diffraction efficiency of the grating is utilized [18]. The temperature of the tapered amplifier is controlled with a Peltier element, and it is operated at 25 °C in the experiment. The emission wavelengths λ_1 (from grating G_1) and λ_2 (from grating G_2) of the laser system are tuned by rotating the gratings independently.

First, the range of the wavelengths of the dual-wavelength diode laser system should be determined. Thus, the output power at different wavelengths for the diode laser system with single-Littrow external-cavity feedback, i.e., removing the beam splitter BS_1, is measured at an operating current of 3.5 A. The results are shown in Fig. 2. The laser system is tuned over a 27 nm range centered at 800 nm. The output power is above 1.0 W over the 27 nm tuning range, and as high as 2.15 W output power is obtained at 801.43 nm. The optical spectrum characteristic of the output beam from the single-Littrow external-cavity diode laser system is measured using a spectrum analyzer (Advantest Corp., Q8347). A typical spectrum of the output beam measured at 801.20 nm with an output power of 2.13 W is also shown in Fig. 2. The spectral bandwidth (FWHM) is 0.004 nm (the resolution of the spectrum analyzer is 4 pm), and the amplified spontaneous emission intensity is more than 35 dB suppressed.

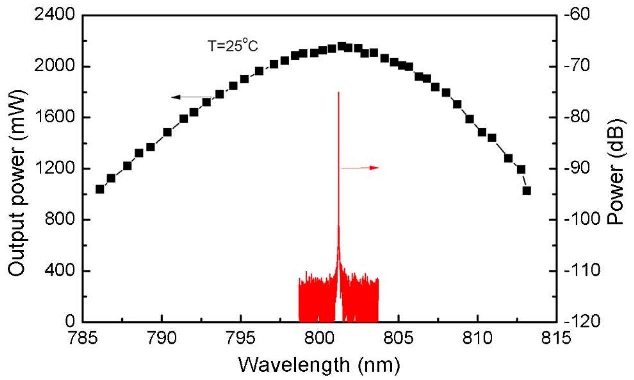

Fig. 2. (Color online) Tuning curve of the tapered diode laser system with single-Littrow external-cavity feedback (squares) and optical spectrum of the output beam from the single-wavelength tapered diode laser system with an output power of 2.13 W (solid curve).

According to the tuning curve of the single-feedback laser system shown in Fig. 2, the gain center of the tapered diode amplifier is around 801 nm. Thus, the two wavelengths from the dual-wavelength diode laser system are tuned at each side of 801 nm. The wavelength λ_1 is the shorter wavelength, and λ_2 is the longer wavelength. The spectrum of the output beam of the dual-wavelength diode laser system is measured at the frequency difference between the two wavelengths from around 0.5 to 5.0 THz. Three spectra with the frequency difference of the two wavelengths of 0.86, 2.60, and 3.80 THz are shown in Fig. 3; the operating current is 3.5 A. The amplified spontaneous emission intensity is more than 20 dB suppressed for all the three spectra. When the wavelength difference is less than 2.0 nm (around 1.0 THz), the side peaks appear in the spectrum and the spectrum is not stable. One lasing wavelength can be suppressed by the other, and the two wavelengths are switchable from one to another occasionally. This may be caused by the competition between the two wavelengths originated from the feedback from the two gratings. When the wavelength difference is more than 2.0 nm, the two laser beams with different wavelengths oscillate simultaneously, and normally the difference of the intensity of the two wavelengths measured in the spectrum is less than 3 dB.

The output power of the dual-wavelength diode laser system at different frequency difference is shown in Fig. 4 at an operating current of 3.5 A, and the corresponding two wavelengths are also shown in Fig. 4. More than 1.5 W output power is obtained when the frequency difference is around 1.0 THz. The output power decreases as the frequency difference of the two wavelengths increases, since both wavelengths of the dual-wavelength diode laser system are tuned further from the gain center

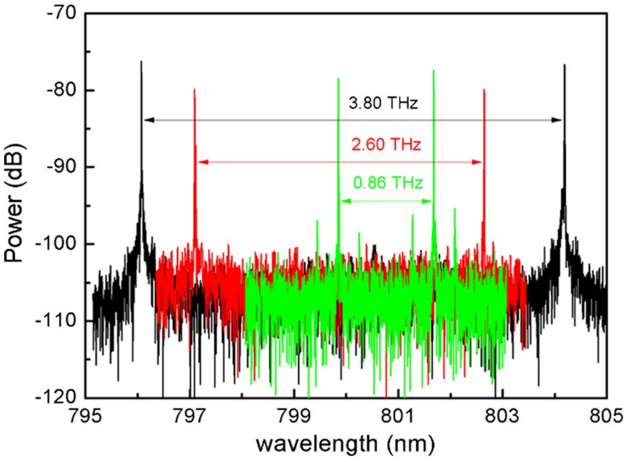

Fig. 3. (Color online) Optical spectra of the output beam from the dual-wavelength diode laser system with the frequency difference of the two wavelengths of 0.86, 2.60, and 3.80 THz. The operating current is 3.5 A.

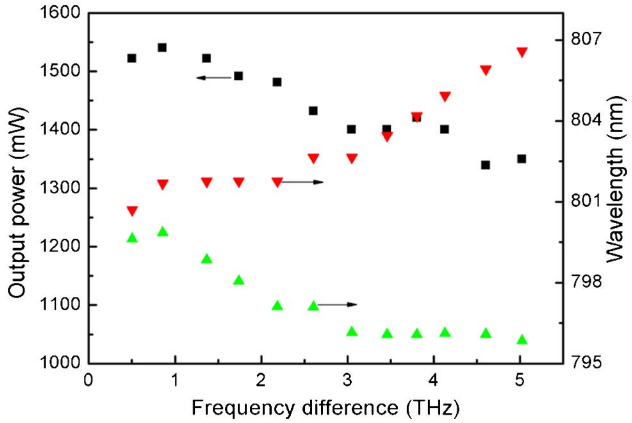

Fig. 4. (Color online) Output power from the dual-wavelength tapered diode laser system versus the frequency difference of the two wavelengths (squares) and the corresponding wavelength λ_1 (triangles) and λ_2 (inverted triangles).

of the tapered amplifier. The output power of the dual-wavelength diode laser system is higher than 1.3 W in the 5.0 THz tuning range of the frequency difference of the two laser wavelengths. At a frequency difference of 2.6 THz, the output power fluctuations are ±2.2% in 30 min. Compared with the single external-cavity feedback condition, the decrease of the output power for the dual-wavelength diode laser system is mainly due to the loss of the cube 50/50 beam splitter, BS_1.

In conclusion, a tunable high-power dual-wavelength tapered diode laser system based on double-Littrow external-cavity feedback is demonstrated for the first time to our knowledge. The frequency difference of the two wavelengths is tunable from 0.5 to 5.0 THz. More than 1.5 W output power is obtained when the frequency difference is around 1.0 THz, and the output power is higher than 1.3 W in the 5.0 THz tunable range of the frequency difference. The amplified spontaneous emission intensity is more than 20 dB suppressed in the 5.0 THz range of frequency difference.

The authors acknowledge Bernd Sumpf and Götz Erbert from Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, for the tapered diode amplifier.

References

1. P. Groot, Appl. Opt. **32**, 4193 (1993).
2. K. Lee and C. Shu, IEEE J. Quantum Electron. **33**, 1832 (1997).
3. M. Tani, P. Gu, M. Hyodo, K. Sakai, and T. Hidaka, Opt. Quantum Electron. **32**, 503 (2000).
4. T. Kleine-Ostmann, P. Knobloch, M. Koch, S. Hoffmann, M. Breede, M. Hofmann, G. Hein, K. Pierz, M. Sperling, and K. Donhuijsen, Electron. Lett. **37**, 1461 (2001).
5. S. Hoffmann, M. Hofmann, M. Kira, and S. W. Koch, Semicond. Sci. Technol. **20**, S205 (2005).
6. T. Hidaka, S. Matsuura, M. Tani, and K. Sakai, Electron. Lett. **33**, 2039 (1997).
7. M. Al-Mumin, C. Kim, I. Kim, N. Jaafar, and G. Li, Opt. Commun. **275**, 186 (2007).
8. A. Klehr, J. Fricke, A. Knauer, G. Erbert, M. Walther, R. Wilk, M. Mikulics, and M. Koch, IEEE J. Sel. Top. Quantum Electron. **14**, 289 (2008).
9. N. Kim, J. Shin, E. Sim, C. W. Lee, D. Yee, M. Jeon, Y. Jang, and K. H. Park, Opt. Express **17**, 13851 (2009).
10. S. Hoffmann, M. Hofmann, E. Bründermann, M. Havenith, M. Matus, J. V. Moloney, A. S. Moskalenko, M. Kira, S. W. Koch, S. Saito, and K. Sakai, Appl. Phys. Lett. **84**, 3585 (2004).
11. I. Park, I. Fischer, and W. Elsässer, Appl. Phys. Lett. **84**, 5189 (2004).
12. W. Wang, M. Cada, J. Seregelyi, S. Paquet, S. J. Mihailov, and P. Lu, IEEE Photon. Technol. Lett. **17**, 2436 (2005).
13. V. Zambon, M. Piché, and N. McCarthy, Opt. Commun. **264**, 180 (2006).
14. C. Friedrich, C. Brenner, S. Hoffmann, A. Schmitz, I. C. Mayorgak, A. Klehr, G. Erbert, and M. R. Hofmann, IEEE J. Sel. Top. Quantum Electron. **14**, 270 (2008).
15. S. A. Zolotovskaya, N. Daghestani, G. B. Venus, L. B. Glebov, V. I. Smirnov, and E. U. Rafailov, Appl. Phys. Lett. **91**, 171113 (2007).
16. S. A. Zolotovskaya, V. I. Smirnov, G. B. Venus, L. B. Glebov, and E. U. Rafailov, IEEE Photon. Technol. Lett. **21**, 1093 (2009).
17. B. Sumpf, K. Hasler, P. Adamiec, F. Bugge, F. Dittmar, J. Fricke, H. Wenzel, M. Zorn, G. Erbert, and G. Tränkle, IEEE J. Sel. Top. Quantum Electron. **15**, 1009 (2009).
18. M. Chi, O. B. Jensen, J. Holm, C. Pedersen, P. E. Andersen, G. Erbert, B. Sumpf, and P. M. Petersen, Opt. Express **13**, 10589 (2005).