High-Power High-Brightness 3 W tapered amplifiers tunable from 940 nm to 980 nm

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ABSTRACT

A variety of applications such as spectroscopy or tunable frequency doubling of diode lasers for blue-green outputs necessitate diffraction-limited tunable narrow linewidths and high output powers in the multiwatt regime. For these applications, tapered devices based on a tapered amplifier gain-guided design are used in an external cavity set up. So far commercially available output powers are in the range of 1 W, limited by the mounting technology so far.
The tuneability and the influence of different packagings on output performance was investigated. Used in littrow-configuration tapered diode lasers on optimized heatsinks show output powers of more than 3 W and an excellent spectral and spatial quality. The beam-quality parameter remains well below $M^2 < 1.5$ for output powers up to 3 W. A tuning range of more than 40 nm could be achieved.

Keywords: high brightness, beam quality, high power, diode laser, tapered laser, AlGaAs-InGaAs, semiconductor, external cavity, tunable lasers, diffraction limited

1. INTRODUCTION

Standard broad-area lasers are able to produce output-powers in the multi-watt regime but they are susceptible to modal instabilities and filamentation which degrades the beam-quality. To overcome these problems a lot of different solutions have been proposed within the last few years [1,2]. The tapered-laser seems to be one of the most-promising candidates if high-power and nearly diffraction limited beam-quality is needed [3,4,5]. The typical linewidth of a tapered laser is in the range of 3 nm and therefore comparable to broad-area lasers. To enable tapered-lasers to be used in the fields of spectroscopy or nonlinear frequency-conversion where a small linewidth is needed, it is possible to use an external cavity setup [6,7]. The drawback of this concept is that because of additional optical losses the efficiency and output power compared to a standard laser is normally reduced significantly. One way to keep the output-power as high as possible is to use high-quality optical components. Additionally the improvement of the laser-chip itself and in almost the same manner the heat-management is important. In this paper we achieved a considerable increase of efficiency of the tapered amplifier compared to standard c-mounts by optimizing the heatsink and minimizing thermal induced losses.

2. DEVICE STRUCTURE

The vertical design of the investigated high power tapered amplifiers consists of a low modal gain InGaAs/AlGaAs structure. A 7 nm thick single quantum well with 19 % In-content is embedded in an 1.06 µm thick AlGaAs region with 20 % Al-content. This leads to a low overlap of the optical mode with the active region of 1.1 % which has been shown to suppress filamention effects [8]. The internal parameters of the MBE-grown laser structure were determined by investigating Fabry-Perot laser diodes of different length. As a result, low internal losses of lower than 0.5 cm^{-1} and a high internal efficiency of more than 97 % are obtained which proves the high material quality. More detailed information on the structure was published elsewhere [9,10].

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The lateral design consists of an index guided ridge section with a length of 500 µm followed by a gain guided tapered section with a length of 2000 µm resulting in a total device length of 2500 µm. Together with a taper angle of 6° this leads to a front facet width of 216 µm. The ridge section provides a nearly diffraction limited beam which is mainly guided within the taper section and homogeneously amplified over its whole width (see figure 1, (a)). With this design it is possible to reach output-powers of several watts if the rear side is HR-coated (> 95 %) and the front facet is highly AR-coated (< 1%) [11]. In the case of external cavity setups usually tapered amplifier chips with AR-coatings (< 1 %) on both facets are used.
The tapered amplifiers were directly mounted p-side down with In-Solder onto special match-length Cu-Heatsinks which provide free access to the front and rear facets for a wide range of optical lenses. In comparison to standard c-mounts this new mount offers better heat management because interfaces between submounts or mounting stages are eliminated. Additionally handling is simplified because a contact pin and connector is attached to the heatsink which enables comfortable connecting to a current source without soldering near the laser-chip (see figure 1, (b)). The integration in external cavity setups is very easy, because only a standard electrical cooled plate is used to install this heatsink.

(a) (b)

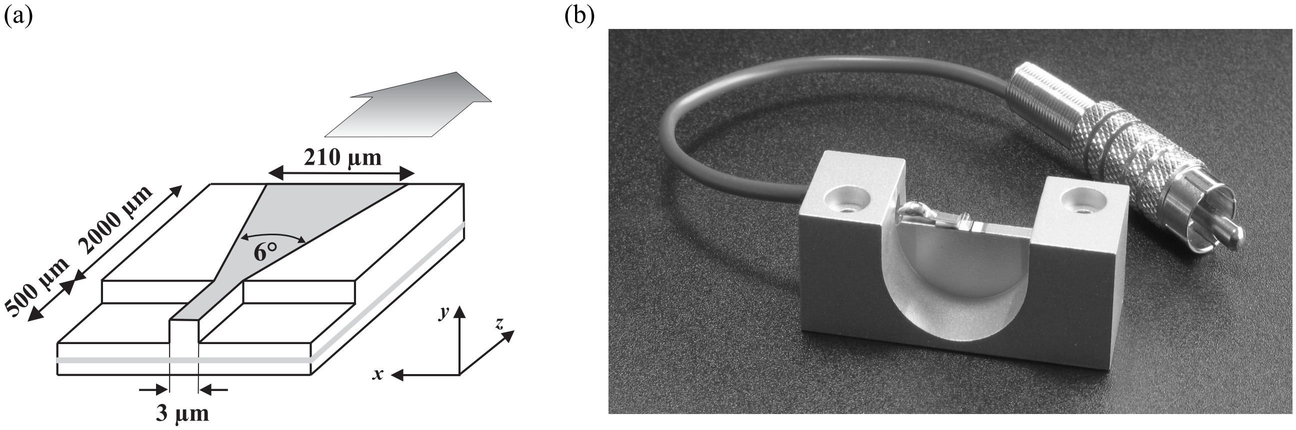

Fig. 1. Lateral design of the investigated tapered-amplifier (a). Photograph of the optimized heat sink for external cavity applications. The tapered amplifier is soldered directly to the heat sink to minimize thermal resistance and maximize output power. The wide openings provide clear access to front and rear-side of the amplifier (b).

3. EXPERIMENTAL SETUP

To combine the advantages of high power high brightness tapered laser diodes with narrow linewidth and excellent tunability an external cavity setup was used (see figure 2). The external cavity consists of a collimating lens with 12.5 mm focal length. A half wave plate is used to correct the polarisation for the littrow-mounted grating. The first order of the dispersed light is reflected back into the highly antireflection coated ridge side of the tapered amplifier. The 1 µm thick waveguide acts as a slit to capture a small part of the light at the lasing wavelength which is used to seed the ridge section and then amplified in the tapered section. The front side is antireflection coated such that a small amount of the light is reflected back to provide oscillation.
This type of external cavity has the advantage that no additional seedlaser and extra electronics is needed to achieve small linewidths which makes it attractive for applications were cost plays an important role. Additionaly no beam walk occurs on the front side while tuning the laser on the rear side. By using tapered amplifiers in the external cavity setup it is possible to reach much higher output powers in comparison with setups were standard ridge lasers are used. This

makes such a setup attractive for applications were high power is needed like for Raman-Spectroscopy or frequency doubling.

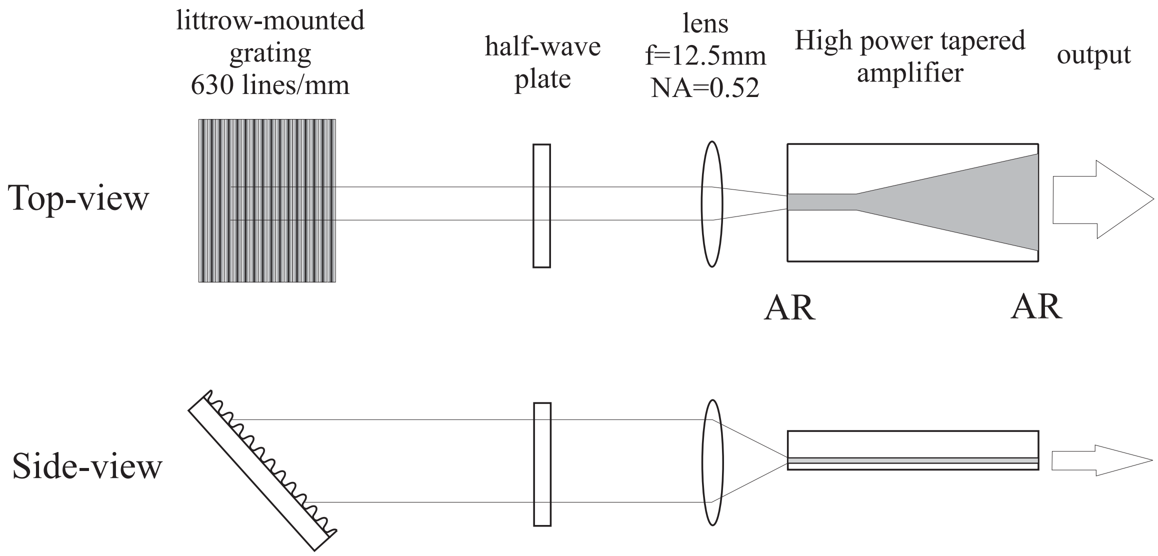

Fig. 2. Principle of the used external cavity setup. First the light of the rear side is collimated. A half-wave plate corrects the polarization for the littrow mounted grating. The first order of the grating is coupled back into the laser. The output wavelength can be tuned by tilting the grating.

4. EXPERIMENTAL RESULTS

External cavity systems in principle have lower wall-plug efficiencies due to the incorporation of optical elements which lead to additional optical losses. Additionally only a fraction of the dispersed light from the rear side of the amplifier is coupled back into the ridge-waveguide. Thru excellent material quality and good heat management the tapered amplifier chip mounted on a special heatsink optimized for external cavity applications reaches optical ouput-powers of nearly 4.5 W at an operation-current of 6 A and a tuned wavelength of 970 nm. This corresponds to a comparatively high wall-plug efficiency of more than 42 % (see figure 3). Comparable tapered amplifiers mounted on standard c-mounts have only reached 3.5 W at an injection current of 6 A leading to a lower wall-plug efficiency of about 30 %. This demonstrates clearly that choosing the right heat sink can have a remarkable impact on the reachable output power.

The typical linewidth of standard tapered lasers is around 3 nm. With an external cavity setup it is possible to reduce the linewidth significantly. To ensure that the amplifier don’t suffer from parasitic oscillation even at high injection currents, which are necessary to gain highest output powers, a high quality antireflection coating on the rear and also front side of the amplifier is necessary. The spectral tuning characteristics and linewidth was measured with an Optical Spectrum Analyzer HP70950B. The gain spectrum determines the overall tuning range of the laser. As can been seen in figure 4 (a) the power amplifier can easily be tuned from 935 nm to 980 nm. A typical sidemode supression of better than 40 dB is reached over the whole tuning range (figure 4 (b)). Up to a operation-current of 4 A no laser-peaks are visible in the intensity spectrum with grating feedback blocked (figure 4 (c)) which verifies the excellent coating quality. The tuning curve for the threshold current and needed injection current for 1 W, 2W and 3 W of optical output power is presented in figure 5. The curves are rather flat and have nearly constant spacings. This is a result of the very broad and flat gain spectrum of the investigated tapered amplifier which leads simultaneously to nearly constant slope efficiencies and high output powers over the whole tuning range.

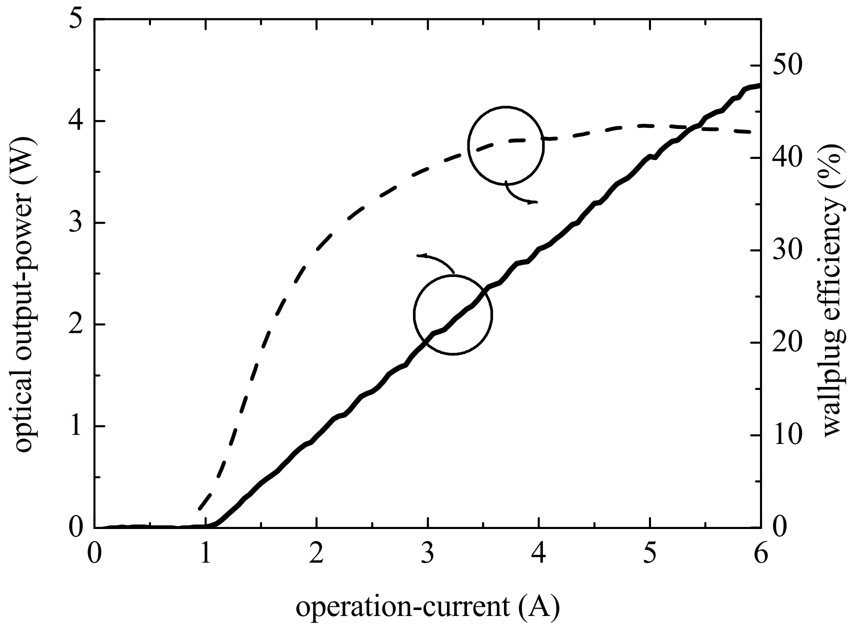

Fig. 3. Optical output power against operation-current of a tapered amplifier with grating feedback tuned to 970 nm. Output powers of more than 4 W at an operation-current of 6 A are reached (straight line). The wallplug efficiency reaches a very high value of more than 40 % (dashed line). The measurements were performed at a heat sink temperature of 20 °C in cw-mode.

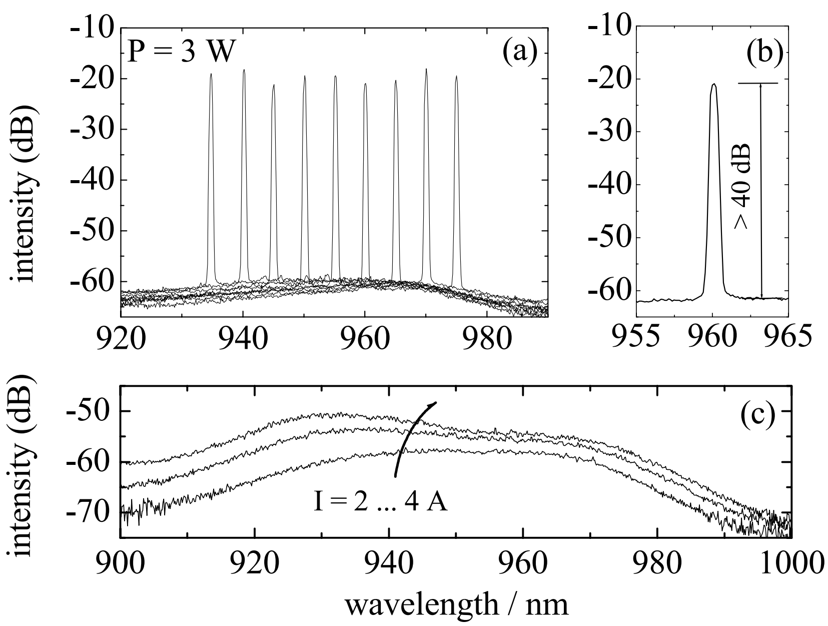

Fig. 4. (a) Intensity spectrum at different tuned wavelengths between 935 nm and 980 nm at an optical output power of 3 W measured at a heatsink temperature of 20°C in cw-mode. (b) A typical sidemode suppression over the whole tuning range is better than 40 dB. (c) Intensity spectrum for operating-currents between 2 A and 4 A with grating-feedback blocked.

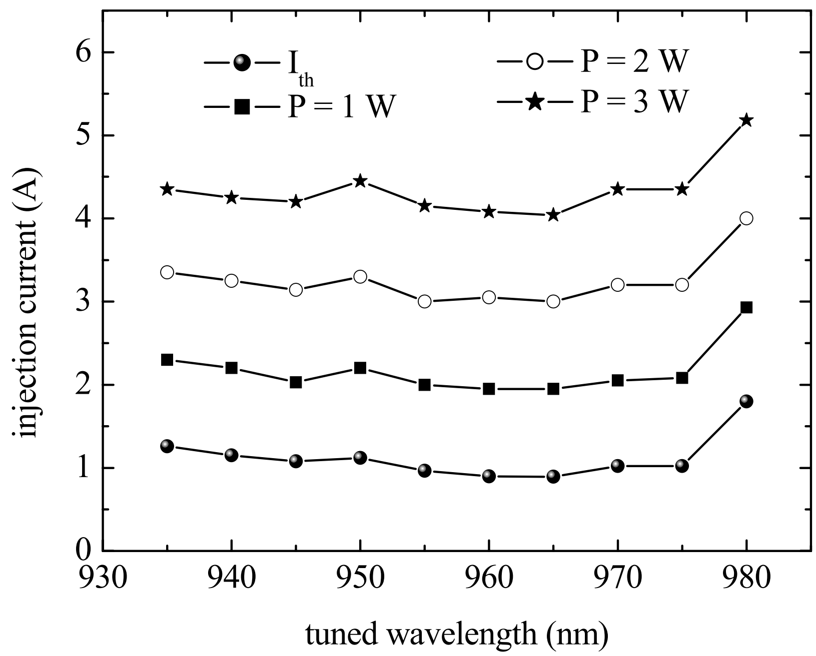

Fig. 5. Injection current for 1 W to 3 W of optical output power in dependence of the tuned wavelength. Additionally the threshold current is plotted. The measurements were performed at a heat sink temperature of 20 °C in cw-mode.

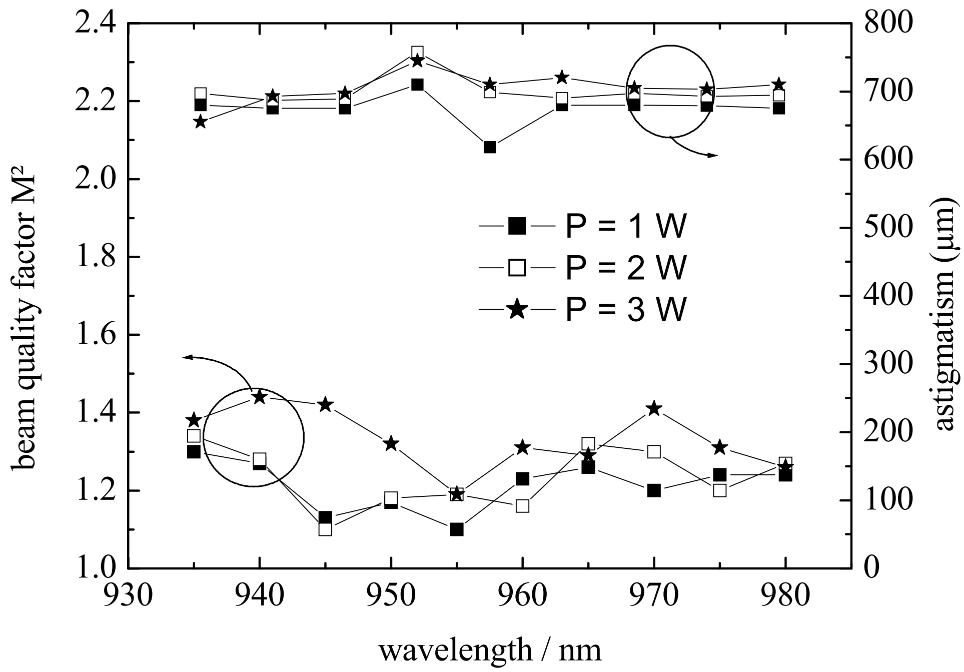

Fig. 6. Beam quality parameter M² and astigmatism in dependence of tuned wavelength for constant optical output powers of 1 W (squares), 2W (open squares) and 3 W (stars) measured at 20 °C heat sink temperature in cw-mode.

Besides a high output power also a good beam quality is necessary for most applications. In figure 6 the beam quality of the slow axis is plotted for optical output powers between 1 W and 3 W in dependence of the tuned wavelength. The beam quality was measured with a commercial beam analyzing system (Mechantek Beam Scope) using the $1/e^2$ method which cuts the beam profiles at a level $1/e^2$. A beam quality of $M^2 < 1.5$ is achieved over the whole tuning range up to optical output powers of 3 W. If we use an integral method which takes into account sidelobes even below the $1/e^2$ level a beam quality of around $M^2 = 1.6$ is achieved over the whole tuning range for output powers up to 3 W.

The knowledge of the astigmatism of the taper side is important for the selection of lenses for the optical system. Furthermore it is preferable that the astigmatism is independent of injection current and tuned wavelength since there is no additional adjustment of the collimating lenses of the taper side needed while changing the output power or wavelength of the external cavity setup. Therefore the astigmatism between fast and slow-axis of the taper side was measured. Figure 6 shows the astigmatism for different tuned wavelengths and output powers. It has a value of approximately 700 µm and stays nearly constant while tuning the wavelength from 935 nm to 980 nm or increasing the output power from 1 W to 3 W.

5. CONCLUSION

In conclusion, we reported on a high power tapered amplifier mounted on an optimized heatsink. To reduce linewidth the chip was used in an external cavity-setup with littrow-mounted grating. A maximum cw output power of nearly 4.5 W was achieved at an operation current of 6 A and a wavelength of 970 nm. Within the external-cavity setup a remarkable high wall-plug efficiency of more than 40 % could be reached. Additionally a broad tuning range from 935 nm to 980 nm with output powers of more than 3 W in cw-mode over the whole tuning range could be demonstrated. The spectral linewidth was better than 0.1 nm only limited by the used spectrometer. The beam quality of this device was nearly diffraction limited with values around $M^2 = 1.4$ for output powers up to 3 W which makes it interesting for a wide range of applications like tunable frequency conversion, or spectroscopy.

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