7.4 W continuous-wave output power of master oscillator power amplifier system at 1083 nm

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A 1083 nm hybrid master oscillator power amplifier system consisting of a DBR laser and a tapered amplifier has been realised. A maximum output power of 7.4 W in single-longitudinal mode operation with a narrow spectral linewidth and a sidemode suppression ratio better than 40 dB is presented.

Introduction: High-power semiconductor diode lasers are well established for various industrial and medical applications. One important medical application uses polarised helium for nuclear magnetic resonance (NMR) lung diagnostics [1]. To polarise the gas, laser light sources emitting at 1083 nm with a narrow spectral linewidth, a good beam quality and an output power larger than 4 W are required. Up to now, ytterbium-doped fibre lasers or Nd-doped lanthanum magnesium hexaluminate lasers have been used for metastability-exchange optical pumping [2].

Owing to smaller size and higher efficiency, semiconductor-based laser systems are a very attractive alternative for this application. Two possible narrow linewidth semiconductor lasers, a distributed Bragg reflector (DBR) laser or a distributed feedback (DFB) laser, have a singlemode and single-frequency operation. However, the output powers are limited to 220 mW [3]. To reach a higher output power, the light from the DFB or DBR laser has to be amplified. This can be performed with a semiconductor optical amplifier. Such a system, called a master oscillator power amplifier (MOPA), consists of a DFB or DBR master oscillator and an optical power amplifier. MOPA systems for various wavelengths were built in previous work. For example at 970 nm an output power of 5 W was reported [4]. At a wavelength of 1060 nm a compact design of a hybrid MOPA with a maximum output power of 3.1 W was demonstrated [5]. In recent work, our group reported at 1083 nm an MOPA system, based on a DBR laser and a tapered amplifier, with a maximum output power of 5.3 W [6].

In this Letter we present a hybrid MOPA using a 1083 nm DBR as master oscillator and an antireflection-coated tapered laser structure as power amplifier, reaching 7.4 W maximum output power. The operation characteristics for various temperatures and amplifier currents are investigated in order to achieve a large output power.

Setup and device designs: Two identical aspherical lenses with a focal length of $f = 8$ mm focused the light of the master oscillator (MO) onto the input facet of the power amplifier (PA). Between these lenses a 60 dB optical isolator was placed to prevent the light of the PA being injected back into the MO. The emitted PA light from the front facet was collimated and directed using a beam splitter to a fibre connected to an optical spectrum analyser for measuring spectral behaviour. The optical output power was measured with an integrating sphere. The complete setup for analysing the MOPA system is shown in [6].

The MO was a three-section DBR laser consisting of gain, phase and grating section [7]. The gain and the phase sections were connected by wire bonding. The active layer consisted of a compressively strained InGaAs single quantum well embedded in a tensile strained GaAsP spacer layer. The first-order grating etched into the GaAs waveguide layer was defined by holography. Growth and overgrowth was performed by metal-organic vapour-phase epitaxy (MOVPE). The total length of the laser was 2 mm, divided into 1000 μm-long gain, 500 μm-long phase and 500 μm-long DBR sections, mounted p-side up on a C-mount. The width of the ridge for the lateral mode confinement was 3 μm. The temperature of the laser was adjusted to 40°C to reach the required wavelength of $\lambda = 1083$ nm.

The active region of the tapered amplifier grown by MOVPE consisted of a InGaAs double quantum well embedded in a 3.6 μm-thick AlGaAs waveguide layer. The 4000 μm-long device was divided in an index-guided 1000 μm straight section and a gain-guided 3000 μm tapered section. The index guiding in the straight section was achieved by a 3 μm-wide ridge. The full angle of the taper was $\varphi_{TR} = 6°$. The front and rear facets were antireflection coated having a reflectivity $R \leq 5 \times 10^{-4}$. The device was soldered epi-side down on a CuW heat spreader which was mounted on a C-mount.

Results: Fig. 1 shows the measured MOPA optical output power against PA current with the heatsink temperature as parameter. Both MO and PA were operated in CW mode. The MO had an output power, which saturated the amplifier. The estimated seed power into the PA was 36 mW. For low currents up to 8 A the power characteristics show strong temperature dependence. In this current region the output power increases with rising temperature. For currents larger than 9 A, all curves converge and finally intersect each other. At 12 A, the maximum output power of 7.4 W for 10°C was achieved. For a temperature of 25°C an output power of 6.8 W was reached. Even higher output powers were limited by thermal rollover. This could be prevented with longer amplifiers due to the lower thermal resistance.

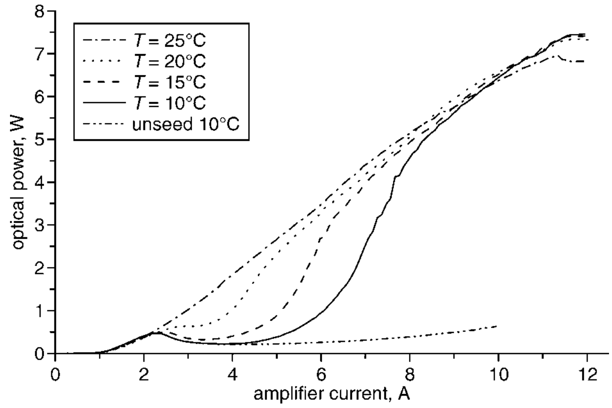

Fig. 1 *Measured optical output power of MOPA against PA injection current under CW operation for various temperature ranges*

$P_{Seed} = 36$ mW

As shown in Fig. 1 the unseeded power current characteristic of the PA itself for a temperature of 10°C is identical to the seeded MOPA P-I characteristic up to an amplifier current of 4 A. That means that for amplifier currents below 4 A and temperatures as low as 10°C no amplification was observed. The explanation for this behaviour is shown in Fig. 2*a*. This shows the amplified spontaneous emission (ASE) spectra of the unseeded amplifier at 10°C for various amplifier currents. As seen in Fig. 2*a* for a low current of 1.9 A, the spectra had no overlap with the seed wavelength of 1083 nm. Therefore amplification is not possible. Given by the design of the epitaxy the gain of the material is located at shorter wavelengths compared to 1083 nm. For larger currents the junction temperature is raised due to Joule heating. The spectra shifted to longer wavelengths with a tuning rate of approximately 3 nm/A. At a current of nearly 4 A the overlap between the ASE spectra, that indicates the gain interval, and the seed wavelength is large enough that amplification starts.

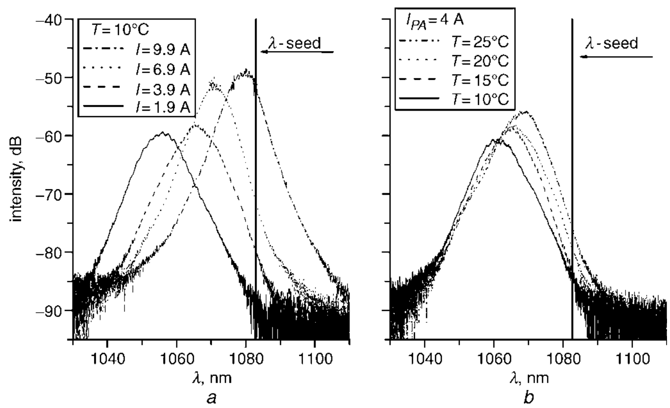

Fig. 2 *Measured unseeded spectra of PA at 10°C for various currents, and at $I_{PA} = 4$ A for various temperatures*

a At 10°C for various currents
b At I_{PA} for various temperatures

As is well known, the shift of the gain spectra can also be realised by increasing the heatsink temperature instead of current-heating. Fig. 2*b* shows the unseeded amplifier ASE spectra for a current of 4 A.

The temperature was used as parameter. As expected, the gain spectra shifts to longer wavelengths. The tuning rate of the gain maximum was about 0.45 nm/K. Because of this shift and better matching of the gain spectra to the seed wavelength for low currents an increase of output power for rising temperatures was observed as seen in Fig. 1.

Fig. 3 shows the spectral behaviour of the MOPA for 20°C for several output powers as parameter. The measured peak wavelength remained stable at the seed wavelength of 1083 nm and did not change with increasing output power of the MOPA. As described above, if the temperature is increased, the difference between the gain maximum and the MO wavelength is decreased and a larger gain at the seed wavelength is obtained for higher temperatures and higher currents, respectively. In Fig. 3 it can also be observed that for higher output powers the ASE was reduced. The improved overlap of the gain spectrum with the seed wavelength resulted in a better conversion efficiency of injection carriers to photons for the seed light at the cost of the ASE. The power ratio between the ASE maximum and the seed wavelength peak increased from 23 dB at 2 W to 49 dB at 7 W. The sidemode suppression ratio (SMSR) of 42 dB inherent to the DBR was preserved. The measured linewidth was below 0.07 nm, limited by the spectrum analyser resolution. Initial measurement results on beam quality were shown in [6].

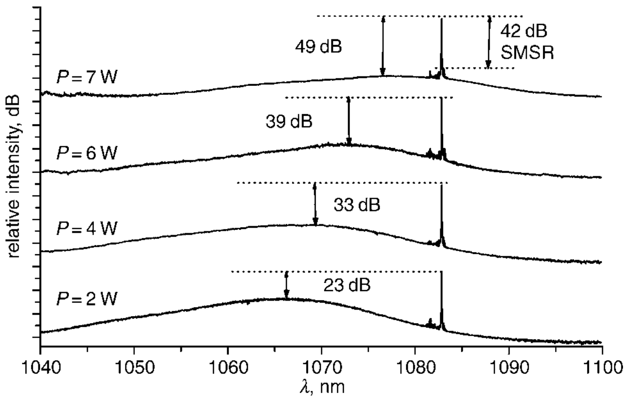

Fig. 3 *Measured MOPA spectra for various optical output powers at T = 20°C*

Conclusion: An MOPA system consisting of a DBR laser as master oscillator and a tapered power amplifier is presented for a wavelength of 1083 nm. By taking into account the wavelength shifts of the material gain with increasing injection current or temperature the overlap of the gain maximum with the seed wavelength was optimised by the epitaxial design for high output powers. At room temperature of 25°C a high output power of 6.8 W for CW operation was achieved.

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