

High power broad area 808 nm DFB lasers for pumping solid state lasers

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ABSTRACT

Experimental investigations on high-power broad area (BA) distributed-feedback (DFB) lasers emitting in the wavelength range around 808 nm are presented. An output power of 4.7 W at 20 °C with a differential quantum efficiency of 1.06 W/A is achieved with BA-DFB lasers having a stripe width of 100 μm and a cavity length of 3000 μm. The measured lateral far field angle is about 10° at a power of 3 W. The vertical far field angle is near 29°. The emission has a narrow spectral width of 0.06 nm (FWHM) at 3 W and 0.10 nm at 4 W. From mappings of the optical spectra a wavelength variation with output power of $\Delta\lambda/\Delta P = 0.44$ nm/W and with injection current of 0.4 pm/mA can be deduced. At a temperature of 50°C a maximum output power of 2 W is measured. From the measurements a temperature coefficient of $\Delta\lambda/\Delta T = 0.075$ nm/K is determined.

Keywords: Semiconductor lasers, distributed-feedback lasers, broad-area lasers, high-power lasers

1. INTRODUCTION

Diode lasers with a small spectral linewidth, stable lasing frequency and high output power are of particular interest for applications as pump sources for advanced solid state lasers, for second harmonic generation, medical treatment, Raman spectroscopy and measuring techniques (3D pattern projection). For these applications, Watt-range CW power and stable narrow spectral width, below 0.2 nm full width half maximum (FWHM), are required. Conventional high-power broad-area laser diodes have clearly certain deficiencies in their performance, because of a spectral linewidth of 2 nm - 4 nm, a wavelength shift with temperature by approximately 0.3 nm/K and big wavelength changes with current and aging time. A spectrally narrowed emission can be achieved by external or internal measures.

External measures can be realized with a common Fabry-Perot (FP) BA diode laser placed together with a grating into an external cavity configuration, which necessitates, however, expensive mechanical and thermal stabilization measures /1,2/. A spectral stabilization of high power laser diodes can be also realized by using volume Bragg gratings (VBGs) /3,4/, where the VBG is glued near the laser facet. A disadvantage is here the needed rigorous precision of the splice of the VBG and its degradation during aging.

Another possibility for wavelength stabilization and spectral narrowing is the integration of a Bragg grating directly into the internal laser cavity. Diode lasers with internal Bragg reflectors need no additional expensive parts and external adjustment. In distributed Bragg reflector (DBR) lasers the Bragg grating is located in a part of the laser cavity only and is operated passively, i.e. without current injection. In contrast, in distributed feedback (DFB) lasers the grating is integrated in the epitaxial layer structure over the whole cavity and is hence operated actively.

The fabrication of lasers with an integrated Bragg grating requires additional technological efforts compared to Fabry-Perot lasers. DFB and DBR laser structures can be fabricated either in single or in multiple growth steps. Single-growth DFB and DBR lasers use laterally coupled or deeply etched gratings, respectively /5,6/. In BA lasers the lateral-coupling scheme cannot be used at all. In contrast, BA DFB lasers fabricated with a two-step epitaxy can reach a high output power of more than 1W. Earles et. al /7/ showed 1.1 W continuous wave emission with a spectral width of 0.09 nm from broad stripe DFB lasers at $\lambda = 893$ nm and 1 W at $\lambda = 980$ nm with a spectral width of 0.15 nm /8/. In /9/ we presented a high power BA DFB laser emitting 2.4 W at a wavelength of 785 nm. The full width at half maximum at 2 W was 0.16 nm.

In this paper, we present experimental results from 100 μm BA DFB lasers emitting at a wavelength around 808 nm that exhibit high power, narrow spectral width, and excellent performance for pumping solid state lasers.

2. LASER STRUCTURE AND FABRICATION PROCEDURE

The broad area DFB lasers were grown by low-pressure metal organic vapor phase epitaxy (MOVPE) in two steps, similarly as described in [10,11]. The layer sequence is schematically drawn in Figure 1. The first growth step consisted of a n-GaAs buffer, n-AlGaAs cladding, 1000 nm n-AlGaAs waveguide, 17 nm GaAsP active single quantum well (QW). The first part of the p-AlGaAs waveguide (600 nm) and an InGaP/GaAsP/InGaP layer sequence. The second order Bragg grating with a period around 240 nm (see Fig. 2) is formed in the InGaP/GaAsP/InGaP layer sequence by holographic photolithography and wet-chemical etching. A frequency quadrupled Nd:YAG laser with an emission wavelength of $\lambda = 266$ nm is used in the holographic setup. After surface cleaning, in the second epitaxial step the remainder of the p-AlGaAs waveguide layer, the p-AlGaAs cladding layer and the p-GaAs contact layer are grown.

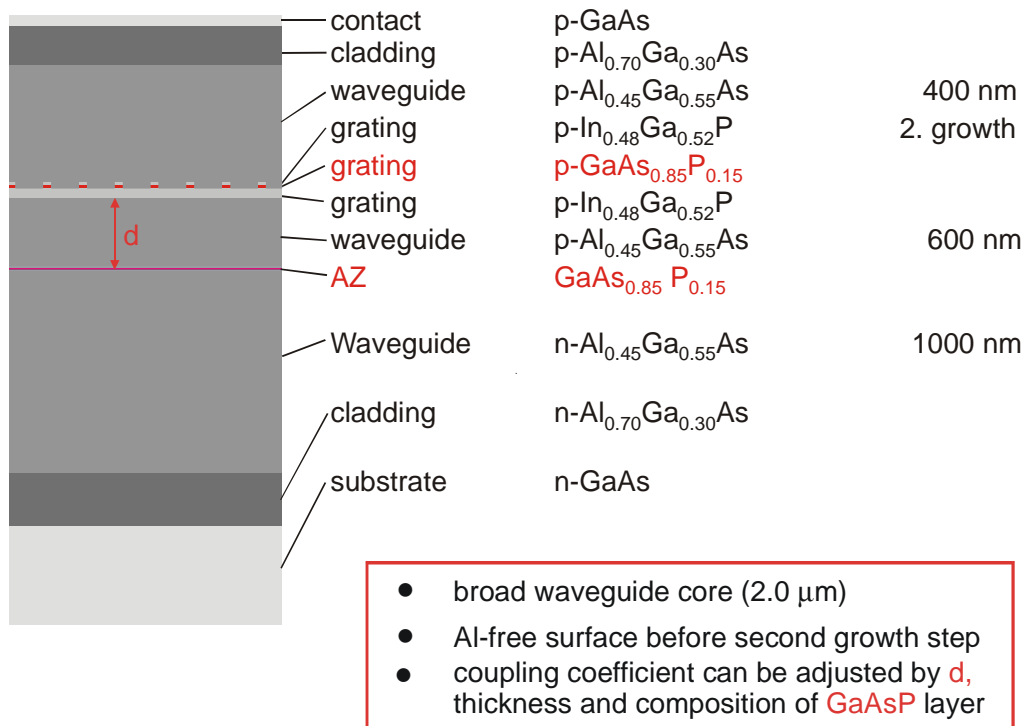


Figure 1. Transverse cross section showing epitaxial layer sequence of the 808-nm broad area DFB lasers investigated.

The coupling coefficient κ of the Bragg grating depends mainly on the thickness and the composition of the GaAsP grating layer and its distance to the active zone. This allows a simple adjustment of κ . A coupling coefficient of about 1 cm^{-1} was determined by fitting amplified spontaneous emission (ASE) spectra measured below threshold to a parameterized theoretical model [12]. A κL value of 0.3 is realized for the 3 mm long laser, which provides enough feedback for the efficient operation of the laser.

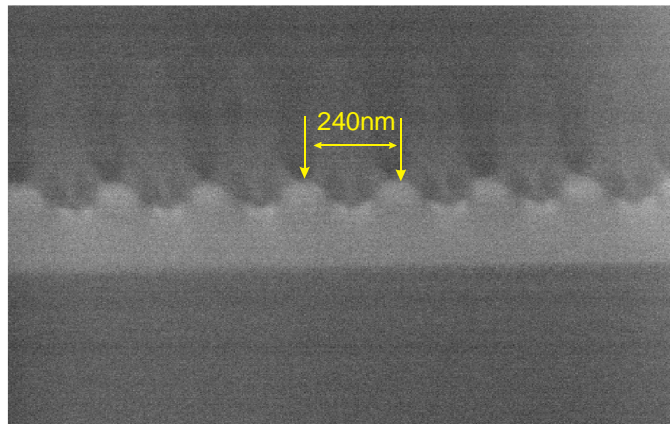


Figure 2. SEM picture showing the buried second order Bragg grating.

Lateral optical confinement and p-contacting is provided by a ridge-waveguide (RW) formed by reactive ion etching and deposition of SiN_x which is opened on the top of the RW before the p-metallization is performed. For our experiments the ridge width is varied between $7.5 \mu\text{m}$ and $100 \mu\text{m}$. After substrate thinning and n-metallization, the wafers are cleaved into bars with lasers having cavity lengths of $L = 1.5 \text{ mm}$ and $L = 3 \text{ mm}$. The facets were anti- and high-reflection coated, which results in reflection coefficients of typically below 10^{-3} at the front facets and 0.95 at the rear facets, respectively. A scheme of the developed BA DFB lasers is shown in Fig. 3.

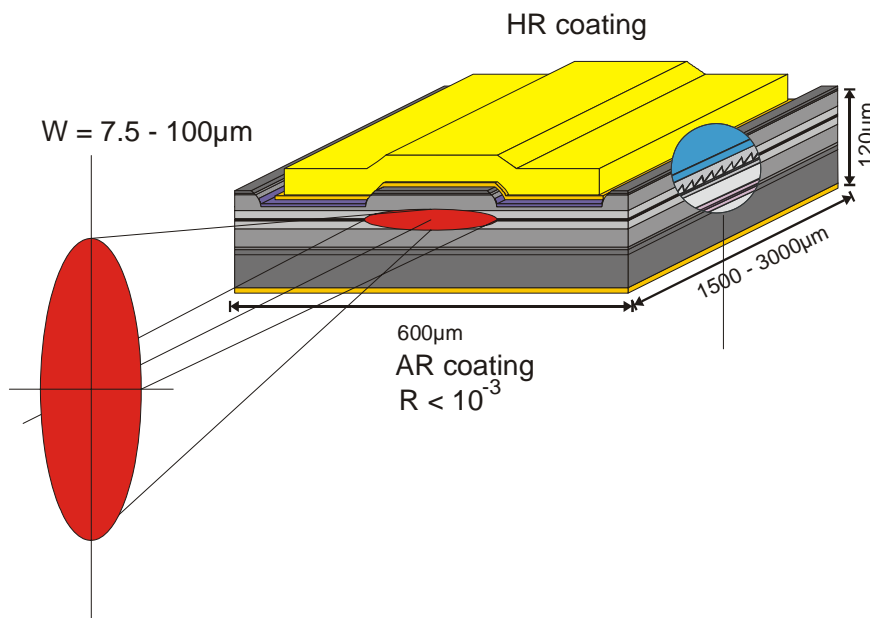


Figure 3. Scheme of a BA DFB laser

For the CW measurements, the chips covered with electroplated gold are soldered p-down on CuW submounts by

exploiting the AuSn ζ phase /13/ and finally mounted on 4 mm long C-mounts.

3. EXPERIMENTAL RESULTS

For the experiments, BA DFB lasers with a ridge width of 100 μm were used. Fig. 4 shows the power-current (P-I) and the voltage-current (V-I) characteristics of a 3 mm long laser measured in CW operation at 20°C. The optical power was detected with an integrating sphere. The threshold current is 0.58 A and the slope efficiency is 1.06 W/A. The P-I characteristics is linear up to 4 W. A further increase of the operating current leads to a decrease of the efficiency due to the self-heating of the laser and a thermal roll over. The maximum output power is 4.7 W, nearly. The high efficiency is the result of the small coupling coefficient κ of the Bragg grating and low optical losses. The wallplug efficiency is 37 % at 3 W CW and 34 % at 4 W output power.

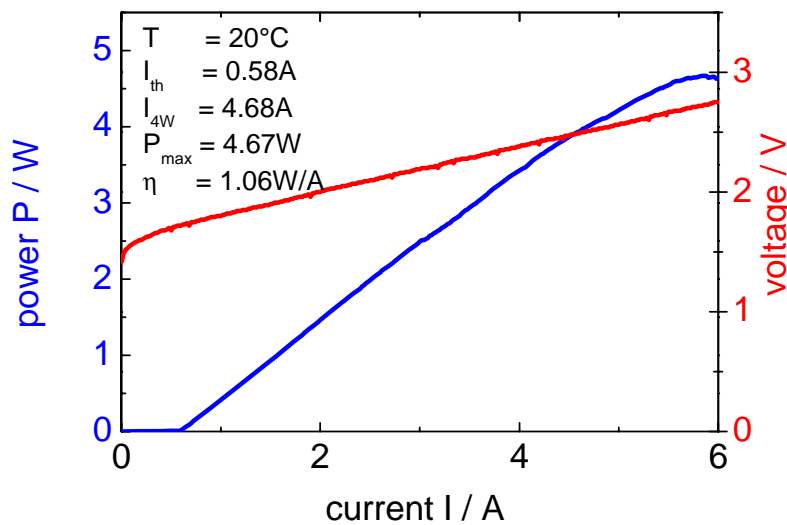


Figure 4. Power-current (P-I) and the voltage-current (V-I) characteristics of a 3 mm long 808 nm BA DFB laser with a stripe width of 100 μm

Figs. 5a and b show the lateral and vertical farfield profiles at injection currents of 3.6 A and 4.8 A corresponding to 3 W and 4 W output power, respectively. The lateral farfield profile has a FWHM of 10° at 3 W and 11° at 4 W. From the lateral profiles it can be seen, that higher order modes are excited.

Owing to the large optical cavity (LOC) with a total width of the AlGaAs waveguide layers of 2.0 μm the vertical far field is narrow as can be seen in Fig. 5b. The vertical farfield profiles are almost power independent with a FWHM of about 29°, nearly.

In Fig. 6, the variation of the full width at half maximum and the full $1/e^2$ width of the lateral farfield profile versus the injection current is shown. At a low output power of 0.8 W the FWHM has a value of 6.5° and increases to 11° at 4 W. The increase of the FWHM and the full $1/e^2$ width with current is linear and has a value of around 1.5°/A for the FWHM.

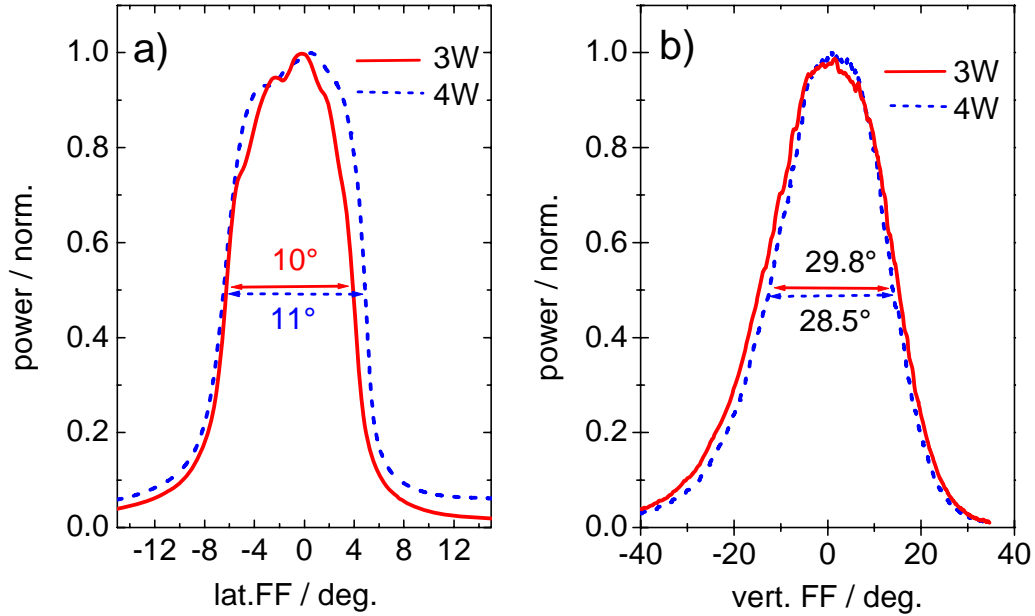


Figure 5. Lateral (a) and vertical (b) farfield profiles at 3 W and 4 W at a temperature of 20°C

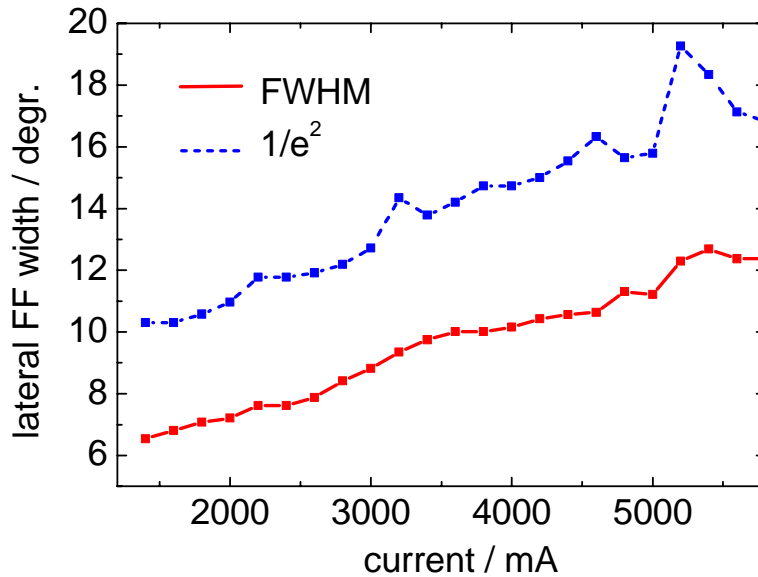


Figure 6. Variation of the FWHM and the full $1/e^2$ width of the lateral farfield profile versus injection current

Optical spectra were measured with an optical spectrum analyzer Q8384 with a resolution of 10 pm. A mapping of the optical spectra of a BA DFB laser versus current is shown in Fig. 7. The power scale is logarithmic. It can be seen, that the mode spectra are very narrow and maintained over a large current range from slightly above threshold (1 A) up to 6 A. The non-linear increase of the lasing wavelength, seen in Fig. 7, is caused by the temperature induced change of the refractive indices due to Joule heating. A wavelength tuning from 804.5 nm at 1 A to 806.5 nm at 6 A can be observed. From the wavelength variation of about $\Delta\lambda = 1.2$ nm between 1 A and 4.8 A (corresponding to 4 W), a temperature rise of $\Delta T = 16$ K can be deduced on the basis of a temperature coefficient of $\Delta\lambda/\Delta T = 0.075$ nm/K determined near threshold. The variation of the wavelength with output power is $\Delta\lambda/\Delta P = 0.44$ nm/W and with injection current 0.4 pm/mA. The suppression ratio of the lasing modes to the luminescent modes is of about 45 dB.

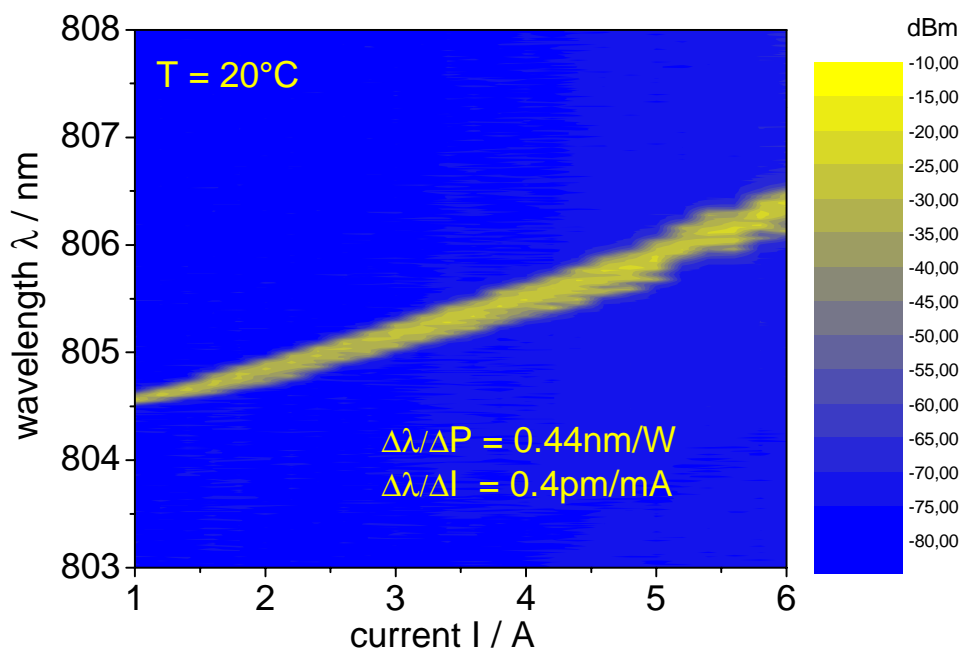


Figure 7. Mapping of the optical spectra of the BA DFB laser versus current at a temperature of 20 °C

The optical spectra of the BA DFB laser measured at 3 W and 4 W at 20°C are shown in Fig. 8. The spectrum at 3 W (Fig. 8a) is predominantly single moded with a FWHM of 0.06 nm. 95 % of the power is included within a width of 0.18 nm. The peak wavelength is here 805.4 nm. The spectral width is determined by the number of simultaneously oscillating lateral modes sharing the same longitudinal mode number. At the higher output power of 4 W the spectrum broadens and more peaks are visible. This can be explained by a larger number of oscillating lateral modes. Here, the spectrum has a FWHM of 0.10 nm and a 95 % width of 0.26 nm. However, for the applications discussed above the width of the emission spectrum is sufficiently narrow.

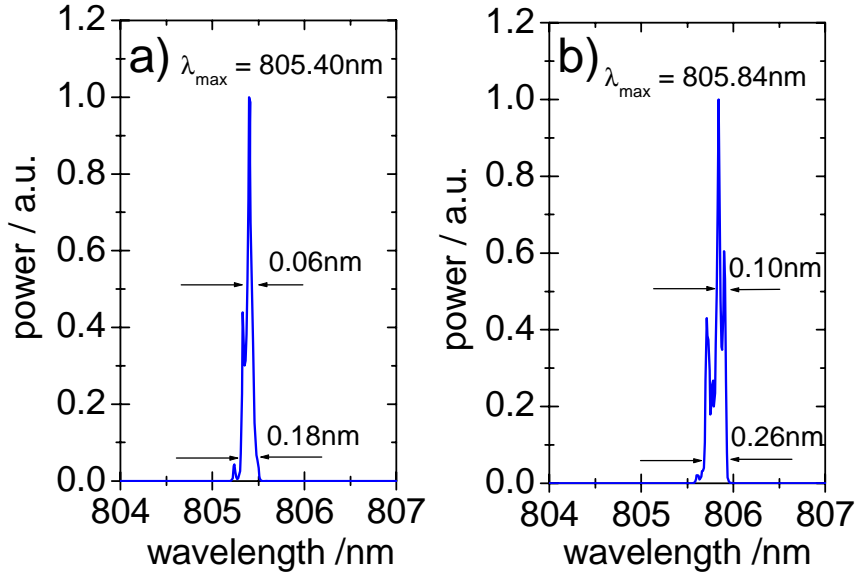


Figure 8. Optical spectra at 3 W (a) and 4 W (b) output power at a heat sink temperature of 20 °C

Now, the temperature dependence of the optical properties will be discussed. Fig. 9 shows the temperature dependence of the power-current characteristics of a BA DFB laser measured between 20°C and 50°C in steps of 5°C.

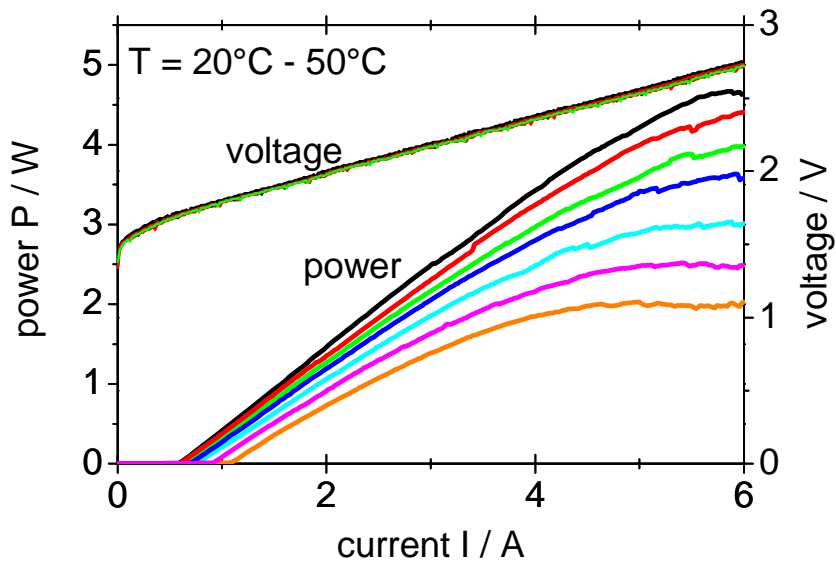


Figure 9. Power-current (P-I) and the voltage-current (V-I) characteristics in the temperature range 20°C to 50°C

The threshold current at 20°C is 0.6 A and the slope efficiency 1.06 W/A. With increasing temperature the threshold current increases, too. The slope efficiency and the current where roll over starts decreases. At 50°C a threshold current of 1.1 A and a slope efficiency of 0.66 W/A was measured. It can be seen from Fig. 9 that a maximum output power at 50°C of 2 W can be reached. The decrease of the maximum output power with temperature can be attributed to the increase of the detuning between peak gain wavelength and Bragg wavelength. Thus, for the achievement of a larger maximum output power at 50°C the peak gain wavelength must be correspondingly adjusted.

Mappings of the optical spectra at 20°C and 50°C are shown in Fig. 10a,b.

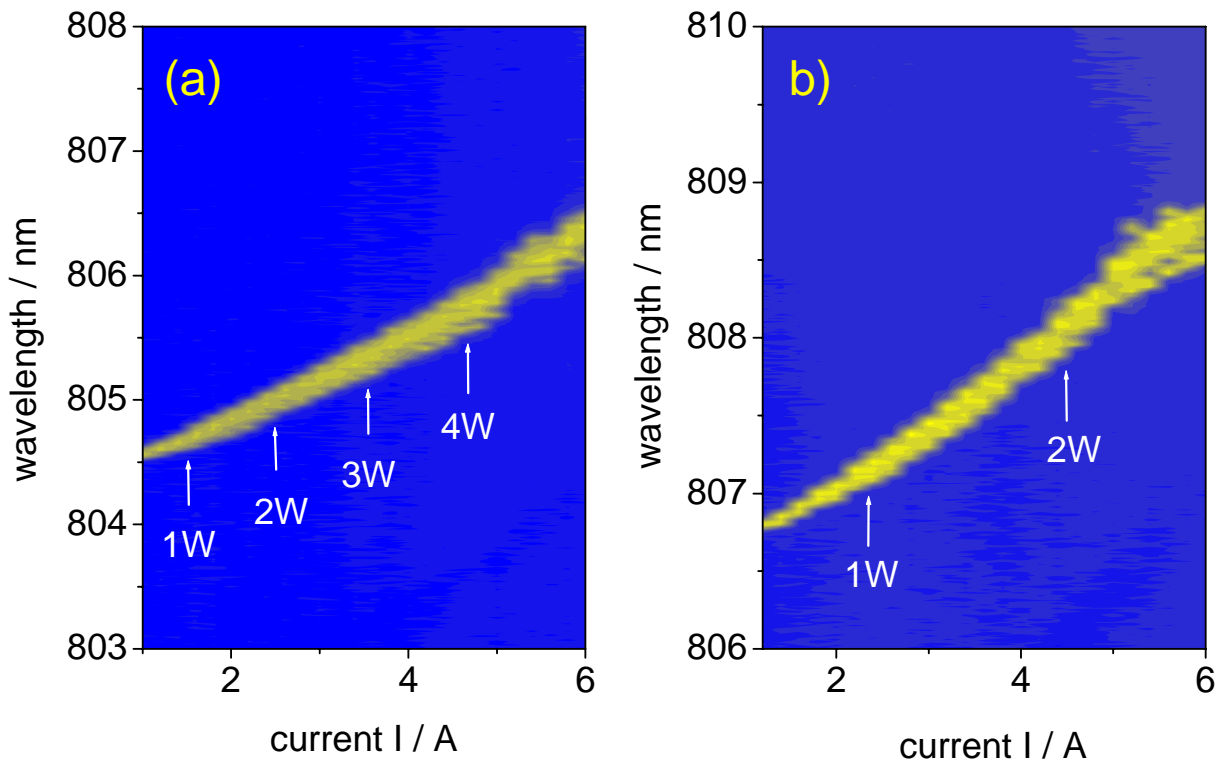


Figure 10. Mappings of the optical spectra at 20°C (a) and 50°C (b)

The power levels of 1 W to 4 W at 20°C and 1 W and 2 W at 50°C are marked with arrows. A wavelength tuning of 2.2 nm with temperature (20°C to 50°C) near laser threshold can be seen. At 50°C the laser wavelength is changed from 806.8 nm near threshold to 808 nm at 2 W. At all temperatures the optical spectra are very narrow and no substantial broadening is observed. These results show, that the internal grating acting as wavelength selective element in these lasers is very effective.

In Fig. 11 results of an aging test over 880 h at a power level of 2 W at $T = 25^\circ\text{C}$ are shown for five 808 nm BA DFB lasers with a ridge width of 100 μm . The test is still going on.

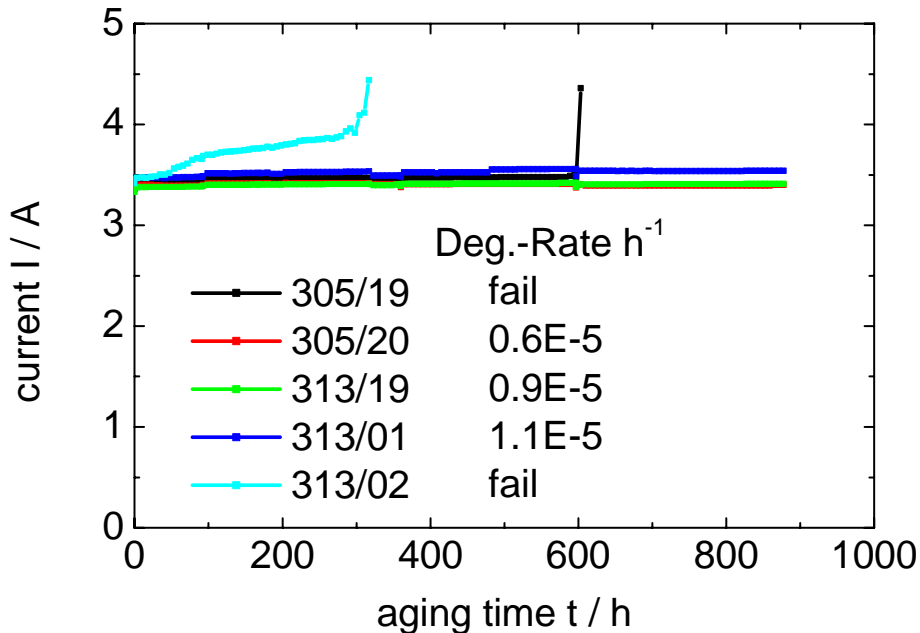


Figure 11. Aging behavior of five 3 mm long 808 nm BA DFB lasers at $T = 25^{\circ}C$ and an output power of 2 W.

The lasers were not burned before this test. One of these lasers failed after 300 h. However the laser could be clearly excluded in a burn-in due to the current increase within the first 100 h. At 600 h a second laser failed which could be caused by a turn off/on of the equipment. Gradual degradation rates are lower $1.1 \times 10^{-5} h^{-1}$.

4. SUMMARY

We have developed BA DFB lasers with a LOC structure emitting in the wavelength range around 808 nm. With these lasers having a stripe width of $100 \mu m$ and a cavity length of $3000 \mu m$ an output power of 4.7 W at $20^{\circ}C$ with a slope efficiency of 1.06 W/A is achieved. Due to the large optical cavity the vertical far field angle is $\sim 29^{\circ}$ and the measured lateral farfield angle is about 10° . Due to the integrated Bragg grating the optical spectra show a narrow spectral width with a FWHM of 0.06 nm at 3 W and 0.1 nm at 4 W.

From a mapping of the optical spectra a wavelength variation with output power of $\Delta\lambda/\Delta P = 0.44 \text{ nm/W}$ and with injection current of 0.4 pm/mA can be deduced. At a temperature of $50^{\circ}C$ a maximum output power of 2 W is reached and a temperature coefficient of $\Delta\lambda/\Delta T = 0.075 \text{ nm/K}$ is determined.

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