High-power 894 nm monolithic distributed-feedback laser

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Abstract: A ridge-waveguide InGaAs/GaAsP laser, emitting up to 250 mW in a single lateral and longitudinal mode at a wavelength of 894 nm, is presented. The distributed feedback is provided by a second order grating, formed into an InGaP/GaAs/InGaP multilayer structure. Owing to the stable lasing frequency, the large side mode suppression ratio (> 40 dB) and small spectral line width (< 200 kHz) the diode laser is well suited for caesium D1 spectroscopy. This was verified by the measurement of the hyperfine structure of the D1 line.

OCIS codes: 140.2020 (diode lasers); 140.0140 (laser and laser optics); 140.3490)distributed feedback lasers); 300.1030 (absorption spectroscopy); 300.6260 (diode laser spectroscopy)

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1. Introduction

High-power single frequency diode lasers emitting in the wavelength region around 894 nm are of particular interest for applications in absorption spectroscopy of the caesium D1 line, trace gas detection of H_2O and HF and atomic clocks. These applications require a stable lasing wavelength with small spectral line width and the possibility of a fine tuning of the wavelength. This can be realized, for example, with a usual Fabry-Perot laser diode placed together with a grating in an external cavity configuration. This requires, however, expensive mechanical and thermal stabilization measures [1-3]. Andalcar et al [2] reached an output power of 20mW with such a setup. Another possibility is the integration of a Bragg grating

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directly into the internal laser cavity, which results in so-called distributed Bragg reflector (DBR) or distributed feedback (DFB) lasers. Their fabrication requires additional technological efforts in comparison to simple Fabry-Perot laser diodes. The achievement of an output power of more than 100 mW in a single transversal mode or a small spectral line width of less than 1 MHz are additional challenges.

DBR lasers suffer from periodic nonlinearities in the light-current characteristics due to longitudinal mode hopping. In contrast, DFB lasers can operate in the same longitudinal mode over a large current range and exhibit a larger side mode suppression. We already achieved an output power of 500 mW with a 940 nm DFB laser having an integrated Bragg grating [4]. Commercially a 894 nm DFB laser diode with a maximum output power of 30 mW is offered [5]. In this letter, a DFB laser operating in the 894 nm range is presented with an output power of up to 250 mW.

2. Device structure and fabrication procedure

DFB lasers can be fabricated either in single or in multiple growth steps. Single-growth DFB lasers use laterally coupled gratings. So far, operation at high output power has not been demonstrated. Additionally, laterally coupled DFB lasers favour the first order lateral mode and hence might exhibit mode instabilities or beam steering at high output power. The DFB laser presented here, were grown by low pressure metal-organic vapour phase epitaxy (MOVPE) in two steps similarly as described in Ref. [7]. The first step consisted of a n-GaAs buffer, n-AlGaAs cladding, a 1800 nm n-$Al_{0.45}Ga_{0.55}As$ waveguide, 7 nm InGaAs active quantum well (QW) embedded in GaAsP barrier layers, the first part of the p-$Al_{0.45}Ga_{0.55}As$ waveguide, and an InGaP/GaAs/InGaP layer sequence in which the second-order grating with a period of about 271 nm was formed by holographic photolithography and wet-chemical etching. After surface cleaning, in the second growth step the remainder of the p-AlGaAs waveguide layer, a p-AlGaAs cladding layer and a p-GaAs contact layer were grown. The waveguide layers form a super large optical cavity (SLOC) structure with a thickness of 3600 nm. Lateral optical confinement and p-contacting is provided by a 2.2 μm wide ridge-waveguide (RW) formed by reactive ion etching and deposition of SiN_x which is opened at the top of the RW before the p-metallization is performed. The cavity length L is 1.5 mm and the front and rear facets are coated with reflection coefficients of 0.05 and 0.95, respectively. The devices were mounted p-down on CuW and an AlN submount attached to a copper heatsink.

3. Results

Figure 1 shows the continuous-wave (cw) optical power versus injection current at a heat sink temperature T of 25 °C. The threshold current is 38 mA and the slope efficiency is 1 W/A. This high efficiency is the result of the small coupling coefficient κ of the Bragg grating. At a current of 300 mA an output power of 250 mW is achieved.

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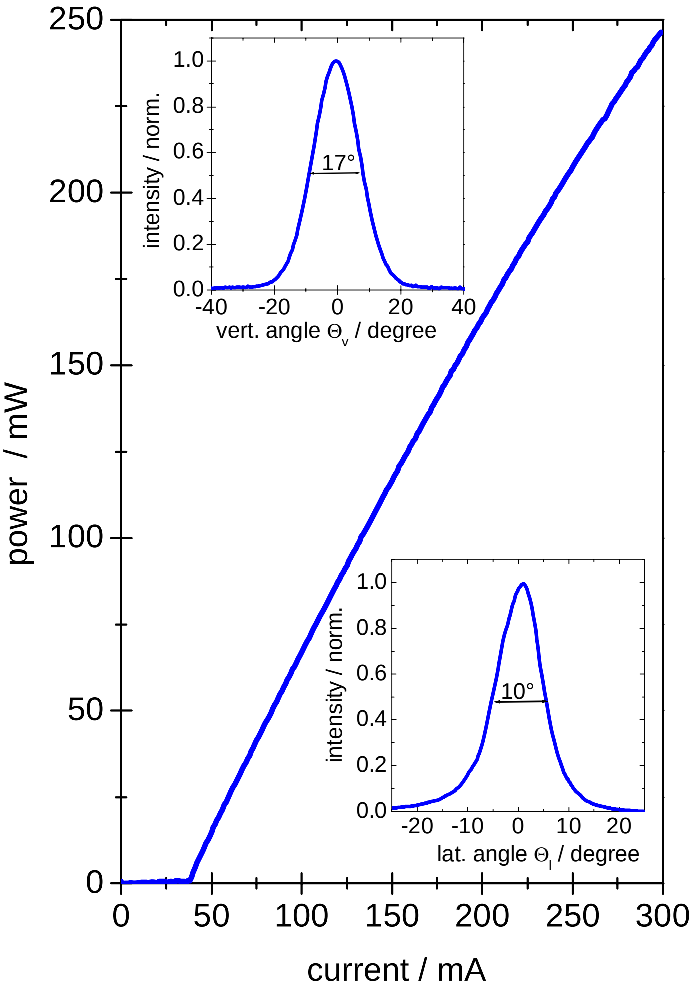

Fig. 1. cw light-current characteristic of a 894 nm DFB laser at 25 °C heat sink temperature. Inset: Normalised vertical and lateral far field profiles at 150 mW

The insets in Fig. 1 show the vertical and lateral far field profiles at 150 mW. Due to the SLOC structure a vertical far field profile with a full width at half maximum (FWHM) of 17 degree is achieved. The nearly Gaussian shape of the lateral far field profile with a FWHM of 10 degrees indicates fundamental lateral mode emission.

Optical spectra were measured with an optical spectrum analyzer Q8384 with a resolution of 10 pm. A mapping of the optical spectrum of the 894 nm DFB laser with a current step of 1 mA is shown in Fig. 2.

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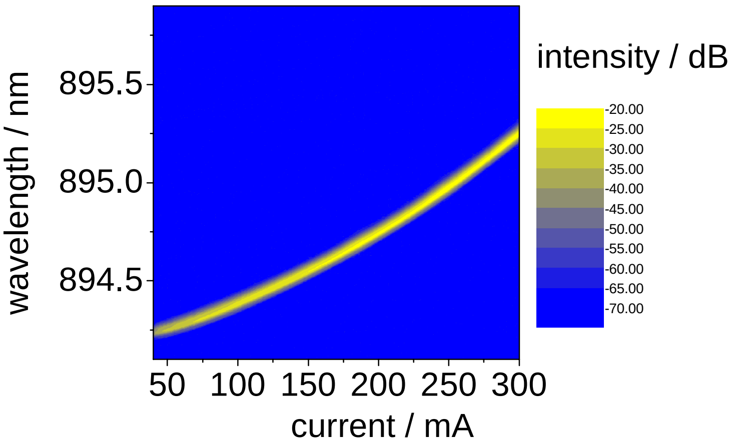

Fig. 2 Mapping of the optical spectrum of the developed DFB laser with a current step distance of 1 mA and a resolution of 10 pm

Stable single-longitudinal mode operation without any mode hopping can be observed within the investigated current range. The nonlinear increase of the lasing wavelength, as can be seen in Fig. 2, is mainly caused by a temperature induced change of the refractive indices due to Joule heating. From the wavelength shift of 1.1 nm between 40 mA and 300 mA a temperature rise of 20 K of the active zone can be deduced on the basis of a temperature coefficient of $\Delta\lambda/\Delta T = 0.055$ nm/K determined near threshold.Figure 3 shows the longitudinal mode spectrum at a current of 100 mA corresponding to a power of 60 mW. A side mode suppression ratio (SMSR) of around 49 dBm can be extracted.

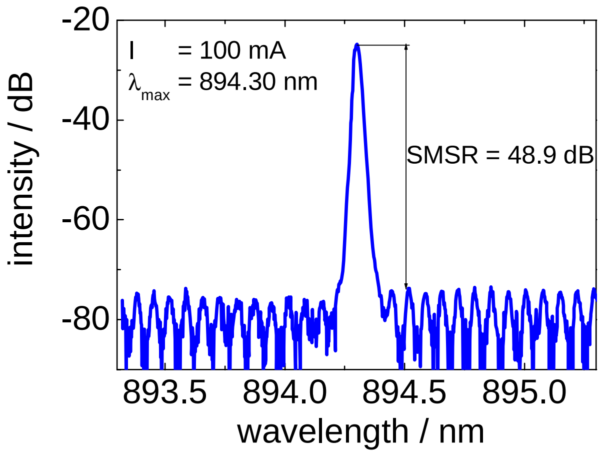

Fig. 3. longitudinal mode spectrum at 100 mA

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In order to determine the spectral line width of the lasing emission we used a heterodyne detection system as described in [6]. The emission of the two identical lasers from the same wafer was combined using a fiber coupler (Y-coupler) and the beatnode signal was detected with a photodiode (NFI-1434). For the measurements described herein a high frequency analyzer (HP71400C) with 20 kHz resolution bandwidth (RBW), 12.80 ms sweep time (SWT) and 3 kHz video band width (VBW) was used. Figure 4 shows the beatnode signal of the two lasers measured at a current of 100 mA corresponding to a power of 60 mW. The full width half maximum (FWHM) of the Lorentzian fit (red curve) is 360 kHz. Under the assumption, that the spectral line width of the two lasers is equal, a value of 180 kHz is determined.

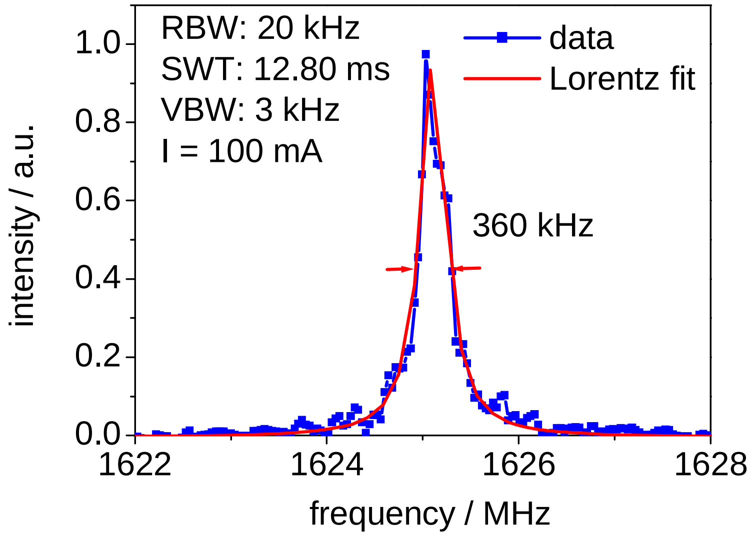

Fig. 4. Beat spectrum of two identical DFB lasers measured at 100 mA (~ 60 mW) recorded with a high frequency spectrum analyzer with 20kHz resolution bandwidth (RBW), a sweep time (SWT) of 12.8 ms and a video band width (VBW) of 3 kHz. The full width half maximum is 360 kHz.

These tunable high-power DFB lasers with a small line width emitting at a wavelength of about 894 nm are very attractive for Caesium spectroscopy, atomic clocks using the Caesium D_1 line (894.6 nm) and trace gas detection of H_2O and HF. In order to verify this, the output beam from the DFB laser was collimated and passed through a 80 mm long Caesium vapour cell and detected with a photodiode. The wavelength of the lasing emission is tuned by increasing the injection current in steps of 0.1 mA. The measured power-current characteristic at 25.5 °C is shown in Fig. 5.

Between 60 mA and 80 mA four absorption peaks can be seen corresponding to the hyperfine structure of the Caesium D1 line. The peaks correlate at 61.5 mA to the F3 – F4 transition, at 63.2 mA to the F3 – F3 transition, at 74.6 mA to the F4 – F4 transition and at 75.9 mA to the F4 – F3 transition [8]. The frequency distance between the absorption peaks at 61.5 mA and 74.6 mA is 9192.6 MHz and between 74.6 mA and 75.9 mA 1167.7 MHz. The change of the current is related to a corresponding change of the output power. However, the wavelength can be also tuned by a variation of the heatsink temperature. Combining both

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tuning parameters allows an adjustment of the output power to any desired value between 10 mW and 250 mW at the D1 absorption line.

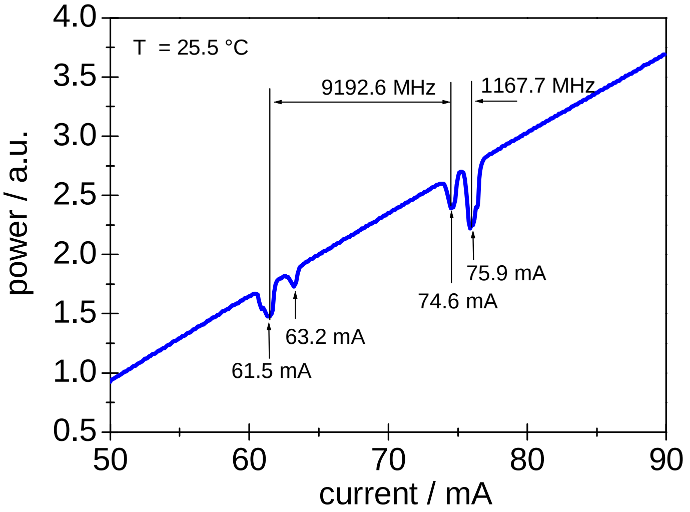

Fig. 4. Power-current characteristic at 25.5 °C in the current range 50-90 mA measured through a 80 mm long Caesium cell. Between 60 mA to 80 mA four absorption peaks can be seen corresponding to the hyperfine structure of the caesium D1 line.

4. Conclusions

We demonstrated single-mode single-frequency operation of a monolithic 894 nm RW DFB laser up to 250 mW cw output power. Owing to the stable lasing frequency and the large side mode suppression the diode laser is well suited for caesium D1 spectroscopy and application in atomic clocks. By changing the output power and / or the heatsink temperature the frequency can be tuned to reveal the hyperfine structure of the caesium D1 line.

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