Compact Tuneable External Cavity Diode Laser with Diffraction Limited 1 W optical power, and their application in BEC and CRDS

Sandra Stry, Lars Hildebrandt and Joachim Sacher

Sacher Lasertechnik^{Group}, Hannah Arendt Str. 3-7, 35037 Marburg, Germany

Phone: +49-6421-305-0, FAX: +49-6421-305299, email:sandra@sacher-laser.com
http://www.sacher.de

Introduction

The combination of high power, small linewidth and fast tuneability is essential for many fields in high resolution spectroscopy [1]. One example is the quickly developing field of laser atom trapping and cooling. Requirements for a laser system used in this field of applications are extensive: a mode-hop free tuning range of a few GHz, with a linewidth in the regime of 1 MHz with an output power of a few 100 mW. In the past, these requirements were fulfilled by master-slave configurations of an ECDL with an amplifying high power laserdiode [2,3]. In this case the ECDL was performing the low linewidth, which can be tuned for a few GHz without showing a mode-hop, but having only a few mW. This master-laser light is coupled into a high power slave-diode, which amplifies it to the required power. Suffering from this amplification, these master-slave configurations can hardly be aligned by non-experts and are cost consuming and bulky.

Results and Discussion

We report a new principle of using high power laserdiodes directly in an external cavity configuration to combine the high power of these diodes with the positive properties of the external cavity (low linewidth and high tuneability) [4]. In figure 1, the principle of the external cavity is shown.

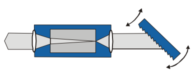

Figure 1: The principle of the external cavity in Littrow configuration. The first order of the grating is reflected back into the diode to build the resonator. The light is coupled out of the rear facet of the diode.

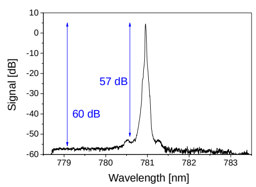

Figure 2: Spectrum of our ECDL with a side mode suppression of 57 dB and an output power of 1 W at 780 nm.

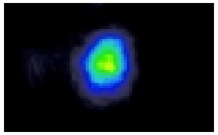

Figure 3: The beam profile.

The very compact design offers an output power of up to 800 mW and an excellent beam quality with a beam propagation factor of $M^2 < 1.2$ in both directions. The coupling efficiency for a single mode fibre exceeds 60 %. The centre wavelength of the 780 nm-diode can be preadjusted between 775 nm and 785 nm, other wavelength are also available. Mode-hop free tuning can be achieved via tuning of the grating with a piezoelectric actuator. This laser system operates single mode with a mode-hop free tuning range of up to 15 GHz without current modulation and a side mode suppression of better than 57 dB, as shown in figure 2. The beam profile is shown in figure 3. For high resolution spectroscopy or for laser cooling a small linewidth is essential. Therefore, we determined the linewidth of this laser system via a heterodyne experiment with a Littman laser system, which has a linewidth of below 500 kHz in 1 ms. It appears that the linewidth of the high power laser is 1 MHz in 1 ms sweep time and in the dimension of 2 MHz in 10 ms. These measurements are shown in figure 5. The determined power stability of our high power laser is better than 1.8 GHz in 30 h as shown in Figure 4.

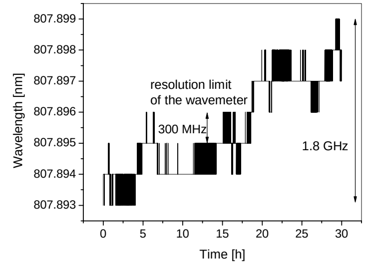

Figure 4: The wavelength of the free-running laser. The excellent thermal management of the high power ECDL ensures a drift below 2 GHz in 30 h measurement time.

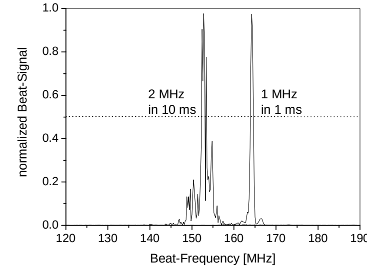

Figure 5: Linewidth in 1 ms and 10 ms sweep time. Resolution bandwidth: 100 kHz

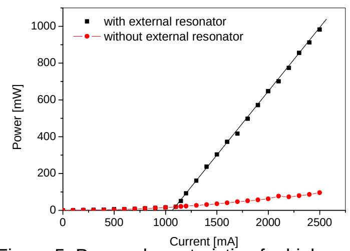

Figure 5: Power characteristic of a high power diode in an external cavity configuration. Dots: without external cavity; Squares: with external cavity.

We have measured the P-I curves for our high power diode laser after antireflection coating the inner facet of the diode with and without external resonator as shown in Fig. 3. Without an external resonator there is no threshold obtainable, with the external resonator the laser has a threshold of 1065 mA and a slope efficiency of 0.69 W/A after threshold with a maximum output power of 1000 mW.

The combination of high power and excellent tuneability in a compact setup offers the potential to use such a laser system in various applications. For example such a laser would be very suitable for difference frequency generation with a high conversion efficiency.

Applications

BEC

Demonstrating the suitability for neutral atom cooling we used this laser as a high power light source in the production of a BEC of over a million ^{87}Rb atoms. The laser was used as a tuneable, narrow-linewidth power-source for the magneto-optical trap. For this purpose it was locked with a variable frequency-offset relative to a master-laser, which itself was stabilised on a Doppler-free saturation dip in a rubidium vapour cell. The use of a frequency-offset lock simplifies the experimental apparatus considerably as it eliminates the use of acousto-optical modulators and injection locked lasers. Using about 130 mW of optical power delivered by a single mode fibre, we have been able to load within 8 s about 10^{10} atoms in a magneto-optical trap at a temperature of 40 mK. Half of these were transferred to a magnetic Ioffe-Pritchard trap and RF-evaporation cooled to below the transition temperature for Bose-Einstein condensation yielding a condensate of almost one million atoms. This clearly demonstrates the suitability of this laser system for high atom number cold atom experiments. Further reduction of the linewidth incorporating a lowest-noise current source is currently in progress in our group.

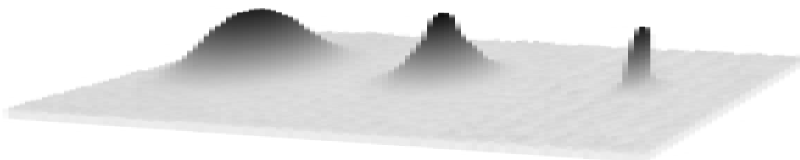

Figure 6: Formation of a BEC by forced RF-evaporation:
Left: Pure thermal cloud. Centre: Two component cloud. Right: Almost pure BEC.

CRDS

Demonstrating the suitability of this light source for high resolution spectroscopy, we tested our laser system in a ultra sensitive absorption technique called Cavity-Ring-Down-Spectroscopy (CRDS). Our ECDL is part of a MIR-light source which utilizes difference-frequency generation in a PPLN crystal pumped by two single-frequency solid state lasers. With the resulting laser light at 3.3µm we were able to perform a high resolution absorption measurement of 50 ppb Ethane, which is shown in figure 8. The combination of this light source with a suitable CRDS-set-up results in a portable trace-gas analyzer with high sensitivity and high specificity which is promising for various environmental and medical applications [6].

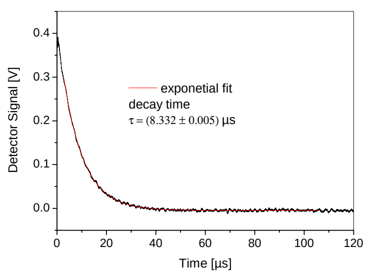

Figure 7: Experimental leak-out signal versus time, single shot. The decay time given by an exponential fit is 8.33 µs.

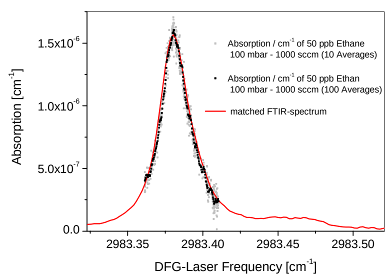

Figure 8: Absorption signal of 50 ppb Ethane measured with CDRS.

Summary

We reported of a new principle of using high power laserdiodes in an external cavity. The very compact design offers up to 800 mW output power and an excellent beam propagation factor of $M^2 < 1.2$ in both directions. The laser system has a small linewidth in the MHz regime and is tuneable without modehops for about 15 GHz. We have also demonstrated the high performance of the lasersystem with a BEC-experiment, as well as with a CRDS-experiment. This study is a proof of the high potential of the ECDL as a cost effective alternative to amplified laser systems. A photograph of the laser system is shown in figure 8.

Figure 8: Picture of the laser system and the driver.

Tiger λ

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Phone: +31-20-6081234, FAX: ++31-20-6684106
email: wvk@amolf.nl
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Phone: ++49-211-811 1372
FAX: ++49-211-811 3121
email: muertz@uni-duesseldorf.de