Compact Tuneable External Cavity Diode Laser (ECDL) with Diffraction Limited 500 mW, and their application in BEC and CRDS

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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 modehop 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 modehop, 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.

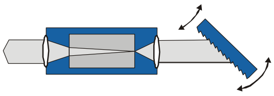

Figure 1: The principle of the external cavity in Littrow configuration. The first order of the grating is reflected back into the diode to build the resonator. The light is coupled out of the rear facet of the diode.

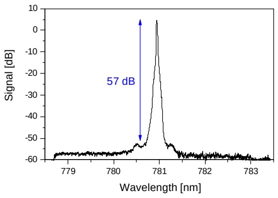

Figure 2: Spectrum of our ECDL with more than 55dB side mode suppression.

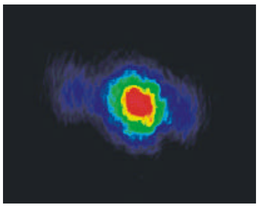

Figure 3: The beam profile.

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 center wavelength of the 780 nm-diode can be preadjusted between 775 nm and 785 nm, other wavelength are also available. Modehop free tuning can be achieved via tuning of the grating with a piezoelectric actuator. This laser system operates single mode with a modehop free tuning range of up to 15 GHz without current modulation and a side mode suppression of better than 55 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 12 MHz in 20 s. These measurements are shown in figure 4.

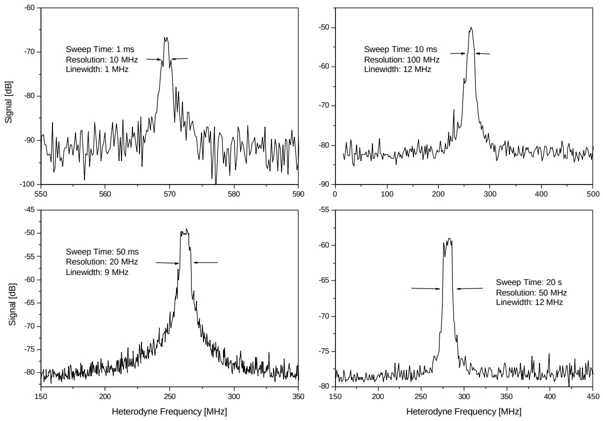

Figure 4: Linewidth of the laser system measured with a heterodyne experiment with a Littman laser system, which has a linewidth of below 500 kHz in 1 ms.

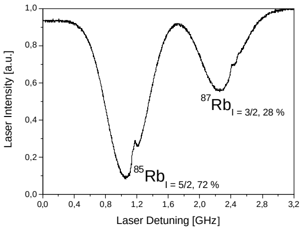

Figure 5: Absorption spectrum of Rubidium.

For Proofing of the tuning behaviour which is needed for high resolution spectroscopy, an absorption spectrum of Rubidium was measured by a simple absorption experiment [5]. While tuning the laser wavelength around 780 nm , the absorption lines of Rubidium can be easily seen by this simple setup as shown in fig. 5. Due to the small linewidth of this laser system, the hyperfine structure is resolved. The combination of high power with tuneability in a compact setup offers the potential that such a laser system can be used in various applications. For example such a laser should be most suitable for all kinds of frequency conversion. Furthermore the Rubidium measurement shows the high potential of this laser system for high resolution spectroscopy or for atom cooling to generate a Bose-Einstein condensate.

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.

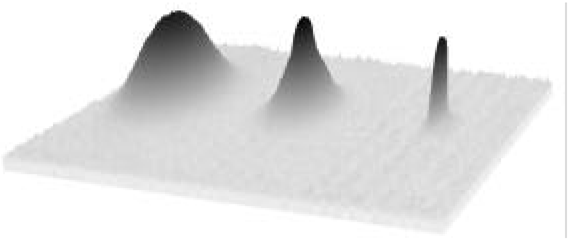

Figure 6: Formation of a BEC by forced RF-evaporation:
Left: Pure thermal cloud. Centre: Two component cloud.
Right: Almost pure BEC.

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 laserlight at 3.3µm we were able to perform a high resolution absorption measurement of 50 ppb Ethane, which is shown in figure 7. 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].

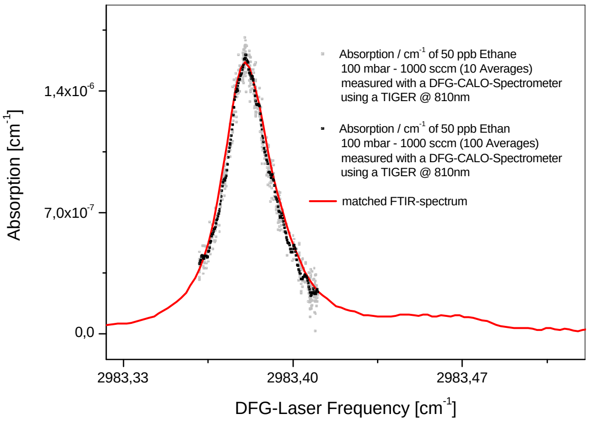

Figure 7: Absorption signal of 50 ppb Ethane measured with CDRS.

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.

References

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