Widely tunable ultra stable 1W two color THz laser source

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ABSTRACT

Coherent cw-THz-radiation allows access to new applications in the field of medicine, industrial process control, data communication and security applications. Major advantages of radiation in this spectral range are that it penetrates through e.g. plastics but is strongly reflected by metals and that molecules show distinct and distinguishable spectra so that a selective sensing of single species is possible. However, existing THz-sources are either very bulky or expensive. THz sources can require cryogenic temperatures or emit only low power radiation. Furthermore the setup is often very complicated and sensitive so that field measurements are not possible.

Generation of THz radiation based on the technology of frequency mixing requires laser radiation with a difference frequency in the order of 0.1-2 THz. Due to the low efficiency of frequency mixers, high optical power is required for pumping frequency mixers. Furthermore, the small efficiency requires short optical pulses for avoiding a high heat dissipation of the frequency mixers.

We investigated an ultra stable 1W two colour THz pump source for the generation of a THz beat signal with rapid single mode tuning over several THz. The system consist of a fixed wavelength and a motorized tuneable laser pump sources which are optical amplified within a pulse operation module. One laser is stabilized to an atomic reference while the other is locked to an optical cavity which can be tuned continuously.

This signal is pump source for a state of the art frequency mixer, which is typically realized as LT-GaAs crystal with an antenna design.

Keywords: THz, pulsed amplification, two colour laser, ECDL, Littman, frequency mixer

1. INTRODUCTION

Requirements for a laser system used in the field of high resolution terahertz generation and terahertz spectroscopy are demanding: Mode-hop free tuning range up to several THz, excellent frequency modulation features, long term stability, linewidth in the regime of 2-3 MHz, optical output power between 100 mW and 1500mW with an excellent beam quality as well as a small physical size are required. An approved concept for fulfilling all these requirements is the modified diode laser based master laser power amplifier (MOPA) configuration [1].

MOPA configurations with an external cavity diode laser in Littman/Metcalf as master laser and a tapered amplifier as power amplifier are well known in literature [2-4] and frequently used in research and development laboratories [5]. Most recently, distributed feedback (DFB) lasers and distributed Bragg reflector (DBR) lasers have become more readily available at non-telecom wavelength. Currently, DFB lasers are available from 760nm up to 2300nm with almost no gap in the spectral coverage. DFB lasers offer a significant advantage in comparison with external cavity diode lasers. The wavelength of each individual DFB laser can be tuned mode-hop free over a total tuning range of +/-1nm without any moving mechanic parts. The lack of mechanic parts qualifies DFB lasers especially for field deployable and space applications. In combination with tapered amplifiers, high optical power can be achieved up to 1.5Watt. Figure 1 provides a schematic view of a typical MOPA setup.

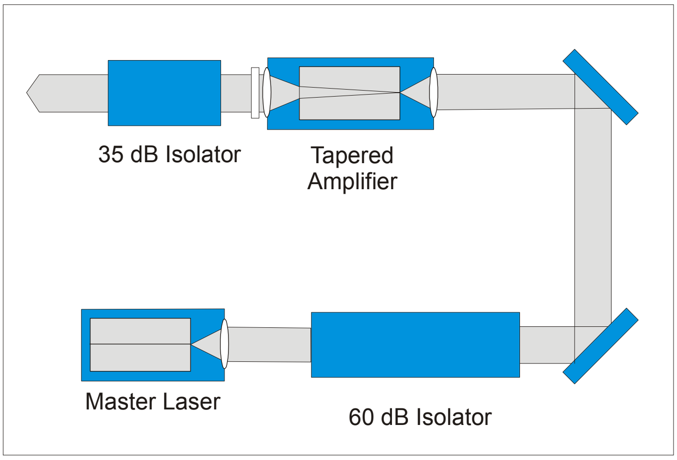

Fig. 1: Schematic view of the master oscillator power amplifier (MOPA) setup. The master laser is decoupled from the tapered amplifier via a 60dB optical isolator. The amplified laser light is collimated via a two stage lens arrangement. A 35dB optical isolator protects the out-coupling facet of the tapered amplifier.

Tapered amplifier systems with two different master lasers are currently very popular for generating terahertz beat frequencies with high optical power. A schematic description of this setup is provided in figure 2. With a difference frequency between the master lasers in the order of 1 – 2 THz, the amplified laser light is modulated with the according beat frequency.. This beat frequency is converted into THz radiation via a frequency mixer such as low temperature grown GaAs. (LT GaAs) or ErAs:GaAs [6]. The high application potential of such a setup causes a strong need for a detailed investigation of the physical properties of such a MOPA system. Features of special interest are linewidth of the individual DFB lasers, the high frequency modulation of the emission wavelength of the DFB lasers as well as the amplification behavior of the tapered amplifier under such operation conditions.

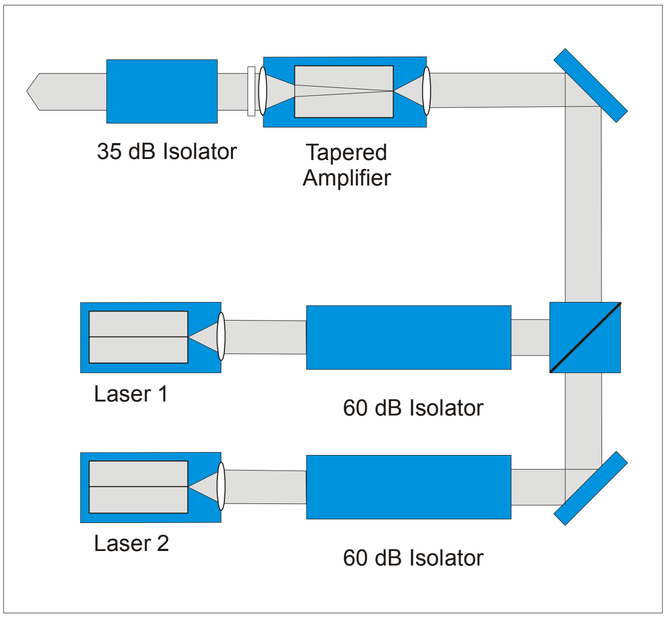

Fig. 2: Schematic view of a THz master oscillator power amplifier (THz MOPA) setup. Both master lasers are decoupled from the tapered amplifier via a 60dB optical isolator. The amplified laser light is collimated via a two stage lens arrangement. A 35dB optical isolator protects the out-coupling facet of the tapered amplifier

Most recently, the interest is not only focused on the primary physical features of such a system, but also on application oriented system features like long frequency stability of the generated coherent THz radiation .

2. RESULTS AND DISCUSSION

The presented report consists of tuning and stability investigations of a MOPA laser system designed for terahertz spectroscopy. Special features of interest are the modulation and tuning behavior of the individual master lasers. With these results, the locking scheme is applied to the terahertz MOPA system for achieving ultrastable performance. The present investigations have been performed within the carrier wavelength regime of 780nm. The results can be directly transferred to other wavelength within the 760nm – 1080nm wavelength regimes.

2.1 Spectral Behavior of the DFB master laser

The spectral behavior of a DFB laser is determined by the Bragg grating within the active area and the antireflection coating of the out-coupling fact for suppressing the Fabry Perot modes of the laser chip. A schematic description is provided within figure 3. Figure 4 shows an optical spectrum of a typical DFB laser. The spectral behavior is fully determined by the wavelength selection of the Bragg grating. The side-mode suppression is determined to be better than 45dB which is comparable to the results of external cavity diode lasers.

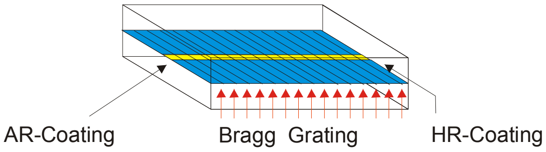

Fig. 3: Schematic view of a DFB laser. The DFB laser includes a Bragg grating with the laser chip as the wavelength selective element. The Fabry Perot modes of the laser chip are suppressed by the AR coating of the out-coupling facet of the laser chip.

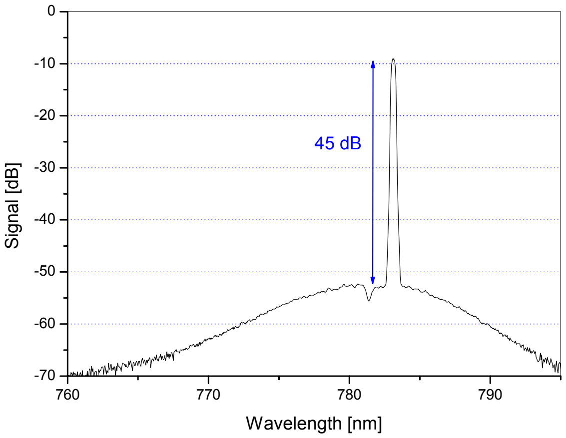

Fig. 4: Optical spectrum of a DFB laser. The wavelength is centered at 782.8nm. The side-mode suppression is 45dB. This measurement was performed by an optical spectrum analyzer.

2.2 Tuning Behavior of the DFB master laser

The exact emission wavelength of the DFB laser is determined by the optical length of the grating period of the Bragg grating within the laser chip. Since the optical length of the Bragg grating strongly depends on the refractive index within the active area, a strong dependence of the emission wavelength of the DFB laser on the temperature within the active area of the DFB laser is present. There are two ways of changing the temperature within the active area of the laser chip. Either the case temperature of the laser mount is changed, or the injection current of the laser diode is varied.

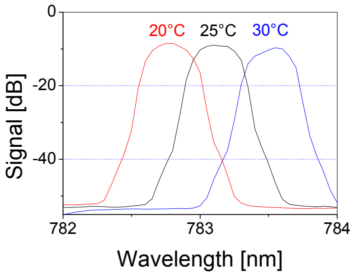

Fig. 5: Wavelength change of a DFB laser with three different temperature values of the laser mount at constant current condition

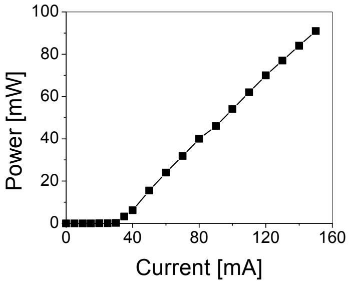

Fig. 6: Injection current – Laser Power – Characteristic, determined at 25°C

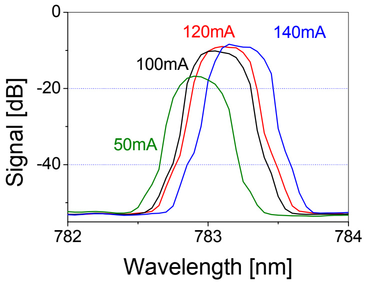

Fig. 7: Wavelength change of a DFB laser with four different injection current values at constant temperature condition

Figure 5 shows the wavelength dependence on the change of the case temperature of the DFB laser operated at a constant injection current of 120mA. The laser emission is tuned from 782.8nm at 20°C to 783.1nm at 25°C and 783.6nm at 30°C. These measurements result into a tuning rate of 24GHz / °C. The total temperature tuning range is mode-hop free. The tuning speed is limited by the thermal capacity of the laser mount.

Figure 6 provided the according Laser Power – Injection Current - Characteristic as reference. Figure 7 shows the results on the wavelength dependence on the injection current. The emission wavelength changes from 782.9nm at 50mA to 783.05nm at 100mA to 783.10nm at 120mA and to 783.15nm at 140mA operation current. These measurements result into a tuning rate of 1.6GHz/mA at 25°C. There is only one mode-hop of 30GHz directly above the laser threshold. Aside of this mode-hop, the total wavelength tuning is mode-hop free.

2.3 Spectral Behavior of Littman/Metcalf master laser

The total available tuning range of a laser diode in an external resonator is determined by its gain profile. With an antireflection coated front facet, the high-power ridge waveguide laser diode can be tuned via grating-tuning from 764 nm to 795 nm with an output power from the rear facet of more than 150 mW and a side mode suppression better than 50 dB. Fig. 8 shows the side mode suppression of the laser system which we could achieve at lowest, center and highest wavelength, analyzed with an optical grating spectrometer (ANDO AQ6315A). We measured that more than 95 % of the emitted power is within the laser line and only about 5 % is due to spontaneous emission background, which can be decreased further by using an optical filter.

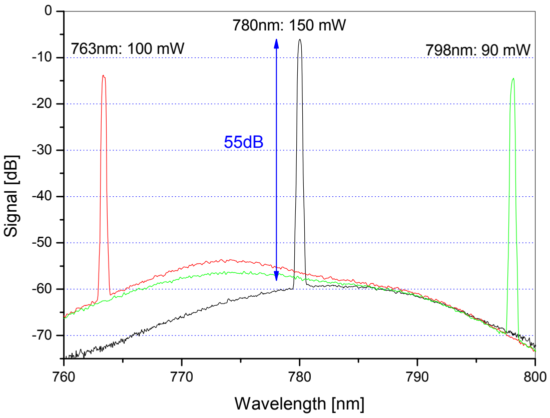

Fig. 8. Spectrum of our ECDL with a side mode suppression of 50 dB and an output power of 150mW for the Littman Laser with FP-Diode

2.4 Modulation Behavior

Both types of laser systems, DFB and external cavity can be effectively frequency modulated via a modulation of the injection current. The injection current modulation behavior is of significant importance for applying locking schemes as they are known in literature by the name of scientists Pond, Drever, and Hall or Hänsch and Coulliard. As pre-characterization of both types of laser systems, we investigated the modulation performance of both types of laser systems. Since the modulation was applied via two identical laser controllers and identical high frequency bias tees at both types of laser systems, the modulation performance for the DFB master laser and the external cavity master laser is comparable. The data shown in Fig. 9 and 10 are measured for the DFB master laser. The data for the external cavity master laser are identical.

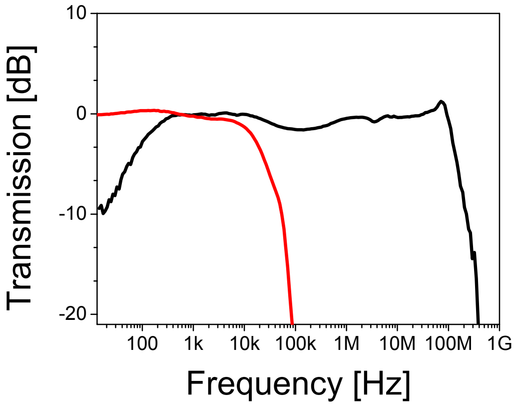

Fig. 9: Amplitude modulation performance of a DFB laser. The curve starting at the 0dB level shows frequency response of the modulation port of the PilotPC laser controller. The curve starting at the –10dB shows the frequency response of the bias tee.

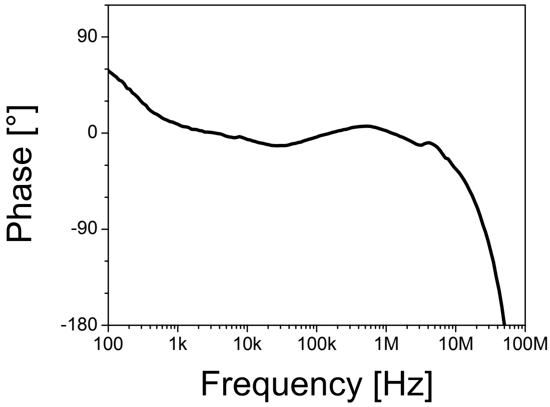

Fig. 10: Phase change of the modulation signal transmitted to the DFB laser via the bias tee plotted for the frequency range from 100Hz to 100MHz. .

The injection current of a DFB laser is modulated via two different modulation paths. Path 1 is the modulation port of the PilotPC laser controller. Path 2 is the bias tee directly attached to the DFB laser. The transmission function of both modulation paths is summarized in figure 9. The modulation path via the PilotPC laser controller ranges from DC to 100kHz. The modulation path via the bias tee ranges over six decades from 100Hz up to 100MHz. For locking the lasers to an external reference, the dependence of the transmitted phase of the modulation signal is of significant importance. The servo bandwidth of a locking setup is typically limited to +/-35°. This condition is fulfilled for the frequency range from 240Hz up to 10MHz.

Both types of laser systems, DFB and external cavity can be effectively frequency modulated via a modulation of the injection current. The injection current modulation behavior is of significant importance for applying frequency locking schemes.

2.5 Tapered Amplifier

In this section, the performance of the tapered amplifier under two-master-laser-conditions is discussed. A tapered amplifier is fully characterized by two different types of measurements. The first type of measurement is the output power of the tapered amplifier as a function of the injection current with a constant master laser power, as shown in figure 11. The second type of measurement is the saturated power curve which shows the effect of the variation of the master laser power with a constant injection current, as shown in figure 12.

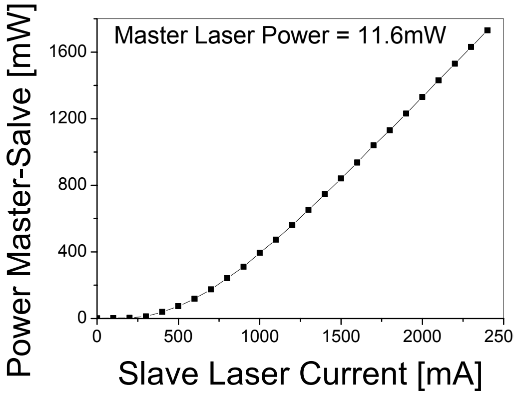

Fig. 11: TA Current – TA Power – Characteristic. The measurement is performed with a master laser power of 11.6mW.

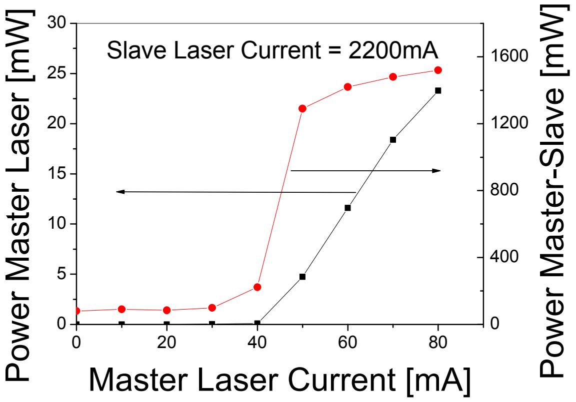

Fig. 12: Saturation curve of a tapered amplifier for a constant TA current of 2200mA. Plotted is the Laser Power - Injection Current – Characteristic of the master laser (left hand scale) and the saturation curve of the tapered amplifier.

The output power of the tapered amplifier exceeds 1.5Watt with a master laser power of 11.6mW at 780nm at an injection current of 2200mA. At this operation condition, no indication of a thermal saturation of the tapered amplifier chip is visible.

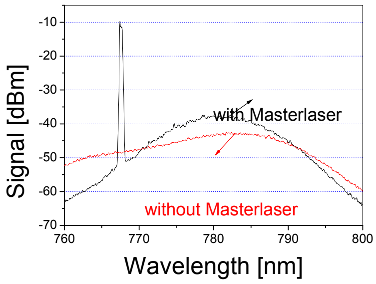

Fig. 13: Optical spectrum of the tapered amplifier with a master laser emitting at 767.5nm.

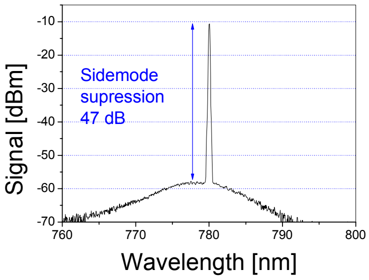

Fig. 14: Optical spectrum of the tapered amplifier with a master laser emitting at 780nm.

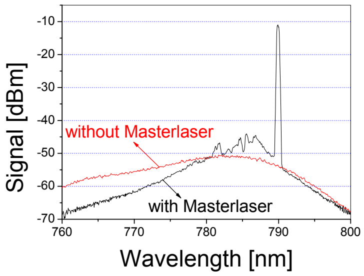

Fig. 15: Optical spectrum of the tapered amplifier with a master laser emitting at 790nm.

Figure 13, 14 and 15 show the coarse tuning behavior of the tapered amplifier with a variation of the wavelength of the master laser. The tapered amplifier is centered at a wavelength of 780nm and is tunable from 767.5nm up to 790nm. Within the wavelength regime of 775nm up to 788nm, optical power of more than 1.5Watt can be achieved.

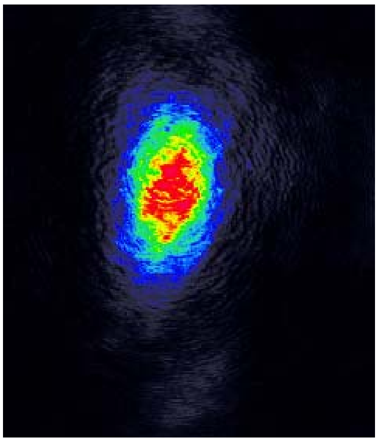

Fig. 16. The beam profile of the MOPA with an $M^2 < 1.2$.

The emission of the tapered amplifier is detected and analyzed via a CCD camera. The beam propagation parameters are detected via the Coherent ModeMaster. The M^2 values are 1.2 and 1.2 for parallel and perpendicular to the PN junction plane of the tapered amplifier. This excellent beam quality is best suited for coupling into optical fibers or optical waveguides. With a coupling efficiency above 60%, optical power of more than 900mW is available in fiber. This extraordinary focus ability is of significant advantage for the efficiency of the frequency mixer for terahertz generation.

2.6 Terahertz Beat Frequency Generation

The generation of laser light with a beat modulation between 0 THz and 2 THz has been performed by using a DFB and an external cavity laser in Littman/Metcalf configuration with a difference frequency between 0 THz and 2THz with an experimental setup as shown in figure 2. The laser beam of the DFB and the external cavity laser are superimposed via a beam splitter and coupled into a tapered amplifier.

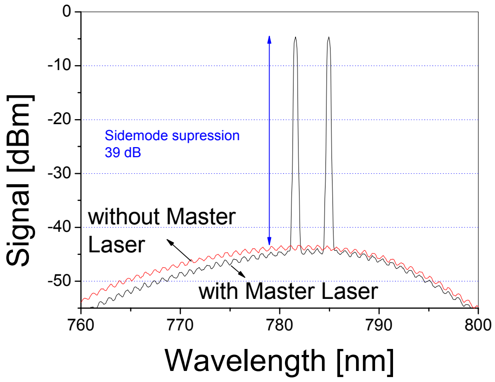

Fig. 17: Optical spectrum of a DFB MOPA laser system with two DFB master lasers.

Figure 17 shows the optical spectrum of DFB MOPA laser system with two DFB master lasers. The DFB master lasers are detuned relative to each other with a difference frequency of 2 THz. For generating THz radiation, it is still required to couple the laser emission of the MOPA to a frequency mixer. Typical frequency mixers are manufactured from low temperature GaAs (LT GaAs) or ErAs:GaAs and include an antenna design for optimizing the THz radiation. ErAs:GaAs photomixers are available from Dr. Elliot Brown at UCSB [6].

2.7 Ultra Stable Diode Laser Terahertz Setup

For technical applications, the stability of both master lasers relative to each other is of significant importance for the frequency stability of the terahertz radiation. Without a proper locking scheme, each master laser shows an individual drift which is independent from the other master laser. Therefore, locking technologies are essential for the generation of terahertz radiation via the frequency mixing approach.

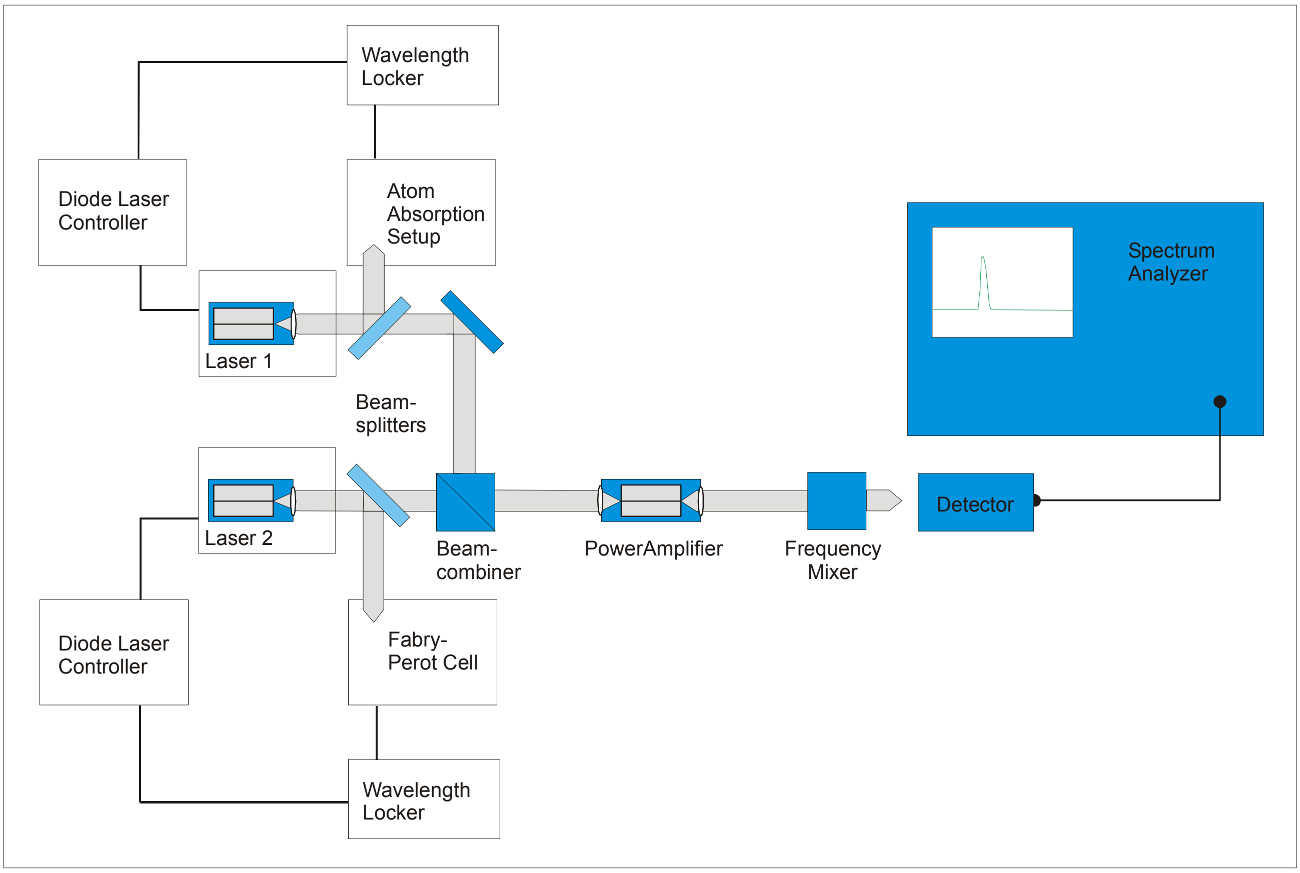

Fig. 18: Schematic layout of the ultra stable diode laser based terahertz laser setup.

Fig. 18 shows a technical realization of an ultra stable diode laser based terahertz laser setup. Master laser 1 is realized as a tunable DFB laser. Master laser 2 is realized a tunable external cavity diode lasers in Littman/Metcalf configuration. Master laser 1 is locked to a rubidium reference cell. Master laser 2 is locked to a temperature stabilized etalon cell. The beam of laser 1 and laser 2 are superimposed via a beam splitter cube and amplified via a tapered diode laser amplifier. The amplified signal is focused to a low-temperature gallium arsenide frequency mixer (LT-GaAs) for generating the terahertz radiation.

Laser 1 is locked to an atomic reference, laser 1 via the Pound Drever Hall locking scheme. The linewidth of the DFB laser is below 1MHz. Due to the atomic reference, the DFB master laser is absolutely stable.

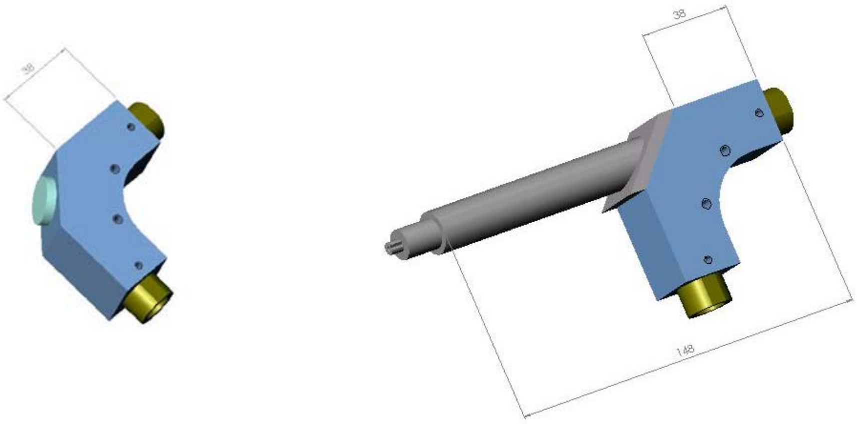

Fig. 19: Technical drawing of the 1GHz FSR etalon cell. The left hand side shows the etalon cell for free beam coupling. The right hand side shows the fiber coupled version of the etalon cell. The linewidth of the cell is 2MHz for p-polarized light and 30MHz for s-polarized laser light.

Laser 2 is locked to an etalon as technical reference. Fig. 19 shows the layout of the angled etalon cell. The 45° mirror is semi-transparent for coupling the light into the cell. The external cavity tunable diode laser is locked to the etalon cell via the Hänsch Gouillard Locking scheme. Therefore, the frequency stability of master laser 2 is determined by the frequency stability of the etalon cell.

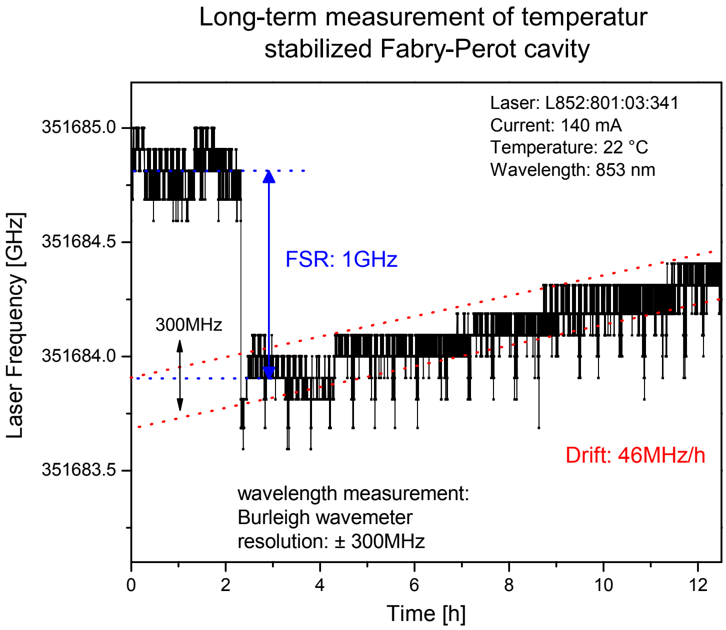

Fig. 20: Drift measurement of the temperature stabilized etalon cell.

Fig. 20 shows the overnight drift measurement of the etalon cell. We find a drift of 45MHz per hour, referenced by a wavemeter, manufactured by EXFO. A wavelength referencing while tuning the external cavity diode laser can be performed by counting the fringes of the etalon.

A further improvement of the stability of the terahertz laser system can be achieved by locking both master lasers one etalon cell.

3. CONCLUSION

We reported a detailed investigation of a terahertz MOPA system. Of special interest was the physical performance of each component of the system as well as the long term stability of the terahertz laser. A solution with a locking scheme was presented for achieving ultra stable system performance.

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