High-frequency tuning of high-powered DFB MOPA system with diffraction limited power up to 1.5W

Joachim Sacher, Richard Knispel, Sandra Stry
Sacher Lasertechnik GmbH, Hannah Arendt Str. 3-7, D-35037 Marburg, Germany
Phone: +49-6421-305-0, FAX: +49-6421-305-299, Email: jsacher1@earthlink.net

ABSTRACT

The combination of high power, small linewidth and fast tunability is essential for many fields in high resolution spectroscopy. External cavity laser diode systems are limited in tuning speed to several kHz by the resonance frequency of the mechanical assembly together with the actuator. We report on the application of a directly modulated DFB laser as master laser within a master laser power amplifier (MOPA) configuration. This DFB MOPA system combines fast frequency tuning up to more then 100kHz tuning speed, a tuning amplitude of more than 10GHz, a narrow linewidth below 5MHz with high output power of 1500mW and an almost Gaussian shaped beam quality (M^2<1.2). The coupling efficiency to optical waveguides as well as single mode fibers exceeds 60%. This concept can be realized within the wavelength regime between 730 and 1060nm. We approved this light source for high resolution spectroscopy by frequency locking to the saturated Rubidium absorption at 780nm. Applying two DFB lasers as master lasers of the MOPA configuration opens the choice to high frequency modulated THz radiation.

Keywords: external cavity laser, tunable laser, diode laser, Rubidium absorption, optical cooling and trapping, high power diode laser, tapered amplifier, master oscillator power amplifier, diffraction limited, terahertz generation

1. INTRODUCTION

Requirements for a laser system used in the field of high resolution spectroscopy and terahertz applications are demanding: Mode-hop free tuning range of a few GHz up to several THz, linewidth in the regime of 2-3 MHz and optical output power between 100 mW and 1500mW with an excellent beam quality are required. Such requirements can be fulfilled by different laser concepts. Two possible laser approaches are a tapered diode laser directly coupled to an external cavity in Littman/Metcalf or Littrow configuration [1], or a master laser power amplifier (MOPA) configuration [2-4]. Whereas the directly coupled tapered diode laser configuration offers a very compact rugged design, the MOPA configuration offers a large flexibility within the optical design of the laser system for various applications. This large amount of flexibility is the starting point of the presented investigations.

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 become more and more 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.

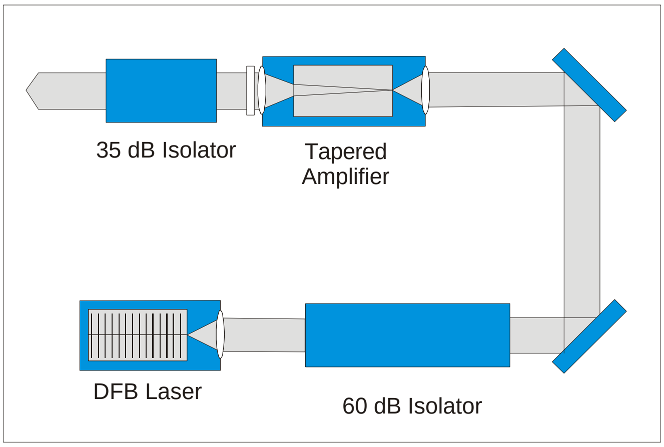

Fig. 1: Schematic view of the master oscillator power amplifier (MOPA) setup. The DFB master laser is decoupled from the tapered amplifier via a 60dB optical isolator. The amplified laser light is collimated via a two stage lens arrangement. A 35dB optical isolator protects the out-coupling facet of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

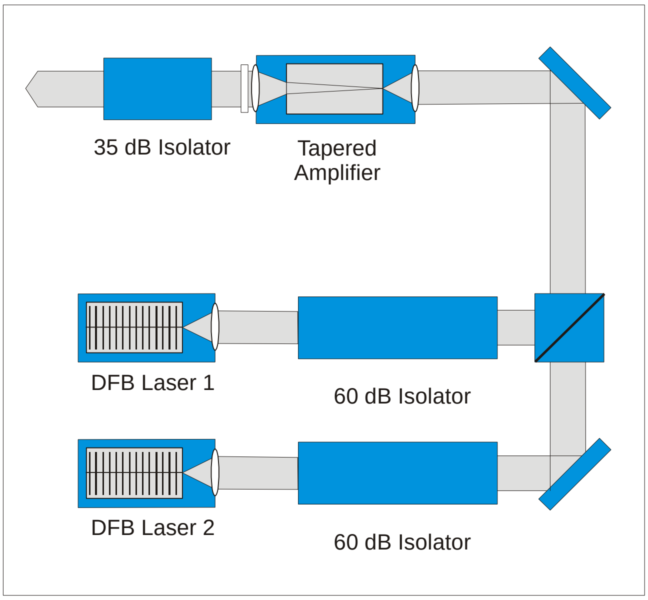

Fig. 2: Schematic view of a THz master oscillator power amplifier (THz MOPA) setup. Both DFB master lasers are decoupled from the tapered amplifier via a 60dB optical isolator. The amplified laser light is collimated via a two stage lens arrangement. A 35dB optical isolator protects the out-coupling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

2. RESULTS AND DISCUSSION

The presented report consists of different investigations of a MOPA laser system for covering all aspects of such a high power laser system. Special features of interest are the spectral behavior of the individual DFB lasers, the tuning behavior depending on laser temperature and injection current, the high frequency wavelength tuning with the laser injection current modulation as well as the amplification properties of the tapered amplifier under such optical pumping conditions. The present investigations have been performed within the wavelength regime of 780nm. The results can be directly transferred to other wavelength within the 760nm – 1080nm wavelength regimes.

2.1 Spectral Behavior

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.

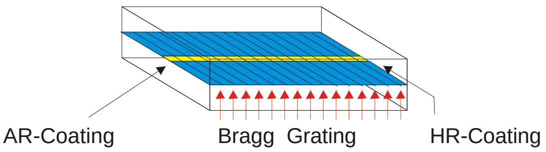

Fig. 3: Schematic view of a DFB laser. The DFB laser includes a Bragg grating with the laser chip as the wavelength selective element. The Fabry Perot modes of the laser chip are suppressed by the AR coating of the out-coupling facet of the laser chip.

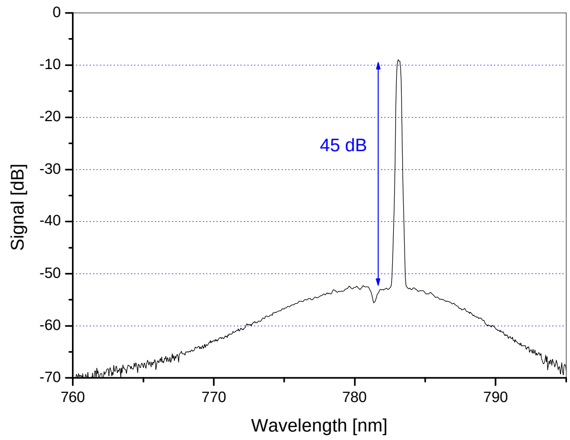

Fig. 4: Optical spectrum of a DFB laser. The wavelength is centered at 782.8nm. The side-mode suppression is 45dB. This measurement was performed by an optical spectrum analyzer.

2.2 Tuning Behavior

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.

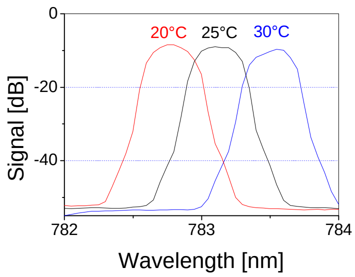

Fig. 5: Wavelength change of a DFB laser with three different temperature values of the laser mount at constant current condition

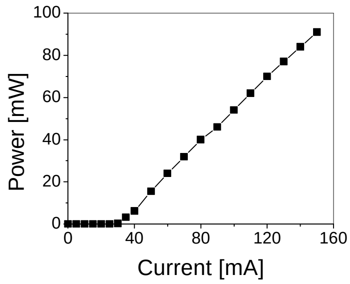

Fig. 6: Injection current – Laser Power – Characteristic, determined at 25°C

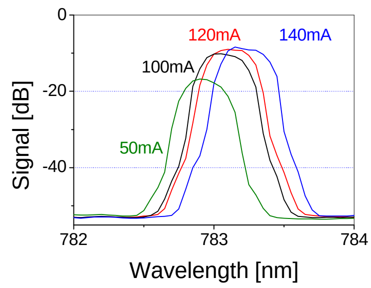

Fig. 7: Wavelength change of a DFB laser with four different injection current values at constant temperature condition

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 7 shows the results on the wavelength dependence on the injection current. Figure 6 provided the according Laser Power – Injection Current - Characteristic as reference. 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 Modulation Behavior

After these initial characterizations of the spectral features and the tuning behavior DFB lasers, all relevant information which are required for the high speed frequency modulation of DFB lasers are present. Since the wavelength tuning is mainly determined by the temperature within the active area of the DFB laser, a strong frequency dependence of the wavelength tuning is to be expected. Goal of these investigations is to determine the physical limits of the high frequency modulation of DFB lasers.

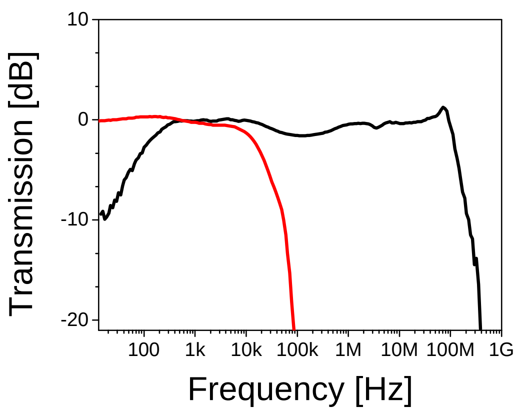

Fig. 8: Amplitude modulation performance of a DFB laser. The curve starting at the 0dB level shows frequency response of the modulation port of the PilotPC laser controller. The curve starting at the –10dB shows the frequency response of the bias tee.

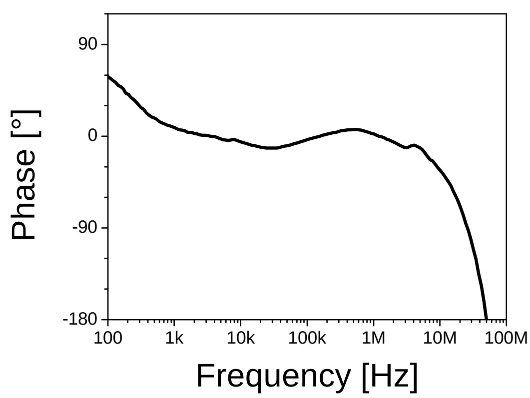

Fig. 9: Phase change of the modulation signal transmitted to the DFB laser via the bias tee plotted for the frequency range from 100Hz to 100MHz. .

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 8. The modulation path via the PilotPC laser controller ranges from DC to 10kHz. The modulation path via the bias tee ranges over six decades from 100Hz up to 100MHz. For optical cooling and trapping, 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.

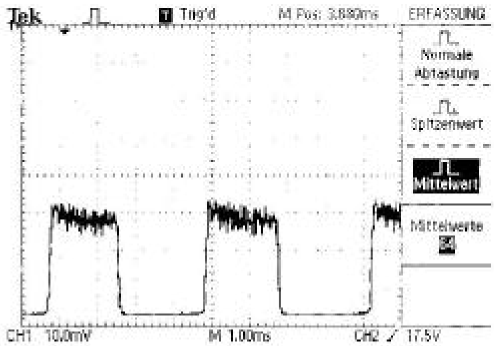

Fig. 10: Fabry Perot spectrum of a DFB laser under injection current modulation conditions. The modulation frequency is chosen to be 10kHz

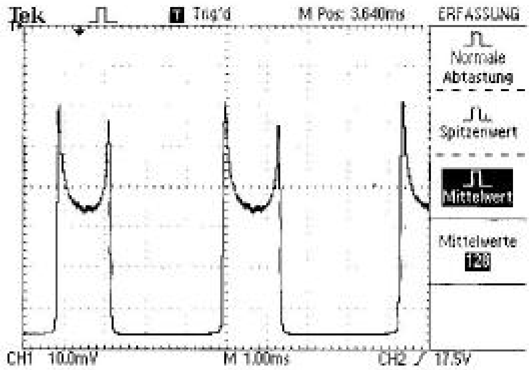

Fig. 11: Fabry Perot spectrum of a DFB laser under injection current modulation conditions. The modulation frequency is chosen to be 100kHz

After this initial characterization of the modulation path of the DFB laser, the investigation concentrates on the modulation performance of the DFB laser itself. The laser current of DFB laser is modulated with a triangular signal. The frequency change is monitored via a slow scanning Farby Perot interferometer. Since the scanning frequency of the Fabry Perot interferometer is slow in comparison to the 10 kHz triangular modulation of the injection current, the effect of the current modulation shows as a linewidth enhancement within the Fabry Perot spectra as seen in figure 10. The situation changes once the laser current modulation is changed to 100kHz. The shape of the Fabry Perot spectrum changes from close to rectangular to a double lobed trace. The explanation of this change is as follows: In the Fourier space, the triangular modulation signal shows significant higher harmonics at multiples of the fundamental modulation frequency. With higher modulation frequencies, the DFB laser is no longer able to transmit these higher harmonics. As a result, the modulation of the laser emission wavelength changes from triangular to sinusoidal. Since a sinusoidal curve has a higher duration at the points of return, the shape of the Fabry Perot spectrum changes from close to rectangular to double lobed. This result proofs a limitation of the thermal frequency modulation of the tested DFB lasers in the order of 100kHz.

The physical reason for this limitation can be found in the heat conductivity of the DFB laser chip itself. Whereas it is a fast process to generate heat within the active area by increasing the injection current of the DFB laser, the heat dissipation is limited by the heat conductivity of the laser chip as well as by the heat conductivity of the laser mount. An improvement of the modulation performance can be achieved by reducing the thermal capacity of the active area of the DFB laser.

For higher modulation frequencies above 100kHz, the physical mechanism of the wavelength modulation will change from thermal modulation to an electronic modulation of the refractive index of the laser chip. The effect of electronic modulation on the value of the refractive index of the laser is about six orders of magnitude below the thermal modulation effect. Furthermore, the direction of the effect is inverted. Whereas the thermal determined change of laser wavelength causes an increase of the laser emission wavelength, the electronic determined change of the laser wavelength causes a decrease of the laser emission wavelength.

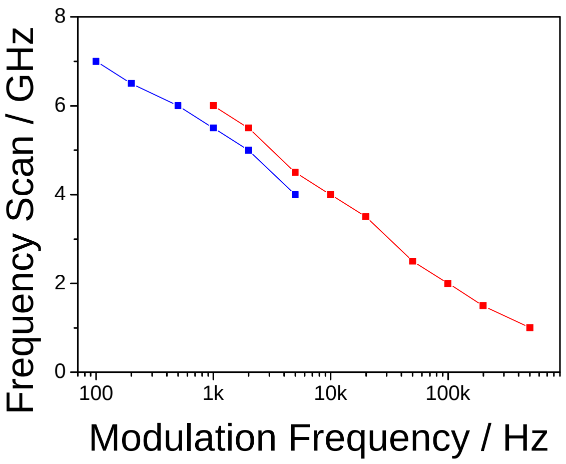

Fig. 12 Wavelength change of a DFB laser with constant modulation amplitude of 20mA and a variation of the modulation frequency. The left hand curve is performed with the modulation via the PilotPC laser controller. The right hand curve is performed via the bias tee.

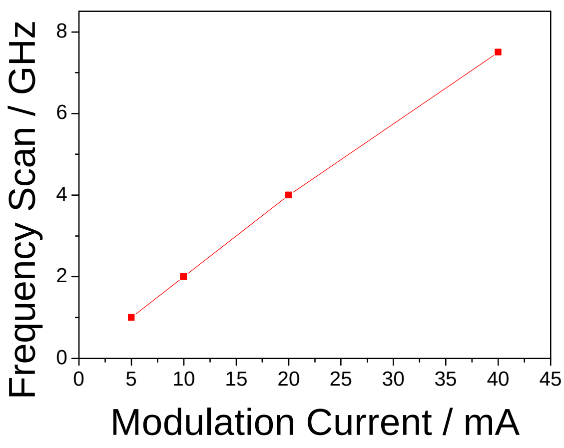

Fig. 13: Wavelength change of a DFB laser with constant modulation frequency of 10kHz and a variation of the modulation amplitude. The modulation is performed via the bias tee.

For most applications, the absolute frequency change which can be achieved is of significant importance. Therefore, the response function of the DFB laser is investigated for a constant modulation amplitude and a variation of the modulation frequency as well as for a constant modulation frequency and a variation of the modulation amplitude. Figure 12 summarizes the results on the variation of the modulation frequency. As expected from the previous results, an exponential decay of the wavelength modulation with increasing modulation frequency can be found. Figure 13 summarizes the results on the variation of the modulation amplitude. Over a wide range of injection current values, a linear dependence can be detected. With these results, the investigation of the modulation performance of DFB lasers did cover all relevant features for the desired applications.

2.4 Tapered Amplifier

In this section, the performance of the tapered amplifier and the transmission of the DFB master laser signals via the tapered amplifier are 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 14. 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 15.

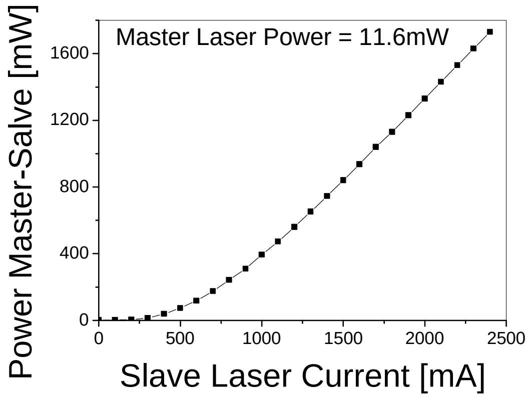

Fig. 14: TA Current – TA Power – Characteristic. The measurement is performed with a master laser power of 11.6mW.

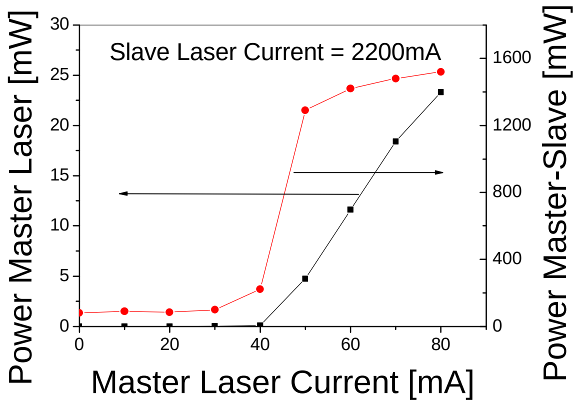

Fig. 15: Saturation curve of a tapered amplifier for a constant TA current of 2200mA. Plotted is the Laser Power - Injection Current – Characteristic of the master laser (left hand scale) and the saturation curve of the tapered amplifier.

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.

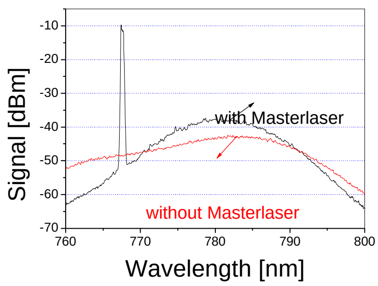

Fig. 16: Optical spectrum of the tapered amplifier with a master laser emitting at 767.5nm.

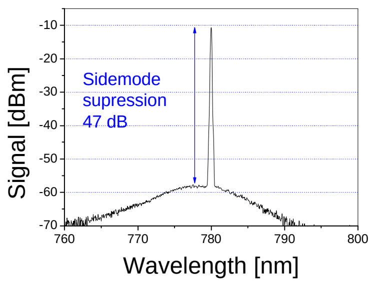

Fig. 17: Optical spectrum of the tapered amplifier with a master laser emitting at 780nm.

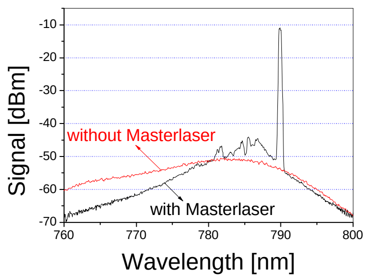

Fig. 18: Optical spectrum of the tapered amplifier with a master laser emitting at 790nm.

Figure 16, 17 and 18 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.

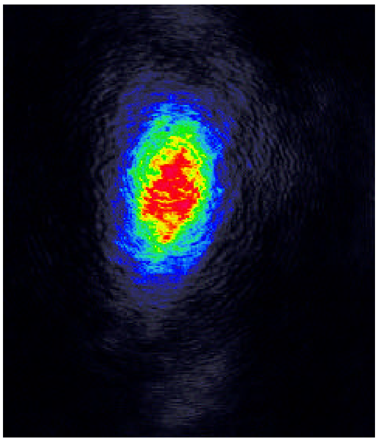

Fig. 19. The beam profile of the MOPA with an $M^2 < 1.2$.

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.

2.5 Modulation Performance of the Tapered Amplifier

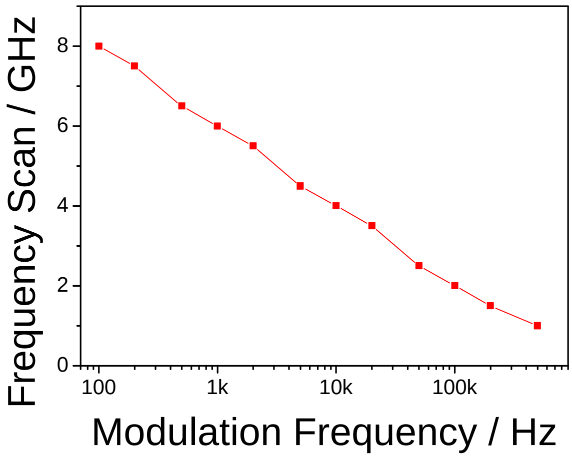

Fig. 20 Wavelength change of a MOPA system with DFB master laser with constant modulation amplitude of 20mA and a variation of the modulation frequency. Modulation is performed via the bias tee. of the DFB master laser. The total output power of the MOPA system during the measurement is above 1.5Watt.

In this section, the frequency modulation behavior of the tapered amplifier is investigated. The main question is whether the frequency modulation performance of the DFB master laser is transferred to the light emission of the tapered amplifier. The experiment shown in figure 10, 11, 12, and 13 have been repeated within the complete MOPA configuration. As a result, a curve comparable to figure 12 is reproduced and is shown in figure 20. The total output power of the MOPA system during the measurement is above 1.5Watt.

2.4 Terahertz beat Frequency Generation
The generation of laser light with a beat modulation between 0 THz and 2 THz can be performed by using two DFB lasers with a difference frequency between 0 THz and 2THz with an experimental setup as shown in figure 2. The laser beam of both DFB lasers are overlaid and coupled into a tapered amplifier.

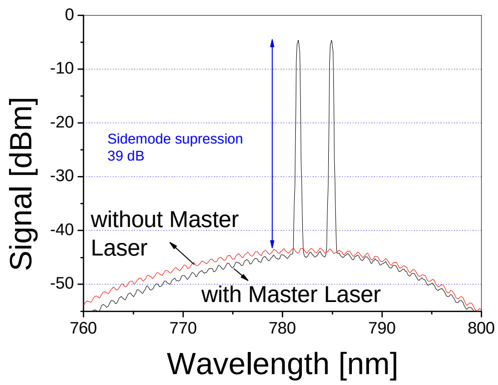

Fig. 21: Optical spectrum of a DFB MOPA laser system with two DFB master lasers.

Figure 21 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 have developed and characterized by Dr. Elliot Brown at UCSB [6].

3. CONCLUSION

We reported a detailed investigation of a DFB MOPA system. Of special interest was the high frequency modulation performance of the DFB MOPA system. Modulation frequencies of up to 100kHz with a modulation amplitude up to several GHz with an output power of 1.5Watt have been presented.. Of special interest is the possibility to use such a DFB MOPA system as laser source for the generation of THz radiation. A photograph of the laser system is shown in figure 22.

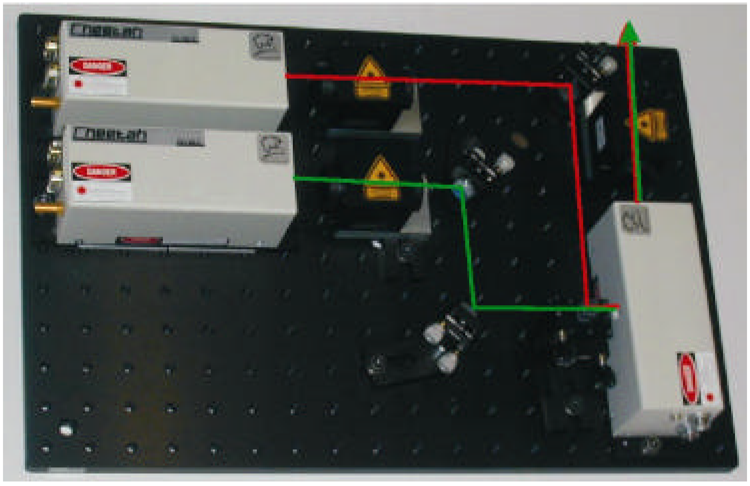

Fig. 22. Photograph of the THz DFB MOPA laser system

REFERENCES

1. S. Stry, L. Hildebrandt, J. Sacher, C. Buggle, M. Kemmann, W. von Klitzing, "*Compact tunable diode laser with diffraction limited 1W for atom cooling and trapping*", Photonics West 2004
2. J.N. Walpole, E. S. Kintzer, S.R. Chinn, C.A. Wang, L.J. Missaggia, „*High-power strained-layer INGaAs / AlGaAs tapered traveling wave amplifier.*", Appl. Phys. Lett. **61** (7), 1992, 740-742.
3. D. Wandt, M. Laschek, K. Przyklenk, A. Tünnermann, H. Welling, Optics Comm. **130**, 1996, 81.
4. D. Wandt, M. Laschek, F.v. Alvensleben, A. Tünnermann, H. Welling, „*Continuous tunable 0.5 W single-frequency diode laser source.*", Optics Comm. **148**, 1998, 261-264.
5. K.B. MacAdam, A. Steinbach and C. Wieman, *A narrow-band tunable diode laser system with grating feedback, and a saturated absorption spectrometer for Cs and Rb*, Am. J. Phys. **60**, 1098-1111, 1992
6. E. R. Brown, J. Bjarnason, T. L. J. Chan, D. C. Driscoll, M. Hanson, and A. C. Gossard, "*Room temperature, THz photomixing and its application to spectroscopic transmission through organic materials*", Rev. Sci. Instruments 75 (12), 2004, 5333-5342