1. Introduction

Usually, in a master-oscillator power-amplifier (MOPA) setup, edge-emitting single-mode lasers are used for generating the laser signal. The diffraction limited beam of several milliwatts is optically amplified to an output power of some watts by nearly preserving the beam quality. However the master laser must not necessarily be an edge emitter. Also surface-emitting lasers are interesting signal beam sources. Vertical cavity surface emitting lasers (VCSELs) are well established devices in optical data transmission, like for example in short distance high-speed optical data link applications. However, for some other applications they suffer from their low optical output power. Especially if operation in the fundamental mode is required, the optical power that can be provided is in the range of a few mW. One possibility to overcome that problem is the use of an edge-emitting power amplifier. For applications which require an even higher optical power in the fundamental mode, the VCSEL can be substituted by a diode-pumped semiconductor disk laser which can provide that [1]. Both types of semiconductor lasers have in common that the wavelength can be adjusted to an arbitrary value over a wide range. The proper choice of the different system parts leads to a tailor-made solution for many applications.

2. Experimental Results

2.1 Vertical-cavity surface-emitting master oscillator

For the first time we demonstrate the amplification of the laser emission of a VCSEL up to values significantly over 1 W. In Fig. 1, the according curve shows the measurement
Fig. 1: Output characteristics of a laser amplifier with 6° full taper angle and a length of 2.5 mm. The optical input power is provided by an optically pumped external-cavity semiconductor disk laser and coupled over a single-mode fiber with 5.9 μm core diameter and a Faraday isolator. The curve with 2.1 mW optical input power shows the measurement with a single-mode VCSEL. Here, the optical power is coupled into the amplifier by two 6.5 mm focal-length-collimator lens systems and a Faraday isolator.

where the 2.1 mW optical power in the collimated beam is boosted up to a value of 1.52 W at an amplifier current of 3.65 A. The coupling has been performed by two 6.5 mm focal length collimator lens systems and a Faraday isolator for optical feedback suppression. By turning the VCSEL around his optical axis, the polarization direction has been optimized. The 2.5 mm-long tapered laser amplifier was mounted on a temperature stabilized heat sink at 18°C with a copper-tungsten heat spreader.

2.2 External-cavity disk-laser master oscillator

The emission of an optically diode-pumped semiconductor disk laser with a fairly high output power of up to 42 mW in a 5.9 μm core diameter single-mode fiber is suitable to achieve good saturation of the tapered amplifier. This leads to an even better suppression of the amplified spontaneous emission. According to Fig. 1, at a current of 4.2 A the optical output power in the collimated beam was measured to be 2.7 W. Together with the comparatively broad focal beam width in the vertical direction, the high optical input
Fig. 2: Comparison of the sensitivity of coupling in the vertical direction for a circular beam (left) emitted from a single-mode fiber with 5.9 μm core diameter and an edge-emitting single-mode laser (right). The accuracy of positioning to achieve 50% of the maximum value is shown, as well as the tolerance for achieving 20% absolute coupling efficiency.

Fig. 3: Dependency of the coupling efficiency and the useful optical output power on the coupling lens position in vertical direction. The 22.1 mW optical emission from a 5.9 μm core-diameter single-mode fiber was coupled into the same amplifier as in Fig. 1. Please note the different scaling of the x-coordinate compared to Fig. 2.

power lowers the required accuracy in positioning for the optical coupling. Figure 2 illustrates the coupling issue in the most sensitive vertical direction. Depicted is the difference in coupling sensitivity between a circular beam (left) created by a single mode fiber and an elliptical beam emerging from an edge-emitting single mode laser (right). For a single mode fiber with an aspect ratio of 1:1, the focal diameter in the vertical direction is bigger than the one which is created by the edge emitter. As a result, the range where a moderate coupling efficiency of about 20% can be achieved is bigger for the fiber, whereas the maximum value of the efficiency that can be reached is bigger for the edge emitter. The method of measuring the coupling efficiency is described in detail in [2]. The amount of optical power that actually is coupled into the amplifier is the optical input power which can be measured multiplied the coupling efficiency. As a result, with a sufficiently high input power the coupling efficiency which is necessary for good saturation can be lowered. Figure 3 shows that with an input power of 22.1 mW emitted from the single-
mode fiber, even with an absolute coupling efficiency of 20\%, the optical output power can be stabilized at a high level. This is due to the good saturation of the amplifier. It has already been demonstrated that with a disk laser 170 mW optical power in a single-mode fiber is possible. In that case, the described effect gets more distinct.

3. Conclusion

It has been shown, that a MOPA combined with a VCSEL master oscillator can provide a relatively high optical power of 1.52 W. The promising properties of this system are its capabilities for free-space data transmission [3], the low feedback sensitivity of the master laser, and its low fabrication costs. The results with the disk laser exhibit the capacity of our laser amplifiers as multi-watt near diffraction-limited light sources. We also demonstrated that the circular laser beam, which is emitted from the single-mode fiber, leads to smaller requirements in positioning accuracy for the coupling optics also because the optical power emitted from the disk laser is sufficiently high.

References

