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Generation of second harmonic light with a wavelength of 560 nm in a compact module

Julian Hofmann*, Alexander Sahm, Wilfred John, Frank Bugge, Katrin Paschke

Ferdiand-Braun-Institut Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany

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ABSTRACT

We demonstrate a continuous wave 133 mW laser module at 560.5 nm on a 50 mm · 10 mm optical bench. The setup consists of a 1121 nm distributed Bragg reflector ridge waveguide laser and a MgO:$LiNbO_3$ quasi-phase matched ridge waveguide crystal, which are coupled by a grin lens, as well as two cylindrical lenses for beam collimation behind the crystal. A novel approach to ensure phase matching is used. The laser and the crystal are stabilized by the same heat sink and only the wavelength of the laser is tuned by heating the distributed Bragg reflector section of the laser. This reduces the influence of temperature variations on the module's performance enabling operation with output power variations <10% over a temperature range of 20 K. The size and robustness against temperature variations of this setup make it an interesting candidate for future biomedical applications.

1. Introduction

Compact and efficient laser sources around 561 nm, which are capable of direct modulation up to 10 MHz and show spectral as well as a spatial single mode operation, are demanded for several applications e.g. atomic spectroscopy [1], confocal microscopy [2], flow cytometry [3,4], excitation of mid-range red fluorescent proteins [5], photocoagulation in ophthalmology, medical skin treatments [6] and cancer phototherapy [7,8]. Laser sources at 561 nm based on diode-pumped solid state lasers [3], dye lasers [9] and fiber lasers [10] are already demonstrated as well as other systems using a near infrared laser and frequency-doubling. Most of these other systems are based on Nd:YAG lasers [11–16]. Also a system based on a Nd:KGW laser and sum-frequency mixing is demonstrated [17] for the generation of laser light at 561 nm. All these systems cannot be modulated directly which is needed for various biomedical applications. Most recently Fedorova et al. demonstrated generation of light at 561 nm with a quantum dot fiber Bragg-grating laser frequency-doubled in a periodically poled MgO:$LiNbO_3$ quasi-phase matched ridge waveguide crystal achieving an output power of 90 mW [18]. But this experiment was a table top experiment with a more complex lens system. Neither a stable output power over a large temperature range nor a long term stability could be demonstrated.

Additionally, most of the before mentioned laser systems are not micro integrated and the alignment is relatively complex and susceptible to temperature changes. In this letter we present an approach using a micro integrated setup which is simple to align, long time stable and capable of intensity modulation up to 10 MHz. The setup is based on a frequency doubled distributed Bragg reflector ridge waveguide laser (DBR-RW) emitting at 1121 nm [19]. The emitted light is directly coupled into a periodically poled MgO:$LiNbO_3$ quasi-phase matched ridge waveguide crystal [20] by a grin lens [21] for second harmonic generation. The whole setup is realized on a micro optical bench with a footprint of 50 mm·10 mm, which is clamped onto a copper holder during the measurements. A water-cooled heat sink thermalizes the whole system including the MgO:$LiNbO_3$ crystal. Thus, the phase matching between laser and crystal is not ensured by heating the crystal, but through a novel approach. In this system the wavelength of the laser is tuned by heating the distributed Bragg reflector section of the laser to ensure phase matching. In this paper we show adjustment tolerances of the grin lens and experimental tests of this device.

2. Setup and tolerances

The setup consists of only three main components. A DBR-RW laser, a grin lens and a MgO:$LiNbO_3$ quasi-phase matched ridge waveguide crystal assembled on a micro optical bench as shown in Fig. 1. Behind the crystal a pair of cylindrical lenses collimates the beam.

The used DBR-RW laser has a central wavelength of 1121 nm at 25 °C. We chose a vertical layer design of the laser with a 4.8 μm AlGaAs waveguide in order to reduce the divergence angle to 15 °

* Corresponding author.
E-mail address: julian.hofmann@fbh-berlin.de (J. Hofmann).

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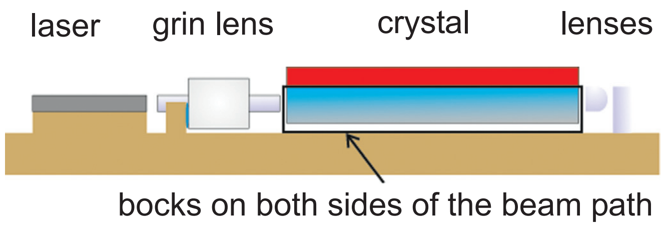

Fig. 1. Schematic of the setup: on the left side the laser is mounted with its submount onto the micro optical bench. Near the laser on its right site the grin lens is placed. It is fixed in a lens holder which is glued to two blocks on the micro optical bench. The next component is the crystal. Its top-side is glued to a Cu-holder. The holder again is glued to two bocks in the micro optical bench, which are outside the light path. The last component are a set of cylindrical lenses which collimate the beam behind the crystal.

at full width at half maximum (FWHM) and a 4 μm wide ridge for lateral index guiding (ridge waveguide). The active region consisting of a double InGaAs quantum well is embedded asymmetrically (closer to the p-side of the laser) into the waveguide to keep the series resistance low. The laser has a total length of 4 mm which is separated into a 1 mm long Bragg grating section and a 3 mm long gain section. The partly reflective front facet (R_{front} = 10%) and the Bragg grating define the laser resonator. The rear facet is anti-reflective coated in order to suppress Fabry-Pérot resonator oscillation. The Bragg grating section can be heated by a resistive heater in order to tune the wavelength of the emitted radiation. The laser is the first element, which is placed on the micro optical bench during assembly. A schematic of the laser is shown in the inset of Fig. 3.

The next component is a periodically poled MgO:LiNbO$_3$ quasi-phase matched ridge waveguide crystal, which is Y-cut, for second harmonic generation. It has a length of 10 mm. The height of the waveguide is 4 μm and the width is 6 μm. Its front and rear facet are anti-reflective coated and polished under an angle of 6° in order to minimize back-reflections onto the laser. The top of the crystal is fixed to a Cu-holder, which minimizes distortion due to heating. Thus, the setup can be used over a wide temperature range. The Cu-holder again is glued to AlN bocks on each side of the optical bench (outside the optical path). The crystal with its holder is the second component, which is placed onto the micro optical bench during the assembly. The distance between the ridge waveguide of the crystal and the laser needs to be carefully adjusted, which depends on the length and working distance of the grin lens. Small deviations in the range of a few microns already induce a considerable decrease of the coupling efficiency.

The used grin lens has a length of about 4 mm, a diameter of 1 mm and a working distance of 200 μm on both sides. It is fixed in a lens holder consisting of a square glass block. The holder is glued in turn to two blocks on the micro optical bench with a minimal gap of only a few microns (see Fig. 1). This way the shrinking of the adhesive during the curing process displaces the lens only minimally and only in the optical axis which is most insensitive to misalignment as shown later. The usage of only a single optical element between laser and crystal, which only needs adjustment in the axes perpendicular to the optical axis, allows a very simple and fast adjustment of the system.

The whole setup is temperature stabilized by a heat sink. No separate thermalization of the crystal and the laser is needed, as a novel approach is used to ensure phase matching between the laser and the crystal. Here, the wavelength of the laser is fine-tuned by heating the Bragg grating section of the laser to generate the phase matching. This is done by conducting a current I_g through a resistive heater near the grating (see inset Fig. 3). As the temperature dependent shift of the wavelength of the laser and of the crystal are almost identical, phase matching can be assured over a wide temperature range with only small adjustments of the current I_g.

The adjustment tolerances of the grin lens are estimated by varying the position of the lens in all directions before adhering and measuring the respective power of the generated second harmonic light. The results are shown in Fig. 2. Along the optical axis, the system is relatively insensitive to variations of the lens position. However, along both other axes the system is extremely sensitive to adjustment errors. A displacement of the lens of only 1.1 μm in lateral direction or 0.5 μm in vertical direction causes a decrease of the power of 50%. The already described adhering scheme takes advantage of these results as the lateral and vertical displacement during the shrinking of the adhesive is minimized.

3. Measurements and results

All measurements were performed in CW operation. The package was fixed to a heat sink. In all following measurements only the second harmonic light with a wavelength of 560.5 nm was examined. The fundamental light was guided to a beam dump by a low pass filter eliminating 99.9% of fundamental light.

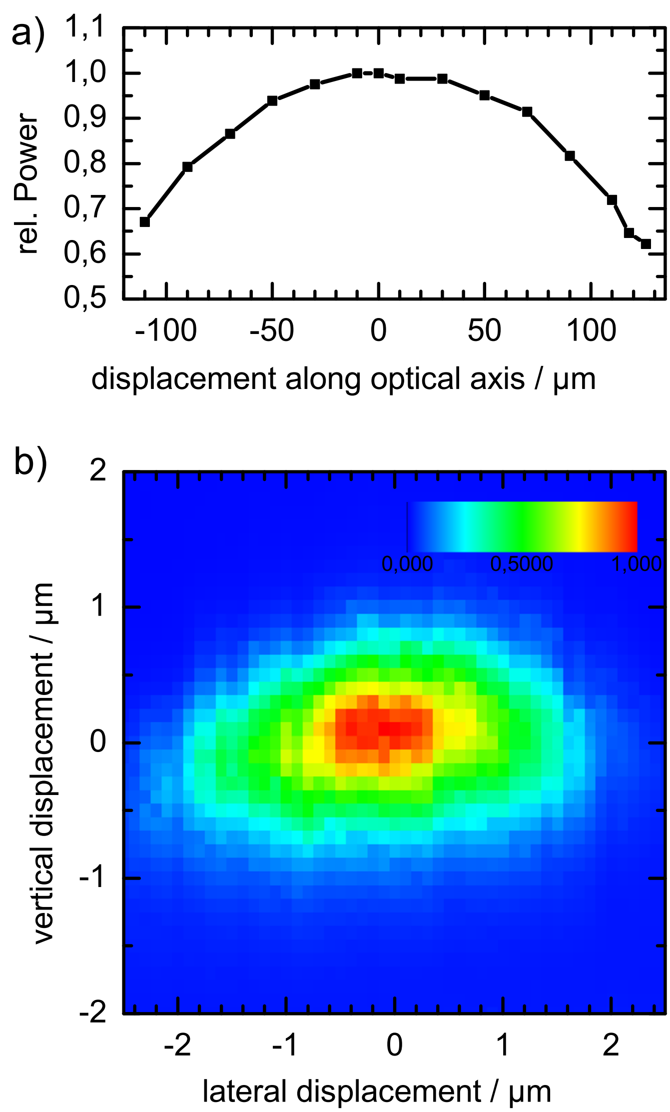

Fig. 2. Relative power of light at 560.5 nm against grin lens displacement: (a) displacement of the lens along the optical axis (b) lateral a vertical displacement of the lens.