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High power diode lasers converted to the visible

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***Abstract*— High power diode lasers have in recent years become available in many wavelength regions. However, some spectral regions are not well covered. In particular, the visible spectral range is lacking high power diode lasers with good spatial quality. In this paper, we highlight some of our recent results in nonlinear frequency conversion of high power near infrared diode lasers to the visible spectral region.**

***Index Terms*—Nonlinear frequency conversion, frequency doubling, second harmonic generation, sum frequency generation, tapered diode laser, nonlinear optics, diode laser.**

I. Introduction

HIGH power near infrared diode lasers have evolved rapidly in the recent years and lasers with good spatial and spectral quality have been demonstrated [1]. In the visible spectral region, the technology is not as mature and lasers with good spectral and spatial properties are limited to power levels below 1 W. Nonlinear frequency conversion is a technique to convert the wavelength of light to the desired spectral range. By using second harmonic generation (SHG) and sum frequency generation (SFG) it is possible to convert near infrared laser light to visible laser light [2]. We show results on frequency conversion of high power tapered diode lasers to generate light in the green-yellow spectral region.

II. Methods for Frequency Conversion

A. DBR Tapered Diode Lasers

For the experiments described here, we used distributed Bragg reflector (DBR) tapered diode lasers [1]. Such lasers consist of a ridge waveguide section split into a gain section and a passive DBR grating and a tapered section for reaching high output power. The two active sections are contacted separately and the lasers are mounted onto heatsinks for good thermal handling. The DBR tapered lasers used in this work emit up to 12 W output power with narrow spectral width and good beam quality, which is required for efficient nonlinear frequency conversion.

B. Methods for Nonlinear Frequency Conversion

The DBR tapered diode lasers are sensitive to optical feedback. Therefore, an optical isolator is typically used to avoid feedback to the diode lasers in the experiments. A typical setup for second harmonic generation is shown in Fig. 1.

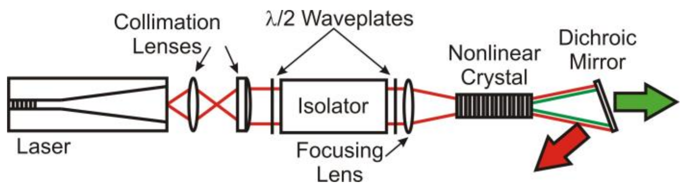

Fig. 1. Typical setup for single-pass SHG of a tapered diode laser.

The output from the tapered diode laser is collimated and focused into a nonlinear crystal. The remaining near infrared light is filtered away and the generated light is sent to the application. One way to increase the conversion efficiency is by using cascaded second harmonic generation. Here, both the visible and infrared light is refocused into more nonlinear crystals to enhance the conversion.

In order to reach spectral regions not accessible by SHG of available tapered diode lasers, SFG between two different lasers is an option. A typical setup is similar to Fig. 1 except that the two laser beams are combined before focusing into the nonlinear crystal.

III. Example Results on Frequency Conversion

A. Second Harmonic Generation

We will present two examples of SHG of DBR tapered diode lasers. Both examples employ cascaded SHG using two nonlinear crystals in series. In cascaded processes, it is important to ensure proper phase relations between different beams in order to have efficient conversion.

A DBR tapered laser emitting at 1030 nm was frequency doubled to 515 nm using one periodically poled lithium niobate (PPLN) crystal and one periodically poled lithium tantalate (PPLT) crystal [3]. The material choice is determined by the high nonlinearity of lithium niobate and the better power handling capabilities of lithium tantalate. The results of the experiments are summarized in Fig. 2. More than 3.5 W of narrow linewidth and diffraction limited output is achieved by

SHG of 9.3 W laser power corresponding to 38% conversion efficiency. All components were mounted in a compact housing and by use of feedback from a photodiode, a peak-peak power stability of better than ±0.4% over two hour operation was demonstrated.

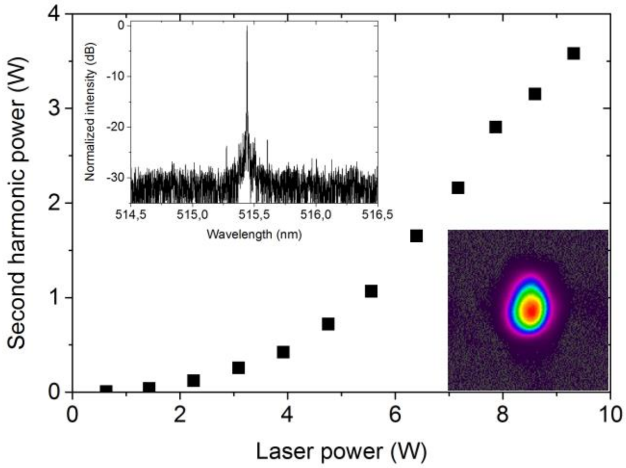

Fig. 2. Summary of experimental results of cascaded SHG of a 1030 nm DBR tapered laser showing output power, spectrum and beam profile.

In a similar experiment, a 1125 nm DBR tapered laser diode was used to generate light at 562 nm [4]. Up to 1.9 W of diffraction limited yellow light at 562 nm was generated from 5.8 W of power at 1125 nm. Excellent power stability was demonstrated over 250 hours of operation. One major advantage of single pass SHG compared to intracavity SHG used in many solid-state lasers is the limited influence of thermal variations. It was demonstrated that more than 30 K temperature variations to the base plate only resulted in minor variations in the SH output power even without active stabilization. Furthermore, the ability to modulate the SH output was demonstrated by modulation of the current to the ridge section only.

B. *Sum Frequency Generation*

Combination of two lasers enhances the power available for frequency conversion and enables access to wavelength regions inaccessible by SHG of available diode lasers.

This approach was demonstrated by combining the output from two DBR tapered diode lasers emitting at 978 nm and 1063 nm, respectively. The combined output was used for SFG in a single PPLN crystal and 1.7 W of light at 509 nm was generated [5]. A picture of the 509 nm light exiting the crystal oven is shown in Fig. 3. The 509 nm output was used for pumping a Ti:sapphire laser emitting sub-20 fs pulses in mode-locked operation with an average power of 185 mW.

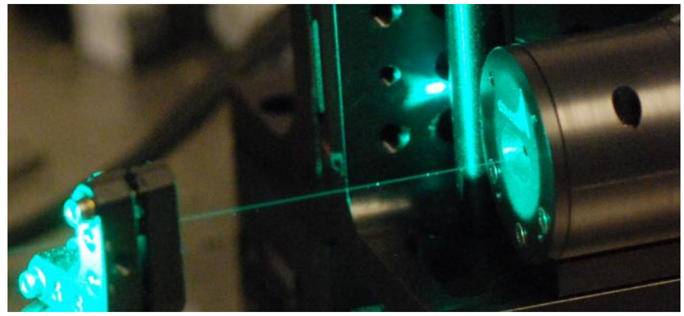

Fig. 3. 509 nm light generated by SFG between two DBR tapered diode lasers.

In another experiment, two DBR tapered diode lasers emitting at 1062 nm and 1063 nm, respectively, were spectrally combined and used for SFG in a cascade of a PPLN and a PPLT crystal [6]. 5.5 W of diffraction limited light was generated in this way, demonstrating 50% conversion of the central lobe of the output from the DBR tapered lasers. The importance of compensating for phase mismatch between the fundamental and SFG beams were investigated. Depending on the phase relations a cascade enhancement between 25% and 252% were achieved.

IV. Conclusion

Nonlinear frequency conversion can be used to convert the wavelength emitted from high power diode lasers to the spectral regions of interest. The efficiency can be high despite the single-pass approach typically employed, as long as the output from the diode lasers have high spectral and spatial quality. One major advantage of diode lasers is the flexibility in the choice of emission wavelength. This enables generation of light at virtually any desired wavelength.

V. Acknowledgment

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