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# High power single-mode 488 nm emission by second harmonic generation of coherently-combined high-brightness tapered lasers

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Frequency conversion of high-brightness DBR-tapered laser diodes (DBR-TPL) in the near-infrared (NIR) is an effective way to obtain high-power laser emission at wavelengths in the visible spectrum from 480 nm to 630 nm which are important for many biomedical applications [1]. Watt level output powers have been reached by second harmonic generation (SHG) in periodically-poled Lithium Niobate (PPLN) bulk crystals and spectral beam combining of DBR-TPLs and power scaling architectures for the SHG have been developed to increase the achievable output power [2]. Nevertheless, the ultimate limitation to power scaling in such architectures is the available diffraction limited power-content within one wavelength channel. This limit can be overcome by the development of simple coherent beam combining (CBC) architectures. We reported recently on a CBC-architecture for tapered amplifiers in master oscillator power amplifier configuration [3]. We present in this paper the application of this setup for single-pass SHG showing the benefits of CBC for efficient frequency conversion.

The CBC-architecture consists of a multiarm-interferometer and individual tapered amplifiers, with active phase control by feedback on the amplifier currents (Fig. 1). A narrow-linewidth (<20 pm, limited by OSA-resolution) single mode DFB laser diode emitting at  $\lambda = 976$  nm is used as the seed source. The three amplifiers and the detailed optical setup for beam combining are described in [3]. This architecture delivers up to 12.9 W in CW at a CBC-efficiency of >65%, which is limited by the beam quality of the amplifiers having a typical power content of 70% in the central lobe and  $M_{4\sigma}^2 \approx 3.5$  (in the slow axis). The power content in the central lobe of the combined beam increases due to constructive interference during CBC while the multimodal part of the beam is filtered out, resulting in significantly improved beam quality for CBC of 2 or 3 amplifiers respectively (> 85% power content in central lobe and  $M_{4\sigma}^2 < 2.5$  with three amplifiers). The setup was modified in order to be able to use the combined beam generated either by all three amplifiers, by two amplifiers or by only one amplifier which affects consequently the brightness level of the used NIR beam.

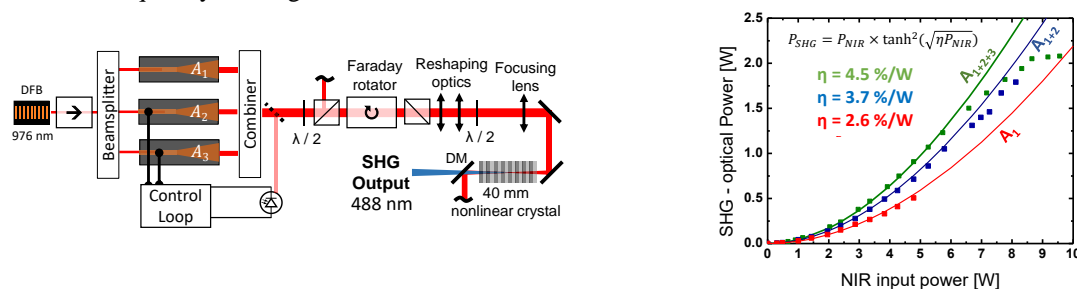


Fig. 1 Experimental Setup (left) and power conversion characteristics with pump depletion fit (right)

After reshaping optics, the beam is focused into a 40-mm-long MgO:PPLN crystal. The NIR and blue components are separated by a dichroic mirror (DM). The measured power conversion curves are shown in Fig. 1 (right). Experimental values for SHG power level follow the theoretical expectation taking pump depletion into account, of  $P_{SHG} \sim P_{NIR} \times \tanh^2(\sqrt{\eta P_{NIR}})$ , for NIR power levels  $P_{NIR} < 6$  W. The beam quality improvement by CBC resulted in an increased nonlinear conversion efficiency, which was measured as 2.6 %/W for an individual amplifier and 3.7 %/W for CBC of two and 4.6 %/W for CBC of three amplifiers, respectively. For higher input powers, thermal effects caused by blue light absorption in the nonlinear crystal limited the conversion efficiency considerably. The SHG power plateaued at about 2.1 W for 9 W NIR input power at close to diffraction limited beam quality ( $M_{4\sigma}^2 < 1.2$ ). The limitations due to thermal effects can be overcome by implementing a cascade setup of two conversion stages as described in [2].

These results demonstrate the importance of CBC architectures for diode laser applications when high brightness and narrow linewidth are required, as for non-linear conversion. The output power in the visible spectral range could be further scaled by combining more elements and by improved SHG architectures. The emission wavelength can also be varied as needed by modifying the design of the tapered lasers, following [1].

## References

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