High-peak-power Ho^{3+} and Tm^{3+}-doped fiber MOPA for mid-IR conversion

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Master-oscillator power amplifiers (MOPA) based on Tm^{3+} and Ho^{3+}-doped silica fibers are ideal pump sources for mid-IR nonlinear frequency conversion as they allow for optimized pump pulse shapes to increase the conversion efficiency in nonlinear converters, e.g. in $ZnGeP_2$ (ZGP) optical-parametric oscillators (OPO) [1]. This allows preserving the beam quality while scaling the average mid-IR output power and makes all-in fiber based MOPAs the most promising candidate for compact and robust OPO pump sources. We present a polarization-maintaining three-stage monolithic fiber MOPA seeded by a laser diode at 2047 nm and its application to pump a ZGP crystal in a linear OPO cavity.

The experimental setup of the MOPA is shown in figure 1. By modulation of the input current a linear pulse shape of the seed laser is created (50 ns pulse width, 50 kHz repetition rate), which allows the incorporation of saturation effects of the power amplifiers while inducing a frequency chirp along the pulse leading to an increased threshold for stimulated Brillouin scattering (SBS). The µW-level seed power is first amplified by a Ho^{3+}-doped-silica fiber, counter pumped by a thulium fiber laser emitting at 1993 nm [2]. Thulium-doped silica fibers are used in the second and third-stage amplifier pumped at 793 nm, which together increase the average signal output power to 19.8 W. By spectral filtering in between the second and third stage spectral degradation caused by modulation instabilities as well as the overall noise level in the output signal are reduced. The pulse peak power is limited by the onset of SBS detected at the backwards port of the tap coupler. A diffraction limited beam quality is obtained and a polarization extinction ratio (PER) >11 dB is measured. After passing an isolator, which induces a reduction of the 2047 nm output power down to 18.4 W, the output of the MOPA is launched into a linear ZGP OPO cavity. In figure 2, the combined signal and idler mid-IR output power is shown versus the launched pump power.

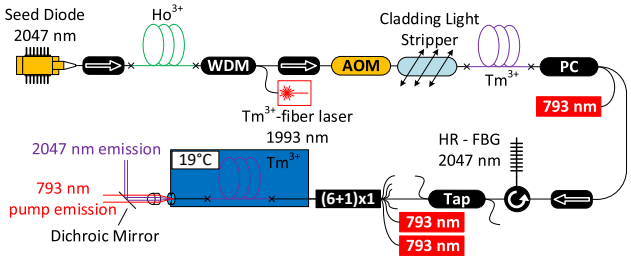

Figure 1: Experimental setup of the all-fiber MOPA.

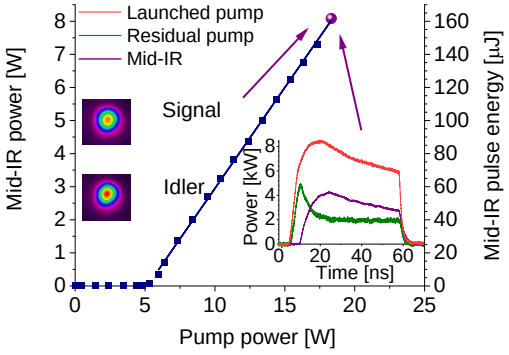

Figure 2: Combined mid-IR power versus launched pump power. The inset on the right shows the launched pump pulse (red) together with the residual pump (green) and the mid-IR pulse (purple). The insets on the left show the beam profile of signal and idler.

A maximum mid-IR output power of 8.1 W (162 µJ pulse energy) is reached at a differential OPO efficiency of 61 % and a total OPO conversion efficiency of 44 %. The launched pump pulse, the residual pump and the combined mid-IR pulse are shown in the right inset of figure 2. The beam quality factors for signal and idler are obtained by separately measuring the beam diameters around the focus spot. An M^2 value of 2.2 and 2.0 is found for signal and idler, respectively. The left insets show the beam profiles of signal and idler.

Further investigations will target the increase of average power and pulse energy by managing nonlinearities in the power stage of the pump laser.

References

[1] Holmen, L. G. and Fonnum, H., "Holmium-doped fiber amplifier for pumping a $ZnGeP_2$ optical parametric oscillator," Opt. Express 29(6), 8477–8489 (2021).
[2] Dominik Lorenz, Clément Romano, Marc Eichhorn, and Christelle Kieleck, "Nanosecond pulsed single-frequency two-stage holmium-doped fiber MOPA at 2054 nm and 2090 nm," Appl. Opt. 60, F27-F32 (2021)