Actively pulse shaped linearly polarized nanosecond hybrid Ho^{3+} and Tm^{3+}-doped silica fiber & Ho^{3+}:YAG MOPA at 2048 nm

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Abstract: Ho^{3+}:YAG amplifiers are able to efficiently scale pulse energy at wavelengths far shorter than the main emission peak. For 24 W input power at 2048 nm a signal output power of 81.6 W is reached, resulting in 5.3 dB gain.

Diode seeded master oscillator power amplifiers (MOPA) based on Tm^{3+} and Ho^{3+}-doped silica fibers are able to create arbitrary shaped nanosecond-pulses over a large wavelength span reaching beyond 2 µm which renders them ideal sources for applications dependent on narrow linewidth, exact wavelength adjustability, pulse shape and linear polarization. Nevertheless, the pulse energy / peak power of fiber based MOPAs is capped; the small mode field area compared to solid-state lasers limits the saturation energy and leads to low nonlinear thresholds which ultimately prevents the peak power scaling (degenerate four-wave mixing / modulation instabilities (MI), stimulated Brillouin scattering, stimulated Raman scattering). Solid state crystal lasers based on Ho^{3+}:YAG offer the possibility to further increase the peak power but are mainly used at the emission peaks at around 2090 nm [1] and 2121 nm [2]. In this work we demonstrate for the first time that Ho^{3+}:YAG crystal amplifiers can be used for efficient power and pulse energy scaling at 2048 nm, at a wavelength far shorter than the main Ho^{3+}:YAG emission peak, while still achieving a gain of 5.3 dB. Our approach offers a pathway to efficiently scale the pulse energy over a broad wavelength span ranging from 2015 nm up to 2125 nm, especially when linewidth, pulse shape, and peak power do matter.

The experimental setup is shown in figure 1. A laser diode emitting at 2048 nm is used as a seed, creating pulses at a repetition rate of 50 kHz. By current modulation a linear increasing pulse shape is achieved, also leading to a change of the charge carrier density and thereby the refractive index of the semiconductor material resulting in a 20 GHz frequency chirp along the pulse (280 pm 3 dB linewidth). The following first stage high gain amplifier based on a polarization-maintaining Ho^{3+}-doped silica fiber provides around 40 dB gain. The pulses get further amplified in a booster stage based on a Tm^{3+}-doped double-clad silica fiber. By filtering the signal, the share of output power accounting to the MI related sidebands is reduced, ensuring the spectral quality in the output spectrum. The final fiber amplifier stage is based on a Tm^{3+}-doped double-clad silica fiber pumped in the cladding by two 793nm diodes [3]. Subsequently, the 2048 nm emission is launched into a free space isolator to prevent back reflections from entering the fiber laser amplifier chain. The following attenuator and half-wave plate enable the adjustability of the power and the state of polarization. A Tm^{3+}-fiber laser emitting at 1908 nm is used to pump the Ho^{3+}:YAG crystal amplifier. The signal and pump beams are combined by a 55° dichroic polarizer and are focused down to a 400 µm beam waist at the first crystal interface, adjusted for matched beam diameter, position as well as angle of both signal and pump beam.

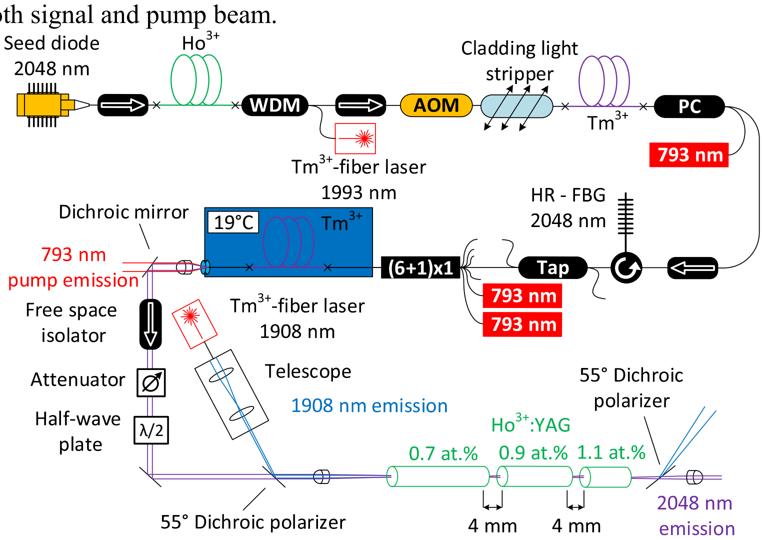

Figure 1: Setup of the linear polarized nanosecond pulsed hybrid Ho^{3+} and Tm^{3+}-doped silica fiber & Ho^{3+}:YAG MOPA at 2048 nm.

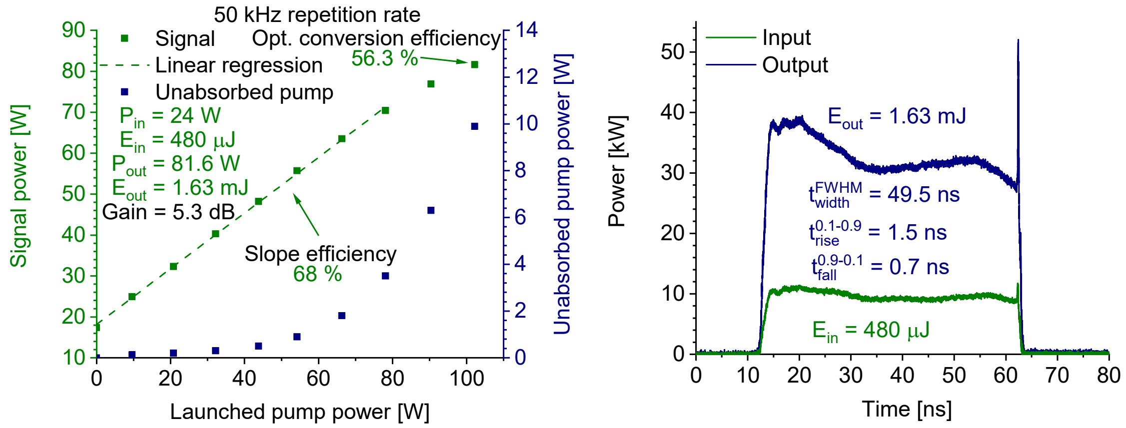

Figure 2 Left – Signal power and unabsorbed pump power versus the launched pump power of the Ho^{3+}:YAG amplifier. Right – Signal pulse shape at the input and the output of the Ho^{3+}:YAG amplifier.

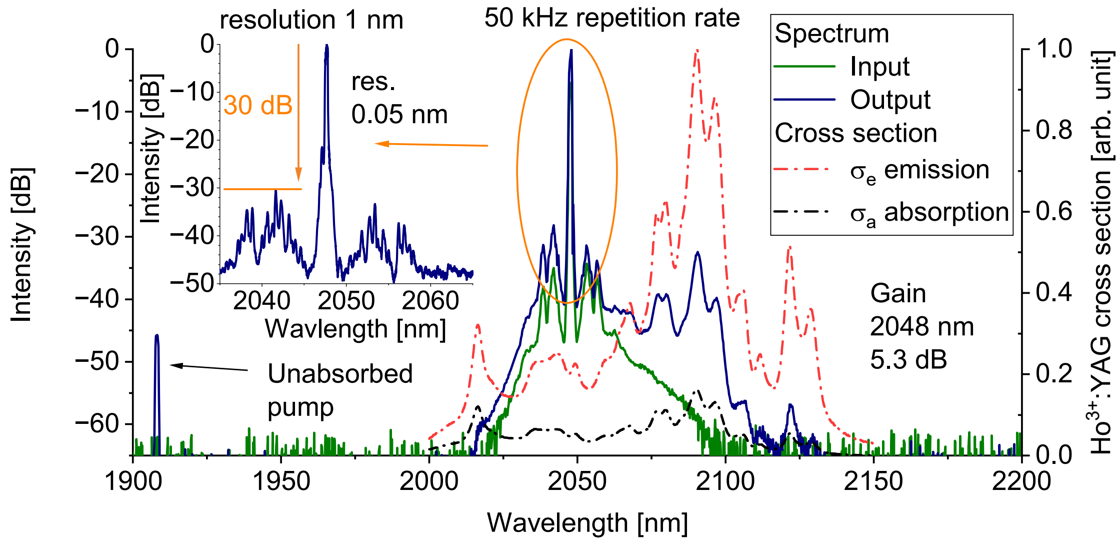

Figure 3 Signal spectrum at the input and the output of the Ho^{3+}:YAG amplifier (left axis). Emission and absorption cross section of Ho^{3+}:YAG given for the wavelength range from 2 µm up to 2.15 µm (right axis).

24 W (480 µJ) of linearly polarized signal power is launched; the beam quality factor of the launched signal is determined as $M_x^2 = 1.04$ and $M_y^2 = 1.05$, the pulse shape and the input spectrum are shown in figure 2 on the right and figure 3, respectively, both times illustrated in green. Subsequently, three Ho^{3+}:YAG crystals with a 4 mm diameter aperture are successively placed in a 4 mm distance. All of the crystals are mounted in a copper holder water cooled at 19° C. The Ho^{3+}:YAG crystals are doped with 0.7 at.%, 0.9 at.% and 1.1 at%, respectively. Finally the unabsorbed 1908 nm pump and the signal are separated by a 55° dichroic polarizer. The power curve of the amplifier is shown in figure 2 on the left. For a maximum of 102.2 W pump power at 1908 nm, a linearly polarized signal power of 81.6 W (1.63 mJ) is reached, resulting in a 5.3 dB gain. A slope efficiency of 68 % is observed until the amplifier starts to bleach and the unabsorbed pump power increases. The large saturation energy of the Ho^{3+}:YAG amplifier leads to a close to unaltered amplified pulse shape at the output, illustrated in figure 3. The output spectrum is shown in figure 4, illustrated in blue. The large Ho^{3+}:YAG emission cross section at 2090 nm leads to a gain of 25.8 dB at this specific wavelength. Nevertheless, these spectral features have no significant contribution to the overall output power. More than 98.2 % of the output power lies within 1 nm around the central signal peak and a 3 dB linewidth of 300 pm is found. Finally, a close to unaltered signal beam quality of $M_x^2 = 1.07$ and $M_y^2 = 1.06$ is obtained.

References

[1] Ben-Rui Zhao, Bao-Quan Yao, Chuan-Peng Qian, Gao-You Liu, Yi Chen, Rui-Xue Wang, Tong-Yu Dai, and Xiao-Ming Duan, "231 W dual-end-pumped Ho:YAG MOPA system and its application to a mid-infrared ZGP OPO," Opt. Lett. 43, 5989-5992 (2018)

[2] Marius Rupp, Katharina Goth, Marc Eichhorn, and Christelle Kieleck, "High average power Q-switched Ho^{3+}:YAG laser with a single-line emission at 2122 nm," Opt. Lett. 48, 5619-5622 (2023)

[3] Dominik Lorenz, Clément Romano, Dieter Panitzek, Patrick Forster, Julian Schneider, Jan Lautenschläger, Marc Eichhorn, Christelle Kieleck, "High repetition rate pulsed all-in-fiber thulium doped fiber MOPA for OPO pumping," Proc. SPIE PC12869, Nonlinear Frequency Generation and Conversion: Materials and Devices XXIII, PC1286909 (13 March 2024)