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Femtosecond pulse generation at 50 W average powers from an Yb:KYW-Yb:YAG planar-waveguide MOPA

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Abstract. An Yb:YAG planar-waveguide power amplifier seeded by an Yb:KYW master oscillator is reported. The system produced 700-fs pulses at 1032 nm at average output powers of 50 W and a frequency of 53 MHz.

1 Introduction

Advances in ultra-short pulse laser technology have generated many high power sources for industrial applications. Solid state master oscillator power amplifier (MOPA) configurations are a strong candidate for the next generation of high power sources. Currently the best choice for achieving higher powers with ultrashort pulse durations in the near-infrared is to utilise ytterbium-doped media such as Yb:YAG because of its favourable spectroscopic characteristics and the availability of high-power pump diode lasers at 840 - 980 nm. Yb-based planar-waveguide amplifiers have high gain and are known for their excellent thermal properties due to their large surface area suitable for multiple-pass amplification. Indeed, planar-waveguide technology has already been show to be power-scalable up to 16 kW [1]. The planar-waveguide configuration presented here has already been used as an oscillator generating 400 W with a slope efficiency of 78% [2].

The work presented here is motivated by the potential of ytterbium-based ultra-fast MOPA systems for applications in high-throughput precision materials processing. The MOPA was based on an Yb^{3+}:$KY(WO_4)_2$ (Yb:KYW) oscillator [3], a system which offers highly efficient generation of femtosecond pulses [4,5], and possesses sufficient tunability to allow its output wavelength to be exactly matched to the 1032-nm gain peak of Yb:YAG.

2 MOPA configuration

The Yb:KYW oscillator (Fig. 1) was pumped using a linearly polarized pump diode array (*Apollo C32-981-0*) generating 26 W of power with an M^2 of 16. The pump beam was focused into the Yb:KYW crystal to produce a spot radius of ~100 μm which matched the intracavity mode in the Yb:KYW gain crystal. The 10 mm-long Yb:KYW crystal was 1.5 at.% doped. The crystal was Brewster-Brewster cut and was oriented with the polarization of the pump parallel to the N_m optical axes of the crystal. The oscillator consisted of a modified asymmetric, astigmatically compensating z-fold cavity.

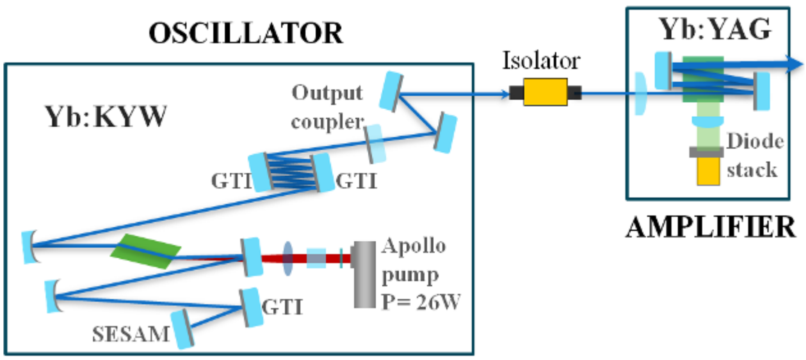

Fig. 1. Layout of the Yb:KYW oscillator and Yb:YAG planar-waveguide amplifier

Two curved mirrors of -500 mm radius of curvature were used compensate for astigmatism generated by the Brewster-cut crystal. At the end of the short arm of the cavity we inserted a SESAM (*BATOP GmbH*) of 1.5% absorbance to initiate and maintain modelocking. The opposite arm of the cavity was terminated by a 10% output coupler giving emission centred at 1036 nm. To optimise the laser oscillator output wavelength to match the absorption peak of the Yb:YAG amplifier, a 15% output coupler was used to shift the oscillation wavelength from 1036 nm to 1032 nm, making use of the non-saturated reabsorption losses in the Yb^{3+} quasi-three level gain system. This increase in loss forces the wavelength to shift to a region where the gain cross-section is larger so the same measure of net gain can be sustained [6]. For the Yb^{3+} gain system the laser is forced to operate at shorter wavelengths when the cavity loss is increased.

The cavity included Gires-Tournois interferometer (GTI) mirrors to compensate for the large positive group-delay dispersion (GDD) of the crystal. A mirror with a GDD of -800 ± 100 fs^2 was placed in the short arm, and the beam in the long arm was multi-passed 5 times between 2 mirrors of -1300 ± 100 fs^2.

The amplifier consisted of a 13 × 12 mm, 2 at.% doped Yb:YAG planar waveguide with a core size of 150 µm, 1-mm thick sapphire claddings. The amplifier was pumped by a single-sided diode stack formed by six diode bars capable of generating 450 W. A phase plate was placed after the diode stack to correct for aberrations. A 38-mm lens was used to focus the pump beams of the diode bars into the waveguide.

An isolator was inserted between the oscillator and the amplifier to avoid feedback from the amplifier causing the oscillator wavelength to shift from 1032 nm. The beam from the oscillator was reshaped to become 1 mm diameter and subsequently focused into the waveguide using a f = 150 mm cylindrical lens. The amplifier folding scheme consisted of two 95% reflectivity cylindrical mirrors with -15.5-mm radii of curvature. These created a plane-plane folding system in the unguided direction while giving Case-III waveguide coupling in the guided direction [2], thereby propagating the beam through the amplifier as a fundamental waveguide mode and maintaining good beam quality. The 95% reflectivity was chosen to prevent catastrophic damage to the planar waveguide in the event of the folding mirrors forming a stable laser resonator during the alignment process.

3 Results

The oscillator had an output beam quality of M^2 = 1.2 and it was tunable between 1020 nm and 1057 nm for CW operation with a 30% slope efficiency and an output power of 5.5 W. For modelocked performance the laser generated pulses of durations 480 fs ($sech^2(t)$ intensity profile assumed) at a repetition frequency of 53 MHz with an average output power of 4.5 W and a bandwidth of 3 nm at 1032 nm. The average power coupled into the amplifier was 3.5 W due to the insertion losses associated with the isolator.

Amplification in the waveguide was achieved for 1, 2, 3 and 5 passes. For CW operation of the oscillator this generated 12 W, 26 W, 34 W and 40 W average output powers respectively. For modelocked performance the beam diameter of the oscillator had to be enlarged to 1.8 mm to avoid saturation. In this case the average output powers for each of the passes through the waveguide were 11 W, 35 W and 50 W for 1, 3, and 5 passes. Five-pass amplification showed pulse broadening from 465 fs to 700 fs when the gain in the amplifier was increased by increasing the incident diode-laser pump power (Fig. 2). The measurements also show spectral narrowing due to gain narrowing in the amplification process and dispersive pulse broadening during each pass of the amplifier.

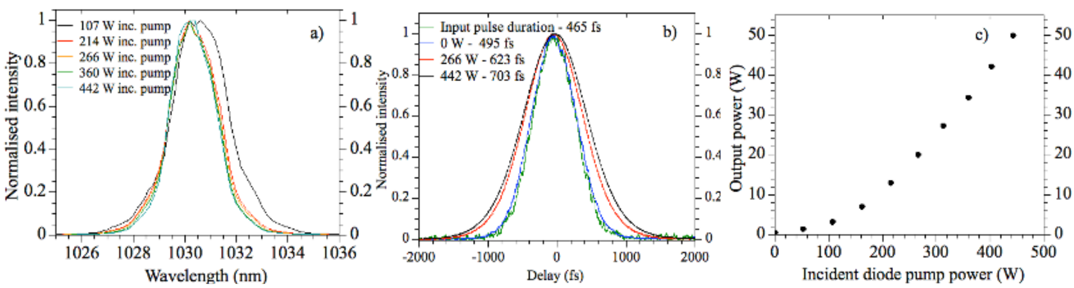

Fig. 2. (a) Measured optical spectrum and (b) intensity autocorrelation of the Yb:YAG waveguide amplifier (c) Output power of the amplified pulses as the incident diode-laser pump power was increased

4 Conclusions

A MOPA configuration has been demonstrated using a Yb:KYW oscillator and a Yb:YAG planar waveguide. For five passes through the amplifier 700-fs pulses at average output powers of 50 W and a 53—MHz repetition frequency were produced.

Future modifications of the system are in progress to obtain higher average output powers and greater pulse energies by using double-sided pumping of the amplifier. These modifications combined with more passes through the waveguide are expected to increase the average output powers to more than 100 W.

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