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Subnanosecond 1 J laser for medicine and technology

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Abstract We developed gigawatt laser system on diode-pumped Nd:Cr:YAG microchip sub-nanosecond laser and lamp pumped Nd:YAG multistage amplifier. Pulse energy up to 1 J with pulse duration of 0.7 ns at the wavelength of 1064 nm was achieved with very good beam quality. We demonstrated good agreement of computer simulation and experimental data.

Keywords Pulsed solid-state laser · High-energy · Subnanosecond pulses

1 Introduction

Development of gigawatts sub-nanosecond lasers recently attracts a lot of attention in medicine (laser tattoo removal Freedman et al. 2014), technology (laser shock peening Fortunato et al. 2013) and science (particle image velocimetry Tang and Li 2008). To achieve corresponding level of output energy in sub-nanosecond pulses a master oscillator-power amplifier (MOPA) laser is a common approach, since traditional active and passive Q-switch lasers are typically not capable of generation of pulses shorter than few nanoseconds. High power MOPA lasers require very careful and accurate optimization of radial intensity distribution. Fundamental Gaussian beam profile featured by high peak axial intensity and low amplifiers energy extraction efficiency. The attempts to increase Gaussian beam diameter usually lead to diffraction ringing due to even very minor clipping of beam by amplifier aperture which is provoking small-scale self-focusing in the amplifier stages especially for high energy sub-nanosecond pulses (Kryzhanovskii et al. 1983; Mak

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et al. 1990). To prevent self-focusing we suggested to use soft filtering of edges of Gaussian beams and avoid traditional vacuum spatial filtering cells implementation (Mak et al. 1990), which are too complex for compact and low cost laser systems (Gagarskiy et al. 2014).

2 Results

In this paper we are discussing master laser beam modification and pulse shaping approach that leads to development of MOPA laser system capable of generating up to 1 J of output energy at 0.7 ns pulse duration.

We used a diode-pumped microchip sub-nanosecond laser as a master oscillator. Active media is Nd:Cr:YAG crystal with special orientation to obtain stable linear polarization of output radiation with single longitude and transverse modes. For microchip laser pumping we used fiber pig-tailed diode laser with <10 mJ of pulse energy. We found that sub-milijoule energy of microchip laser was sufficient to get 1 J energy with two lamp-pumped Nd:YAG amplifiers. In presented MOPA laser layout (Fig. 1) we successfully avoid use of complex beam shaping components (Laskin and Laskin 2012) and expensive active Q-switch modulator (Gagarskiy et al. 2014).

Small-scale self-focusing usually takes place in amplifier active rod due to high level of intensity modulation caused by diffraction rings. Special optical system with beam apodization filter and beam expander (Fig. 1) was designed to for optimal beam distribution to get excellent energy extraction and high threshold of small-scale self-focusing in amplifiers. We optimized master laser beam profile by computer simulation of actual beam profile amplification in combination with diffraction phenomena. Smooth spatial and temporal structure of microchip laser radiation (Figs. 2, 3) gives way to achieve stable sub-nanosecond laser pulses with up to 1 J energy (Figs. 4, 5, 6). We managed to achieve

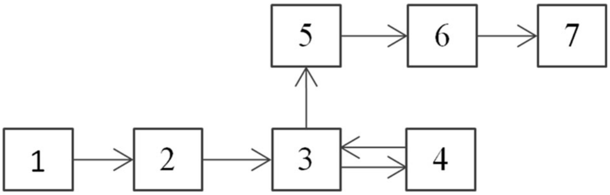

Fig. 1 General schematics of MOPA laser system: *1* uChip laser (master oscillator), *2* beam apodization optical system, *3* isolator, *4* amplifier (double pass), *5* telescopic optical system, *6* power amplifier (single pass), *7* KTP crystal

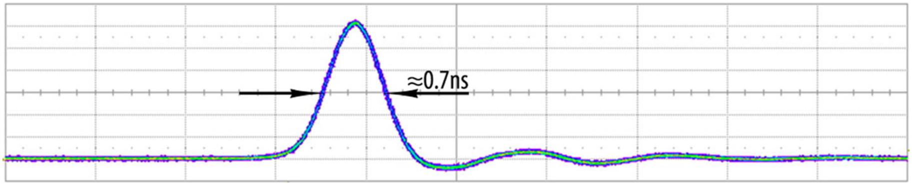

Fig. 2 The temporal distribution of microchip laser radiation (pulse repetition rate 10 Hz, 200 shots exposure, 1 nS/div). Traces were obtained by fast 5-GHz Thorlabs SIR5 photodiode and LeCroy WaveRunner 62Xi oscilloscope

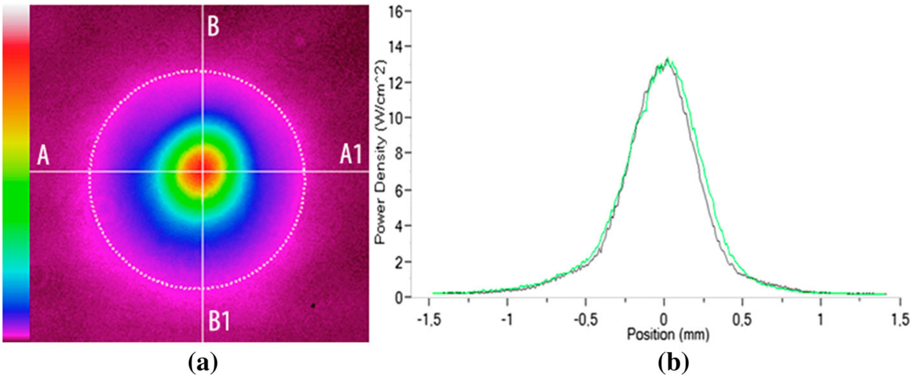

Fig. 3 Typical transversal beam shape distribution of microchip laser: *a* 2d distribution, *b* distribution in the A–A1 and B–B1 cross section. The beam quality factor $M^2 = 1.98$. Beam distribution parameters were measured by Ophir BeamStar FX 50 beam profiler

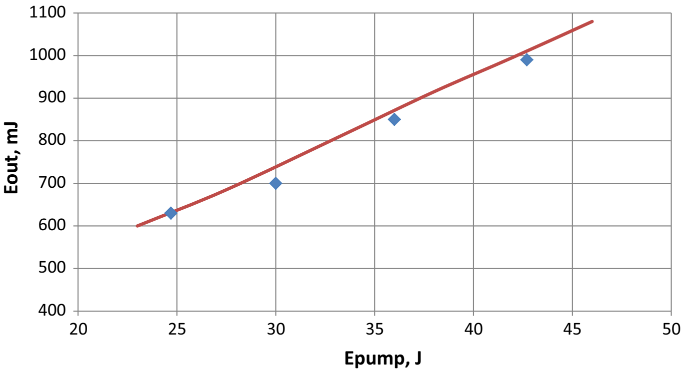

Fig. 4 Experimental output energy of sub-nanosecond pulses at 1064 nm wavelength after second amplifier versus its electrical pumping energy

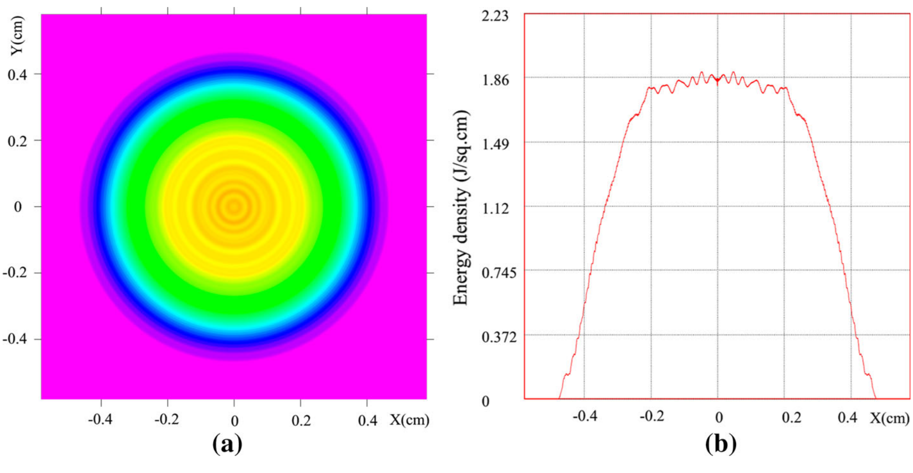

Fig. 5 Simulation results for the output beam distribution after single pass amplifier (theory): **a** 2d distribution, **b** distribution in the cross section

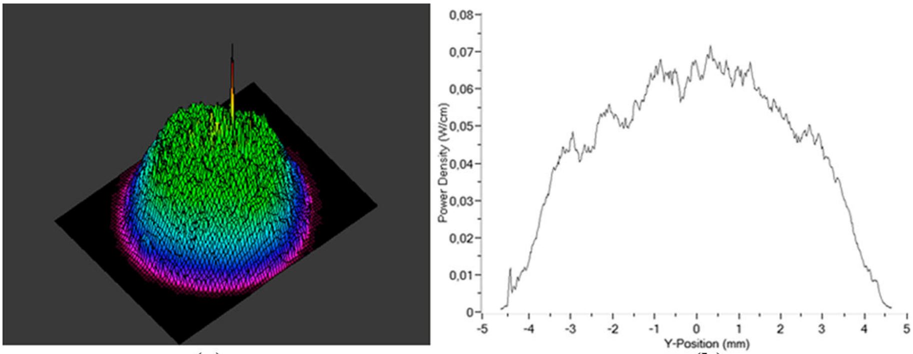

Fig. 6 Experimental results for the output beam distribution after single pass amplifier: **a** 3D distribution, **b** distribution in the cross section. Distributions were obtained by means of CCD camera Ophir BeamStar FX 50

higher than 65% conversion efficiency of second harmonic when using KTP crystal with optimum length at energy density of laser radiation of 0.8 J/cm^2 which indicates excellent laser beam parameters.

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