

LETTERS

PACS numbers: 42.55.Rz; 42.60.By; 42.60.Jf
DOI: 10.1070/QE2013v043n07ABEH015239

Neodymium glass laser with a pulse energy of 220 J and a pulse repetition rate of 0.02 Hz

A.A. Kuzmin, O.V. Kulagin, E.A. Khazanov, A.A. Shaykin

Abstract. **A compact neodymium glass laser with a pulse energy of 220 J and a record-high pulse repetition rate of 0.02 Hz (pulse duration 30 ns) is developed. Thermally induced phase distortions are compensated using wave phase conjugation. The integral depolarisation of radiation is decreased to 0.4% by using linear compensation schemes. The second harmonic of laser radiation can be used for pumping Ti : sapphire multipetawatt complexes.**

Keywords: *neodymium lasers, high pulse repetition rate, compensation of thermally induced effects, wave phase conjugation.*

At present, the most powerful sources of coherent optical radiation are petawatt lasers. In most of them, an energy of the order of a kilojoule is first stored in neodymium ions in glass as population inversion. Petawatt lasers can be divided into three main groups: in the first group, the amplifying medium is neodymium glass [1]; the amplifying medium of the second group is Ti : sapphire [2]; and the third group is based on parametric amplification in DKDP crystals [3]. In the two latter cases, the second harmonic of a neodymium glass laser with an energy of several hundreds joules is used for pumping either a Ti : sapphire crystal or a parametric amplifier. Thus, a high-power neodymium glass laser is one of the main components of petawatt laser systems. The main advantage of neodymium glass is the possibility of manufacturing large-aperture active elements, which can store a great amount of energy and operate under the conditions preventing an optical breakdown. However, the low thermal conduction of glass considerably restricts the pulse repetition rate. In existing petawatt lasers based on neodymium glass and in all multipetawatt projects, the pulse repetition rate is several pulses per day, which considerably reduces scientific research efficiency and the possibility of application of petawatt and multipetawatt lasers in practice due to a slow experimental data extraction.

Recently, two main trends in the development of petawatt systems have surfaced. The first one is to increase the laser peak power to the multipetawatt level. There are numerous projects aimed at solving this problem, in particular, pan-European ELI (Extreme Light Infrastructure) [4], Russian PEARL-10 and XCELS [5], French Apollon-10P [6], British Vulcan-10PW [7], Japanese Gekko EXA [8], American [9], and Chinese [10] 10-PW projects. The second trend is associated with increasing pulse repetition rate in petawatt systems [11, 12]. It seems very important to merge these two ways, i.e., to design a multipetawatt laser with a high pulse repetition rate (of the order of a pulse and more per minute).

It is important to note that the scientists of the French company Thales developed in 2012 a BELLA Ti : sapphire laser [12] with a peak power of 1 PW and a pulse repetition rate of 1 Hz. The extremely high pulse repetition rate was achieved owing to the use of Nd : YAG crystals instead of neodymium glass. Existing technologies do not allow one to produce high-quality Nd : YAG rods with diameters exceeding 20 mm, which restricts the energy stored in one Nd : YAG amplifier to ~10 J. To develop a petawatt system, one needs a large number of these amplifiers (the BELLA laser contains 12 amplifiers with the total radiation energy of 170 J). Thus, farther scaling is almost impossible because extensive increase in the number of Nd : YAG amplifiers is of little effect. One needs active elements with a stored energy of several hundreds of joules. At present, such elements can be made only of neodymium glass.

In [13], we analysed the repetitively pulsed regime of a laser amplifier developed by us based on a neodymium phosphate glass rod 45 mm in diameter with a pumped region 250 mm long (we denote this amplifier as A45). The amplifier was pumped by six IFP-5000-2 gas-discharge lamps; the active element was cooled by room-temperature running water. The original design of the pump cavity made it possible to store energy of more than 100 J with approximately homogeneous population inversion distribution at a pulse repetition rate of 1 pulse min^{-1} and a five-fold safety factor with respect to a thermo-mechanical breakdown. In this letter, we describe an A45-based prototype of a laser for pumping a Ti : sapphire multipetawatt complex with a pulse repetition rate of 0.02 Hz.

The laser scheme is shown in Fig. 1. The master oscillator based on a Nd : YLF laser, whose wavelength almost completely coincides with the wavelength of the neodymium phosphate glass amplifier (1054 nm), emitted giant pulses with an FWHM duration of 30 ns and an energy up to 20 mJ. The output beam of the master oscillator was diffraction limited.

After passing a Faraday isolator and a polariser, the beam was coupled into the high-power channel consisting of four double-pass amplifiers A45 placed in series and a nonlinear-optical mirror providing wave phase conjugation (WPC) due to stimulated Brillouin scattering (SBS) [14]. Although the total double-pass small signal gain in the channel was about 7×10^6, self-excitation of the A45 amplifiers did not occur due to the threshold character of the SBS. After a double pass through a Faraday rotator with an aperture of 18 mm placed

A.A. Kuzmin, O.V. Kulagin, E.A. Khazanov, A.A. Shaykin Institute of Applied Physics, Russian Academy of Sciences, ul. Ul'yanova 46, 603950 Nizhnii Novgorod, Russia; e-mail: alexeyhsgap@yandex.ru

Received 24 May 2013
Kvantovaya Elektronika **43** (7) 597 – 599 (2013)
Translated by M.N. Basieva

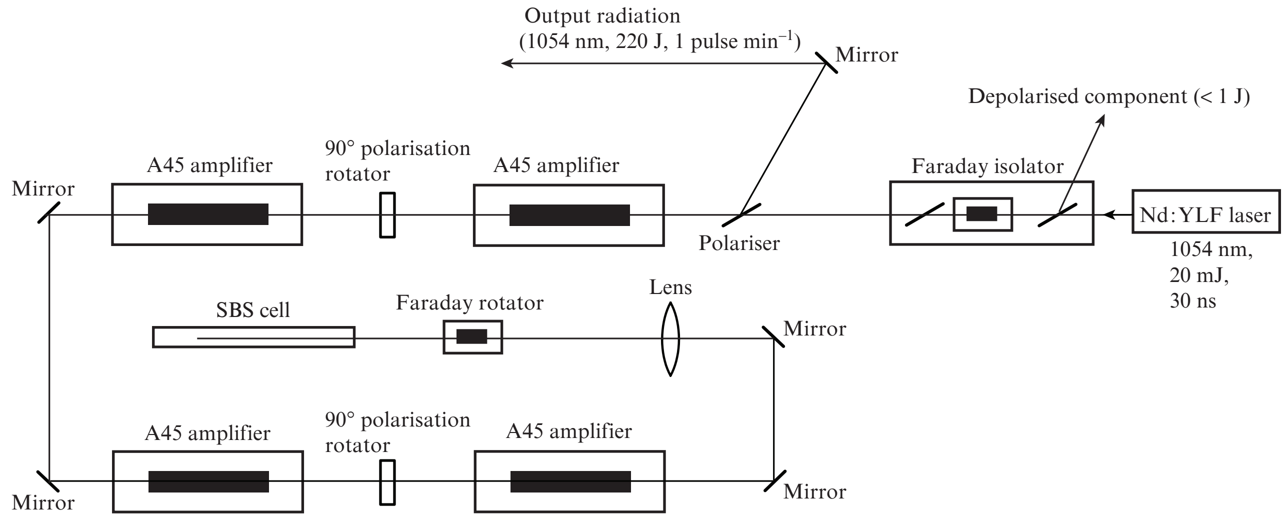

Figure 1. Scheme of the laser setup.

in front of the SBS cell, the beam polarisation plane was rotated by 90° and, as a result, the radiation was coupled out of the scheme by a polariser.

Thermally induced distortions (depolarisation and thermal lens) in the A45 amplifiers were compensated. The depolarisation was compensated by 90° quartz rotators placed between the active elements (Fig. 1), as well by the Faraday rotator and the WPC mirror. The use of a Faraday rotator in front of the SBS cell is more efficient than the use of a quarter-wave plate, which ensures channel isolation but does not reduce depolarisation uncompensated by the quartz rotators [15].

The phase distortions were reduced due to WPC. The SBS cell was 1 m long and filled with C_8F_{18} perfluorooctane, which was studied in [16] (the SBS threshold for 30-ns pulses is 5.7 mJ). The beam was focused into the cell by a lens with a focal length of 1.7 m. The reflection coefficient for laser pulses with an energy up to 12 J exceeded 90%.

Figure 2 shows the calculated and experimental dependences of the laser output energy E_{out} on the pulse energy incident from the master oscillator E_{in}. The maximum energy was 220 J at a pulse repetition rate of 1 pulse min^{-1}. The output beam intensity distributions in the near- and far-field zones are shown in Fig. 3. The beam has a rather flat top, and its divergence is 120 μrad (two diffraction limits).

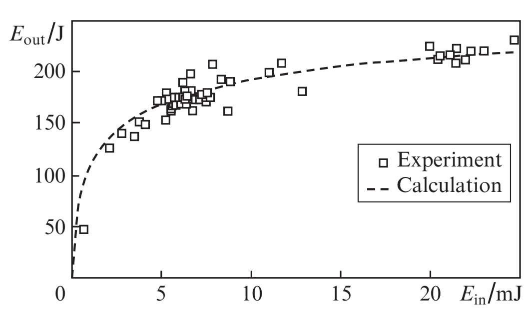

Figure 2. Calculated and experimental dependences of the laser output energy E_{out} on the incident energy E_{in} (from the master oscillator).

The depolarised component with an energy of 0.4% of E_{out} was coupled out of the facility using a Faraday isolator (see Fig. 1). The intensity distribution of this beam is shown in Fig. 3c.

The laser pulse shape almost did not change upon reflection from the SBS cell and amplification in the active elements and remained close to the master oscillator pulse shape with a FWHM duration of 30 ns even at the laser output (Fig. 4).

We expect to obtain an energy up to 150 J at a wavelength of 527 nm using second harmonic generation. This radiation can be used for pumping Ti:sapphire crystals in the scheme of a femtosecond chirped pulse amplifier. The output energy of our laser can be significantly increased by using several parallel amplifying channels; after frequency doubling, the number of channels can be decreased twofold when using type-II phase matching. The developed system is a prototype of a pump laser for a multipetawatt system with a high (~1 pulse min^{-1}) pulse repetition rate.

Acknowledgements. The work was partially supported by the Russian Foundation for Basic Research (Grant No. 12-02-31222).

References

1. Perry M.D. et al. *Opt. Lett.*, **24**, 160 (1999).
2. Aouama M. et al. *Opt. Lett.*, **28**, 1594 (2003).
3. Lozhkarev V.V. et al. *Laser Phys. Lett.*, **4**, 421 (2007).
4. Chambare J.-P. et al. *Proc. SPIE Int. Soc. Opt. Eng.*, **7721**, 77211D (2010).
5. www.xcels.iapras.ru.
6. Le Blanc C. et al. *Proc. Intern. Commit. Ultra Intense Lasers Conf. (ICUIL 2012)* (Mamaia, Romania, 2012) p. 32.
7. Hernandez-Gomez C. et al. *The Vulcan 10 PW project.* CLF Annual Report 2008-2009, pp 267–270.
8. Kawanaka J. et al. *Proc. Intern. Commit. Ultra Intense Lasers Conf. (ICUIL 2012)* (Mamaia, Romania, 2012) p. 14.
9. Ditmire T. *Proc. Intern. Commit. Ultra Intense Lasers Conf. (ICUIL 2012) (*Mamaia, Romania, 2012) p. 18.
10. Ruxin Li et al. *Proc. Intern. Commit. Ultra Intense Lasers Conf. (ICUIL 2012)* (Mamaia, Romania, 2012) p. 22.
11. Yu T.J. et al. *Opt. Express*, **20**, 10807 (2012).
12. Leemans W.P. et al. *Proc. Intern. Commit. Ultra Intense Lasers Conf. (ICUIL 2012)* (Mamaia, Romania, 2012) p. 35.

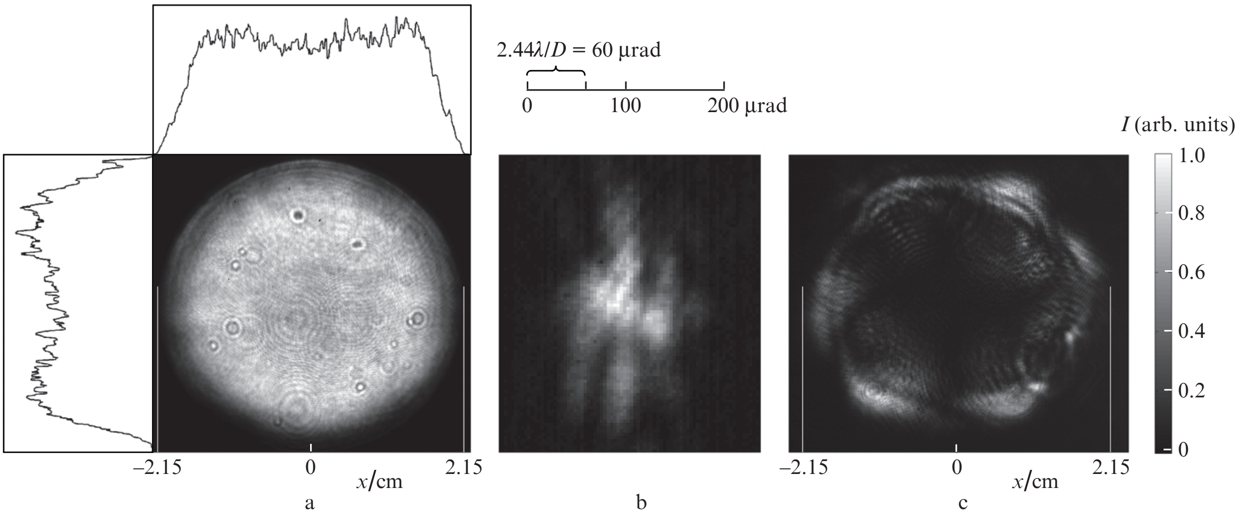

Figure 3. Transverse intensity distributions of the output beam in the (a) near- and (b) far-field diffraction zones and (c) depolarised component intensity distribution. The colour range is the same in all the figures.

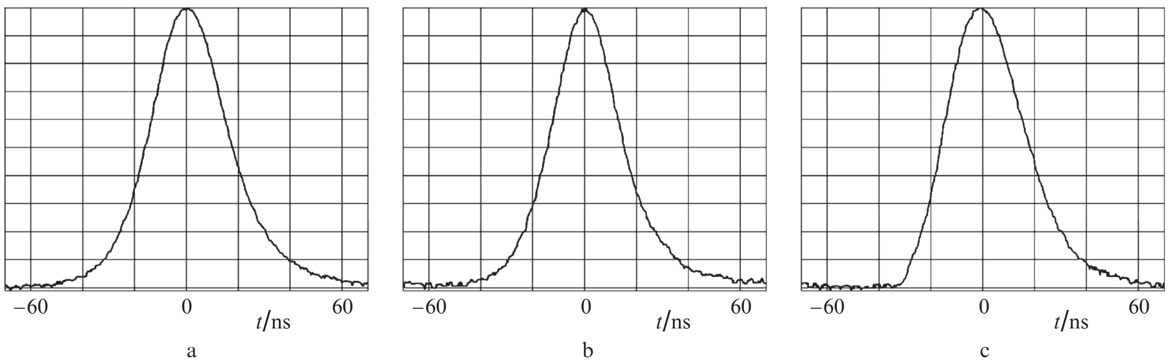

Figure 4. Oscillograms of the output pulses of (a) the master oscillator, (b) SBS cell and (c) laser.

13. Kuzmin A.A., Khazanov E.A., Shaykin A.A. *Kvantovaya Elektron.*, **42** (4), 283 (2012) [*Quantum Electron.*, **42** (4), 283 (2012)].
14. Zel'dovich B.Ya., Pilipetskii N.F., Shkunov V.V. *Obrashchenie volnovogo fronta* (Wave Phase Conjugation) (Moscow: Nauka, 1985).
15. Carr I.D., Hanna D.C. *Appl. Phys. B*, **36**, 83 (1985).
16. Andreev N.F., Kulagin O.V., Palashov O.V., Pasmanik G.A., Rodchenkov V.I. *Proc. SPIE Int. Soc. Opt. Eng.*, **2633**, 476 (1996).