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Multiterawatt femtosecond hybrid system based on a photodissociation XeF(C–A) amplifier in the visible range

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Abstract. **This paper describes a multiterawatt hybrid laser system based on a Ti:sapphire front end and 25-cm-aperture photodissociation XeF(C–A) amplifier. The front end generates 50-fs pulses with second-harmonic (λ = 475 nm) energies of up to 5 mJ. The gain medium of the amplifier is produced in a XeF_2-N_2 mixture by VUV radiation excited in xenon by a high-power electron beam. Through amplification of a negatively chirped 1-ps pulse, followed by pulse compression in bulk fused silica, a peak power of 14 TW, record-high for the visible range, has been achieved.**

Keywords: *hybrid femtosecond system, photodissociation XeF(C–A) amplifier, negatively chirped pulse, compression in bulk glass.*

1. Introduction

In recent years, significant advances have been made in the hybrid approach (solid/gaseous gain media) to the development of ultrahigh-power femtosecond laser systems based on a photodissociation XeF(C–A) amplifier (see e.g. Refs [1–5]). This approach has a number of advantages: the lower optical nonlinearity of gaseous gain media compared to solids, visible emission range, high contrast, and the possibility of scaling up the end-stage amplifier. The lower optical nonlinearity of the gain medium makes it possible to amplify femtosecond pulses stretched to picosecond durations by applying negative chirp and to employ normal dispersion in bulk glass for compressing amplified pulses. This offers the possibility to dispense with a vacuum compressor based on diffraction gratings – one of the most complex and expensive devices in solid-state systems.

In this paper, we report on the multiterawatt, 25-cm output aperture, hybrid laser system built at the Institute of High-Current Electronics, Siberian Branch, Russian Academy of Sciences (Tomsk) and present the first results of experimental studies of the gain medium of the XeF(C–A) amplifier and the amplification of femtosecond pulses (λ = 475 nm).

2. Apparatus and measurement techniques

The generator used in the laser system is a Start-480M facility (Avesta Project Ltd.). It ensures second-harmonic (λ = 475 nm) pulse energies of up to 5 mJ and a pulse duration of 50 fs. The gain medium of the XeF(C–A) amplifier results from the photodissociation of XeF_2 molecules by VUV radiation at ~172 nm. This process produces XeF(B) excimers, which relax to the C state of the laser transition (C–A) through collisions with N_2 buffer gas molecules. The XeF(C–A) amplifier is shown in Fig. 1. It includes two high-voltage pulsed generators and a vacuum diode which generates six convergent electron beams. The beams are injected into a gas chamber (converter) filled with xenon to a pressure of 3 atm. The 172-nm radiation excited by the electrons in the xenon passes through CaF_2 windows into a laser cuvette (25-cm aperture) immersed in xenon. A more detailed description of the XeF(C–A) amplifier can be found in Ref. [4].

The small-signal gain profile across the laser cuvette was measured with a Sapphire-488 cw semiconductor laser at 488 nm, i.e. near the peak gain wavelength of the XeF(C–A) transition. Femtosecond pulses were amplified in a 33-pass optical scheme consisting of 32 round mirrors of gradually increasing diameter, located along the perimeter of the inner flanges of the laser cuvette. The beam made two round trips along the inner perimeter of the laser cuvette. In the last pass, the pulse was amplified along the axis of the laser cuvette. A

Figure 1. Appearance of the XeF(C–A) amplifier.

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divergent beam 2 cm in diameter was injected into the amplifier. Its diameter at the output was 12 cm. Before amplification, the pulse was stretched to 1 ps in a prism stretcher with a negative group velocity dispersion. After amplification, the beam diameter was increased to 20 cm, and the pulse was compressed by passing it twice through three 4-cm-thick fused silica plates mounted at the Brewster angle. The pulse duration was measured with an ASF-20-480 autocorrelator, and the pulse energy, with an Ophir meter.

3. Experimental results

Figure 2 shows the spatial gain profiles in the gain medium at different XeF_2 vapour pressures. With decreasing vapour pressure, the spatial gain distribution becomes more homogeneous, but this is accompanied by a substantial drop in gain at the periphery of the laser chamber. In final optimisation of the mixture, we used the net gain measured in the 33-pass scheme. The highest gain was obtained when the XeF_2 partial pressure was 0.2–0.25 Torr and the nitrogen pressure was 0.25 atm.

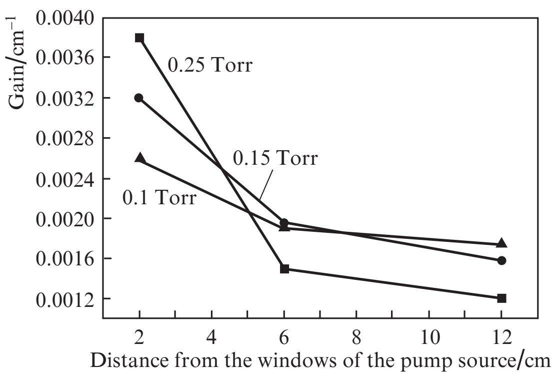

Figure 2. Small-signal gain profiles between the pump source and the axis of the laser cuvette at a nitrogen pressure of 0.25 atm and different XeF_2 vapour pressures.

In experiments intended to amplify a picosecond pulse, the energy at the input of the XeF(C–A) amplifier was varied in the range 0.04–2 mJ. In the unsaturated gain regime, the total gain coefficient reached 5×10^3, and near the saturation of the amplifier (50 mJ cm^{-2}) it dropped to 5×10^2. The amplified pulse energy reached 1 J.

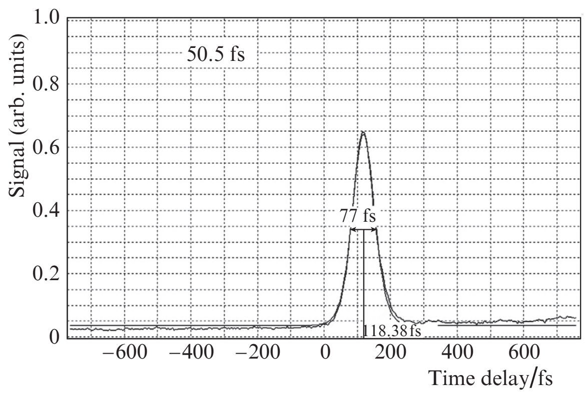

Figure 3. Autocorrelation trace of a 0.7-J output pulse.

At a beam energy of 0.7 J, we performed compression of amplified pulses. Figure 3 shows the autocorrelation trace of a compressed pulse, which corresponds to a pulse duration of 50 fs ($\mathrm{sech}^2 x$ pulse shape). This result indicates that a peak power of 14 TW has been reached. According to data in the literature, the highest femtosecond visible pulse power so far has been reached through direct amplification of 250-fs pulses in an electron beam excited XeF(C–A) amplifier (1 TW [6]) and through Ti : sapphire laser frequency doubling (4 TW [7]), which is well below the present result.

4. Conclusions

The physical startup of a hybrid femtosecond laser system has been performed. In the first experiments intended to amplify femtosecond pulses stretched to 1 ps by applying negative chirp, an output energy of 1 J was obtained. At an output energy of 0.7 J, amplified pulses were compressed in bulk fused silica to the original duration of 50 fs and a peak power of 14 TW, record-high for femtosecond visible pulses, was achieved.

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