TEWALAS 20-TW femtosecond laser facility

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TEWALAS facility consists in a Ti:sapphire laser system based on chirped pulse amplification. Oscillator femtosecond pulses, after passing through a booster and intensity contrast improvement module, are stretched up to 300 ps. The stretched pulses are amplified by a regenerative amplifier, two multi-pass amplifiers and re-compressed in a vacuum compressor. More than 10^9 intensity contrast of femtosecond pulses in relation to the amplified spontaneous emission was obtained. Amplified laser pulses, with as much as 440 mJ pulse energy, are compressed down to 23 fs at 10 Hz repetition rate.

1. Introduction

The technique of chirped pulse amplification (CPA) [1] has become a common approach for producing high-peak-power ultra-short optical pulses. The CPA technique involves the temporal stretching of ultra-short pulses with a large spectral bandwidth delivered by an oscillator. This way, the laser intensity is significantly reduced in order to avoid the damage of optical components of the amplifier and the temporal profile distortion by non-linear optical effects during the pulse propagation. After amplification, the laser pulse is back compressed to a pulse duration very closed to its initial value (Fig. 1).
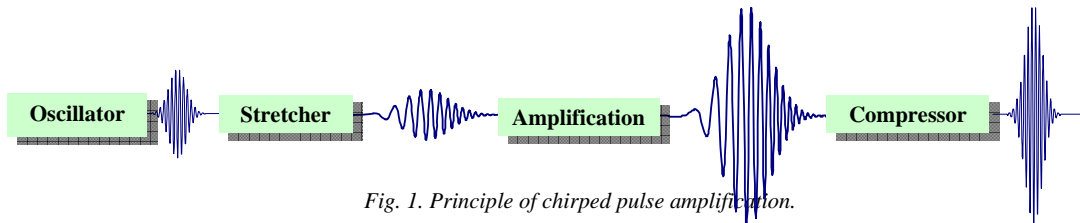
Fig. 1. Principle of chirped pulse amplification.

The stretcher, based on the angular dispersion of the laser radiation on diffraction gratings, produces a "frequency-chirped" pulse. The bluer part of the spectrum is delayed compared to the redder part when traveling through the stretcher. The output pulse is stretched and looks like a temporal rainbow (red in the leading edge and blue in the trailing edge). The stretching factor depends on the spectral width of the input pulse and on the intrinsic characteristics of the stretcher (grooves density of the gratings, distance between gratings, number of roundtrips in the stretcher, incidence angle). For a given stretcher configuration, the wider the input spectrum is, the longer the stretched pulse is.

The amplified pulse is compressed to its initial short duration using a compressor with two parallel diffraction gratings. Since the redder part of the spectrum is delayed compared to the bluer part through the compressor, the output pulse is temporally compressed. The geometry of the stretcher-compressor is designed to obtain the flattest phase dispersion in the overall system. For very high output power, the compressor is placed into a vacuum chamber to prevent from non-linear effects in air. The output pulse duration is inversely proportional to the spectral bandwidth of the amplified pulse.

There are two main gain media employed for CPA: Nd:glass and Ti:sapphire. The main distinction between Nd:glass and Ti:sapphire is associated with the gain bandwidth. The relatively narrow bandwidth of the Nd:glass does not allow the amplification of pulses with duration below few hundreds femtoseconds. The Ti:sapphire has more than one order of magnitude larger gain bandwidth, that allows the amplification of ten-femtosecond pulses. The presence of a broad absorption peak for titanium at ~ 500 nm allows efficient pumping of Ti:sapphire crystals by frequency-doubled radiation from commercial neodymium laser systems. Tens-hundreds of TW peak power could be obtained with relatively low amplified pulse energy (Joule level) from table-top Ti:sapphire laser systems [2-5].

In this paper we describe a recently installed at INFLPR 20-TW amplifier system that produces laser

pulses of more than 440-mJ pulse energy and less than 25-fs pulse duration at 10-Hz repetition rate.

2. Description of the laser system

The schematic drawing of the laser amplifier system is shown in the Fig. 2. The femtosecond oscillator (Synergy Pro, FEMTOLASERS) is based on Kerr-lens self-mode-locking. Chirped mirrors are used in the optical resonator to compensate for the phase distortions in the large spectral bandwidth of the laser pulses.
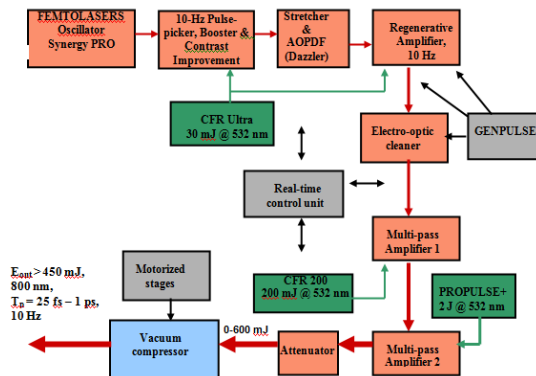

Fig. 2. Schematic drawing of the laser amplifier system.

When pumped by a 5-W cw green laser, the laser oscillator generates ultra-short pulses with ~ 5 nJ energy, less than 15 fs pulse duration (more than 100 nm spectral bandwidth), 790 nm central wavelength, at 75 MHz repetition rate. 10-Hz repetition rate femtosecond pulses, selected by a Pockels–cell pulse picker, are amplified up to ~ 15 µJ energy in a 14-pass amplifier (booster, Amplitude Technologies) pumped by 7-mJ nanosecond pulse energy, a part of the 30 mJ output energy of a CFR Ultra green laser (Quantel-Big Sky). The intensity contrast of femtosecond pulses in relation to the amplified spontaneous emission (ASE) is improved by two orders of magnitude in a saturable absorber that transmits ~ 40% of the input pulse energy. 10-Hz repetition rate pulses are selected by a pulse picker in the booster module. High-contrast microjoule-pulses are stretched up to ~ 300 ps pulse duration in an all-reflective Offner-type optical stretcher [6].

The stretched pulse passes through an acousto-optic programmable dispersive filter (AOPDF) [7], Dazzler (Fastlite). Dazzler is used as a phase modulator to pre-compensate for dispersion and phase distorsions introduced throughout the laser system. The following amplifier chain consists in a regenerative amplifier and two multi-pass amplifiers (Amplitude Technologies). The regenerative amplifier is seeded by pulses of a couple of hundreds nano-joules energy obtained from the Dazzler output. The regenerative cavity includes two Pockels cells: one is used to seed the stretched pulse into the cavity and the other one dumps out the pulse at the maximum energy.

The main limitation for the ultra-short pulses amplification is the spectral gain narrowing.

An acousto-optic programmable gain control filter (AOPGCF), Mazzler (Fastlite), is inserted into the regenerative cavity to optimize the spectrum of the amplified pulse. When pumped by ~ 15 mJ pulse energy from the CFR Ultra laser, the output pulse is amplified in the range of mJ energy. The nanosecond intensity contrast of the amplified pulse is improved by a Pockels-cell pulse cleaner. All Pockels cells involved in the laser system are controlled by an electronic device (GENPULSE).

In the next 5-pass amplifier (multi-pass amplifier 1 – MP1), pumped by CFR 200 (Quantel-Big Sky) nanosecond green laser, the pulse energy is increased up to 25 mJ. The last power 4-pass amplifier (multi-pass amplifier 2 – MP2) is pumped by 2-J pulse energy of a PROPULSE+ green laser (Amplitude Technologies). For the full pump energy, the output pulse is amplified to more than 600 mJ. Through the amplifier chain, the laser beam diameter is successively increased up to 13 mm in the last amplifier.

Using the Mazzler AOPGCF, the spectrum of the amplified pulse can be increased from ~ 30 nm to more than 70 nm after MP1 and 65 nm after MP2 (Fig. 3). By the combined action of Dazzler and Mazzler, amplified pulses re-compressible down to 20 fs can be obtained
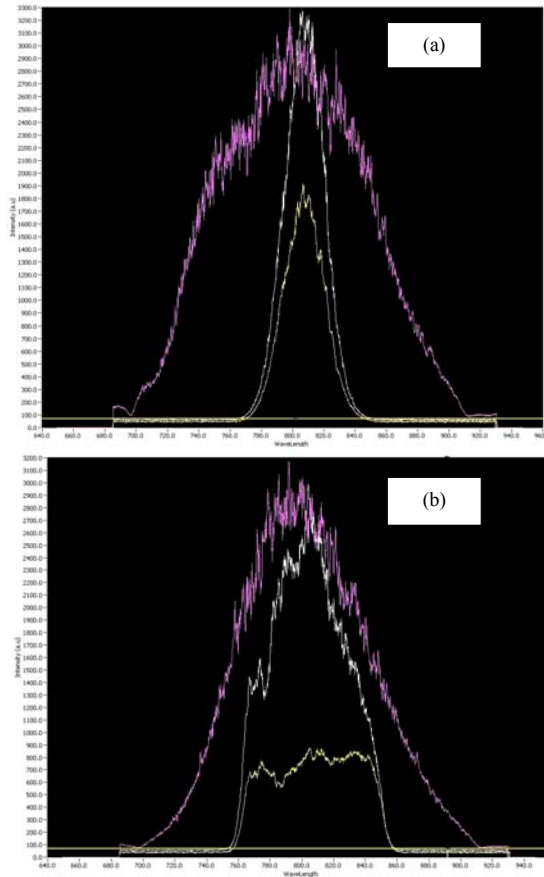

Fig. 3. Laser system spectra: (a) without active Mazzler; (b) optimized by Mazzler. Mauve line – oscillator; yellow line – MP1; white line - MP2.

The amplified pulses are temporally compressed using a classical compressor design with two diffraction gratings. The geometry of the stretcher-compressor is designed to obtain the flattest phase dispersion in the overall system. The compressor is placed in a vacuum chamber to prevent from nonlinear effects in air. One of the gratings is mounted in a motorized stage commanded by an outside driver. By changing the distance between diffraction gratings, the compressed pulse duration can be adjusted in the range tens of fs – couple of ps. 74%-compressor efficiency was measured. As much as 440 mJ pulse energy was obtained in a temporally compressed pulse of 23 fs.

Laser modules are placed on a 1.5 x 5.25 m² optical table (Thorlabs). The laser system is installed in a 50-m² surface, 100,000-class clean room, with air conditioning stabilization within 22 ± 1^0C and 35-65% humidity (figure 4).

3. Femtosecond pulses control and characterization

A complete set of diagnostic sensors is installed through the laser system to control: pump laser energy, beam pointing, spectral bandwidth, beam profiles, laser pulses synchronization. Sensors are linked to a real time command and control unit. Signals out of the permitted range are analyzed by the computer. The equipment is switched-off or one or more shutters are closed in case of trouble.

The spatial beam profiles after MP 1 and MP 2 were measured by two beam profilers (Fig. 5). The laser beam after the 5-pass amplifier has a nearly Gaussian spatial profile (figure 5a). The beam profile of the last amplifier presents some spatial distorsions, probably due to the non-uniformity of the pump laser beam profile (Fig. 5b).

The time dependent intensity and phase of the compressed pulses were measured by spectral phase interferometry for direct electric field reconstruction (SPIDER). As short as 23-fs pulses, having a flat phase distribution over more than 70 nm bandwidth, were obtained (Fig. 6).
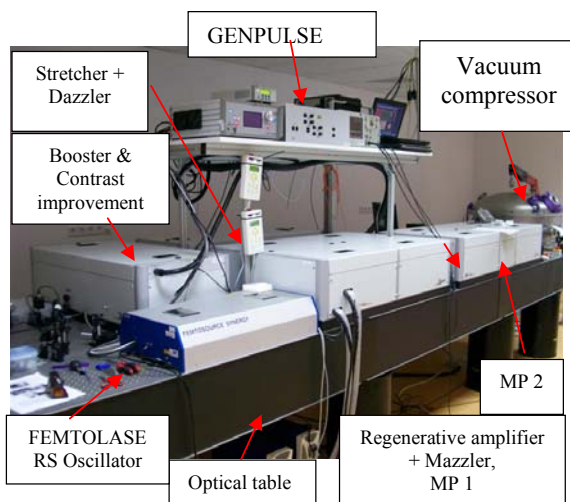
The amplified pulse energy was measured using an energy-meter (Gentec) protected by a diffuser plate in order to avoid the damage of the detector. Short-term RMS stability was in the range of 1.85% at 600 mJ stretched pulse energy.
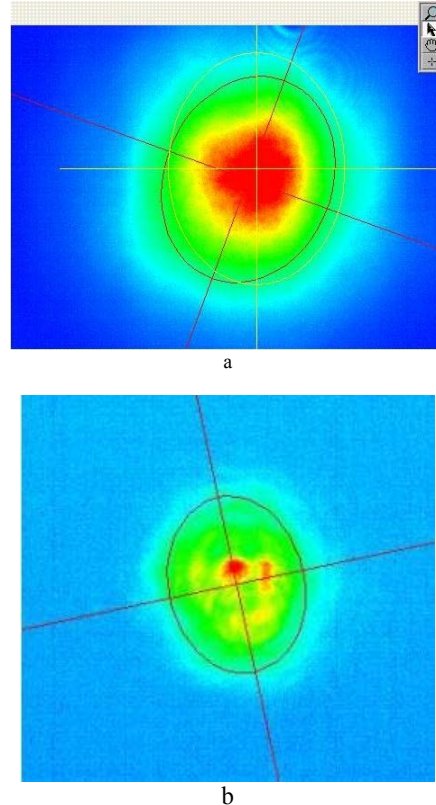

a

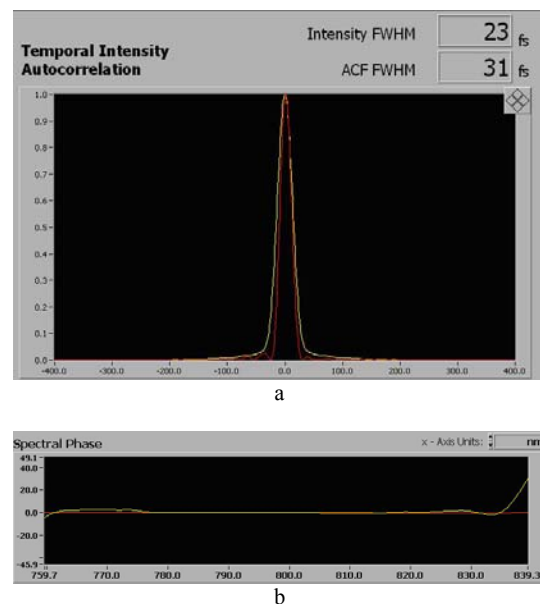b

Fig. 5. Laser beam profile. (a) MP1. (b) MP2.

a

b

Fig. 6. Pulse temporal profile (a) and spectral phase (b) measured by SPIDER.

Fig. 4. Laser system layout.

The intensity contrast of femtosecond pulses in relation to ASE (Fig. 7) was measured with a third-order auto-correlator (Sequoia, Amplitude Technologies). More than 10^9 intensity contrast was obtained at 30 ps before the femtosecond pulse.
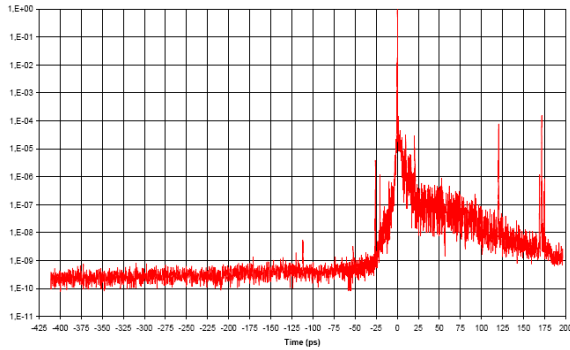

Fig. 7. Intensity contrast of femtosecond pulses in relation to ASE.

Laser facility specifications are summarized in the Table 1.

Laser characteristics	Measured value
Central wavelength	808 nm
Spectral width	> 65 nm
Pulse energy before compression	600 mJ
Pulse energy after compression	440 mJ
Pulse duration	25 ± 2 fs
Repetition rate	10 Hz
Energy stability (RMS)	1.85%
Pre-pulse contrast @ ns	8×10^{-8}
ASE contrast @ 1 ps	2×10^{-5}
ASE contrast @ 3 ps	3×10^{-6}
ASE contrast @ 5 ps	2×10^{-7}
ASE contrast @ 15 ps	2×10^{-8}
ASE contrast @ 30 ps and earlier	7×10^{-10}

4. TEWALAS applications

At low energy level (nJ-µJ), TEWALAS laser facility is used for technological applications: micro/nanostructures and photonic crystals direct laser writing by two-photon photo-polymerization in materials transparent at laser fundamental wavelength, metallic films nano-structuring, materials micro-processing by laser ablation.

At its highest energy level (hundreds of mJ), the laser facility could be used for nonlinear optics (high harmonics generation), plasma physics, and secondary sources of radiation (x-ray laser) experiments.

TEWALAS facility is used for training of students and young researchers involved in "Extreme Light Infrastructure", LASERLAB 2, and other European projects.

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