Laser Developments for Particle Acceleration

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Résumé :

<résumé de la présentation, en français, environ 15 lignes>
Le récent développement de lasers à haute puissance de crête a permis d'ouvrir de nouveaux domaines d'application de la Physique. Avec les champs électriques générés en focalisant le faisceau de ces lasers, il est possible de générer des particules chargées à haute énergie, des rayons γ, rendant possible le processus d'ignition rapide pour la fusion par confinement inertiel. Malgré les récents progrès en techniques d'amplification laser, il subsiste des problèmes de stabilité de l'intensité, de qualité du faisceau et de contraste de pré-pulse. Une nouvelle architecture laser est présentée, basée sur la technique appelée « chirped pulse amplification » (CPA) ou amplification par dérive de fréquences, permettant des propriétés de faisceau favorable à la Physique des champs forts. Le laser est composé d'un préamplificateur optique paramétrique à trois étages et d'un amplificateur basé sur le Titane:saphir. Ce laser hybride permet d'obtenir des intensités de crête de l'ordre du Terawatt (10^{12} W) avec un contraste de pré-pulse inégalé. Dans ces conditions, des électrons peuvent être piégés et accélérés par le champ résultant du sillage laser, permettant des accélérations 6 ordres de grandeurs plus grandes qu'avec les accélérateurs conventionnels. Cela permettrait en principe de réduire la taille de ces accélérateurs de plusieurs kilomètres à quelques millimètres. Cette technique est importante pour l'étude fondamentale de l'interaction onde/matière, et trouve ses applications dans le domaine médical (radiothérapie) et la physique nucléaire.

Abstract :

<résumé de la présentation, en anglais ou japonais, environ 15 lignes>
Recent developments of ultrashort high peak power lasers have opened various new fields of Physics. At the high electric fields obtained by focusing the beam generated by these lasers, interesting phenomena occur, such as high energy charged particle generation, γ-ray generation, fast ignition for inertial confinement fusion studies, etc. Despite the recent advances in laser amplification schemes, generating intense light pulses with stable intensity, good beam quality and high prepulse contrast remains a challenge. We present a novel high peak power laser architecture based on hybrid chirped pulse amplification (CPA) that allows pulse properties highly desirable for high field Physics. The laser consists of a three-stage optical parametric CPA preamplifier, and a three-stage Ti:Sapphire multipass amplifier. This hybrid laser enables peak intensities in the Terawatt (10^{12} W) range with unprecedented prepulse contrast. In these conditions, electrons can be trapped and accelerated by a laser wake-field, allowing accelerations up to 6 orders of magnitude larger than in conventional accelerators. In principle, this would allow to reduce the size of accelerators from kilometers to millimeters. This technique is essential for the understanding of fundamental light/matter interactions, and has applications in the medical field (radio therapy), and nuclear physics.

Introduction :

<Introduction de la présentation. Le choix de la langue laissé au rédacteur>

One of the practical requirements for high field laser physics experiments is that the laser pulse peak power should exhibit a high contrast ratio in order to avoid low density plasma generated by a laser prepulse. Hybrid Ti:Sapphire/Optical Parametric Chirped Pulse Amplification (OPCPA) systems have been proposed as laser source for high field experiment, where prepulse contrast is important [1]. One major limitation of high gain OPA, however, is that the optical parametric fluorescence (OPF) is largely amplified to generate strong AOPF. In this paper, we report on the development of a high peak power OPCPA/Ti:sapphire hybrid laser system. OPCPA has two attractive features for a preamplifier in TW or PW laser systems. Firstly, by using a short enough pump pulse, the contrast ratio between the amplified main pulse (AMP) and the amplified pulse train corresponds to the amplification factor itself. Secondly, noncollinear OPCPA enables wideband amplification over 100 nm in bandwidth. For that reason, OPCPA is an attractive alternative to regenerative amplification [2],[3]. Provided adequate dispersion management is performed, we can expect the generation of sub-10 fs, high peak power laser pulse with OPCPA [4],[5].

<Corps de la présentation comprenant les **parties 1, 2, 3 etc.** Le choix de la langue laissé au rédacteur >

1. OPCPA/Ti:sapphire hybrid laser system

The OPCPA preamplifier presented in this study consists of three-stages. Type 1 β-barium borate (BBO) crystals are used as the nonlinear media. The pump pulse is a commercial seeded Q-switched Nd:YAG laser generating 230 mJ/6 ns pulses at 0.532 µm in wavelength at 10 Hz in repetition rate. In order to obtain a good spatial beam quality, the near field profile of the pump pulse was imaged on each BBO with telescopes. The gain of the preamplifier was ~10^7. However, a strong amplified optical parametric fluorescence (AOPF) was observed simultaneously. The AOPF level was comparable with that of AMP in some cases. To suppress AOPF while keeping enough output energy, controlling the preamplifier gain is one of the most suitable methods. A part of the fundamental pulse of the seeded Q-switched Nd:YAG pumping laser was injected to the first OPA as a quenching beam. By adjusting its energy, the contrast ratio was drastically improved with no loss of output energy. At the three-stage OPA output, 3 mJ of energy were obtained. This pulse was injected in a Ti:sapphire multi-pass amplifier system. Just after the final amplifier, the output energy was over 1 J centered at 0.8 µm. After the pulse compressor, an output energy of over 400 mJ was obtained with 35 fs in pulse width. A schematic of the OPCPA preamplifier setup is shown in Fig. 1.

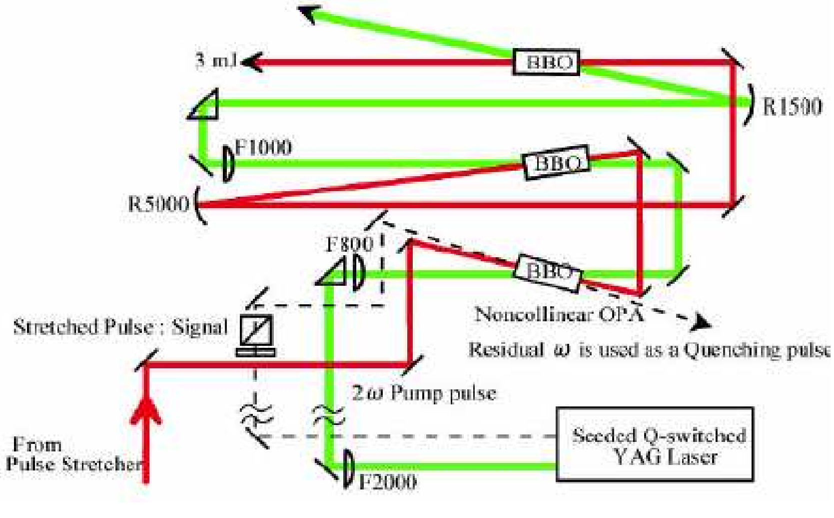

Fig. 1. Schematic of OPCPA preamplifier in the hybrid system

2. Experimental results

The contrast ratio between AMP itself and the amplified pulse trains before AMP was measured to be larger than 10^8 with neutral density filters and a fast PIN photodiode detector. This high value can be easily understood from the principle of OPCPA. On the other hand, the contrast ratio between AMP and AOPF was lower, as shown in Fig. 3, and detectable AOPF was present after the three-stage OPA. However, AOPF cannot be compressed by the pulse compressor because of its incoherent phase. As a result, after the pulse compressor, the contrast ratio between the peak intensity of AMP and the instantaneous intensity of AOPF is estimated to increase by a factor equal to the compression ratio of $\approx 10^4$. If a seed is injected 1.2 ns after the gain peak of OPA, we obtained the temporal profile represented by the thin solid curve in Fig. 2. The apparent rising of AOPF can be observed, and is followed by the more rapid rising of AMP. In this case, the intensity of the AOPF is comparable to that of the AMP, and their contrast ratio is $\approx 10^4$ after the pulse compressor. However, by injecting a seed 1ns before the gain peak of the OPA, the instantaneous intensity level of AOPF was estimated to be lower than 10^{-2} of AMP before compression, with almost the same output energy. After compression, the contrast ratio was estimated to be 6×10^6 assuming a Gaussian temporal profile for AOPF. In this estimation, measured pulse widths were used. With quenching, the intensity ratio was improved $\approx$10 times. From the same estimation, the contrast ratio between AMP and AOPF was increased to 5×10^7 in that case.

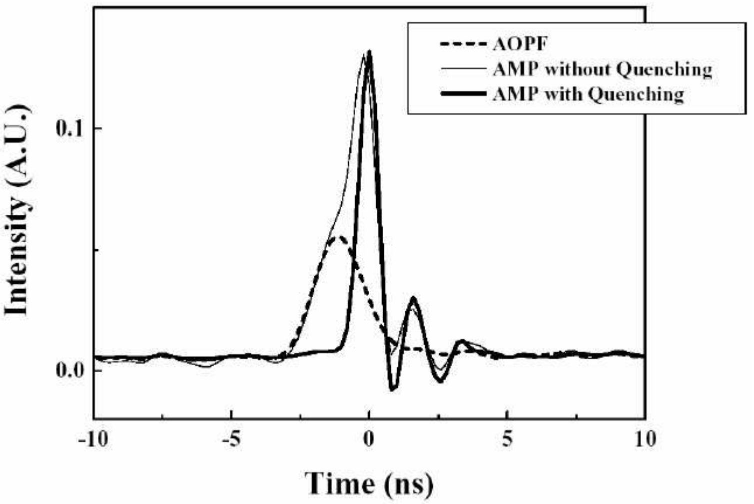

Fig. 2. Temporal profiles of amplified pulse at OPCPA preamplifier stage. The thin solid curve and the thick dotted curve were obtained with and without a seed pulse, respectively. The thick solid curve was obtained with quenching.

3. Laser acceleration experiment

Using laser beams to excite plasma waves for electron acceleration was proposed by Tajima and Dawson in 1979 [6]. Since then, this idea has led to several promising studies on laser-produced plasma accelerators. Using the laser system described above, a laser acceleration experiment was performed by focusing laser pulses on the supersonic Argon gas jet. These pulses were focused with an f/3.2 off axis parabolic mirror. The vacuum focal spot size was estimated to be 5 μm (FWHM) and the laser intensity was estimated to be higher than 2×10^{19} W/cm^2. The electrons were accelerated along the laser propagation axis. The energy spectrum was measured with an electron spectrometer (ESM). The magnetic field for dispersion was produced by a 0.5 T permanent magnet. Each electron was bent in the direction corresponding to their energy and were detected by an imaging plate (Fuji BAS-SR2025). Fig. 3 shows the energy spectrum which was obtained for the gas density of 4×10^{18} cm^{-3}. Energetic electrons of up to 30 MeV were observed.

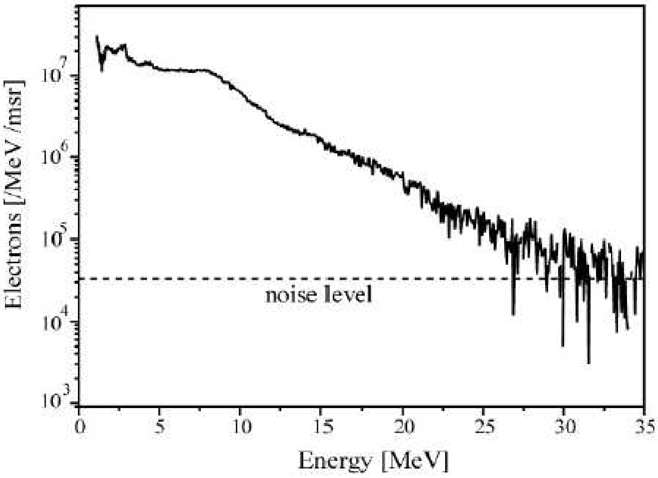

Fig. 3. Electron spectrum from the plasma produced in the Ar gas jet target

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