Amplified spontaneous emission contrast of CPA laser

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The influence on the level of amplified spontaneous emission (ASE) contrast resulting from the different seed pulse energies has been experimentally studied in a 10-TW-level femtosecond Ti:sapphire chirped pulse amplification laser. It is found that, with the seed pulse energy increasing, the ASE pedestal is suppressed more efficiently, and the ASE contrast is improved with a saturable tendency. The measurement of $\sim 2\times10^{-8}$ ASE contrast in the range of more than 50 ps before the main pulse is achieved in the laser.

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Chirped pulse amplification (CPA) technology[1] in femtosecond regime has made it possible to realize the ultra-intense and ultra-fast laser with a focused intensity as high as 10^{22} W/cm^2 [2]. Based on the ultra-intense and ultra-fast laser, many exciting opportunities for a variety of high-field applications have been created[3−5]. However, a typical high-power Ti:sapphire laser system, based on a CPA scheme, generates not only a femtosecond pulse but also an amplified spontaneous emission (ASE) pedestal. The ASE pedestal has the duration of several hundreds picoseconds, and contain enough energy to create plasma before the arrival of the main pulse, which can alter significantly the physics of the laser-plasma interaction[6]. Therefore, ASE contrast, defined by the intensity ratio between the ASE pedestal and the main pulse, has been a crucial problem to the study of high-intensity physics experiments.

Until now, several pulse-cleaning techniques have been developed for ASE suppression, such as femtosecond pre-amplification[7], double CPA[8], and cross-polarized wave (XPW) generation[9,10]. Almost all of these techniques need the pre-amplification of the seed pulses after oscillator, before being stretched for the main amplifier. However, the relationship between the ASE contrast and the seed pulse energy has not been experimentally investigated. Therefore, it is important to study the influence on the level of ASE contrast resulting from different seed pulse energies.

In this letter, the ASE contrast under different seed pulse energies is experimentally studied in a typical 10-TW-level/10-Hz Ti:sapphire CPA laser[11]. It is found that with the seed pulse energy increasing, the ASE pedestal is suppressed more efficiently, and the ASE contrast is improved. It is found that there exists a saturable tendency with the seed pulse energy increasing, which is due to the intrinsic ASE noise in the regenerative amplifier and the multi-pass amplification stages in the CPA laser. The measurement of $\sim 2\times10^{-8}$ ASE contrast in the range of more than 50 ps before the main pulse is achieved in the 10-TW-level femtosecond CPA laser.

The 10-TW-level/10-Hz Ti:sapphire CPA laser consists of an oscillator, a pulse stretcher, a regenerative amplifier, two stages of multi-pass amplifiers, and a pulse compressor in vacuum chamber. The oscillator generates 82-MHz pulse train with 25-fs pulse duration near 785 nm. Then the pulse duration is stretched to 220 ps by a typical all-reflective Offner-triplet stretcher. After the stretcher, the seed pulses can be amplified to 1075 mJ by the injection into the regenerative amplifier and two stages of multi-pass amplifiers with 2.8-J pump pulse energy in the final amplifier stage. After the amplifiers, the central wavelength of the seed pulses shifts from 785 to 795 nm, and the width (full-width at half-maximum (FWHM)) of the seed spectrum reduces from $\sim$39 to $\sim$21 nm. Then, after the pulse compressor, the laser can output the maximum pulse energy of 770 mJ with 44-fs pulse duration near 795 nm, which can be focused into a focal spot size of 5.8 μm (FWHM) and produces $>10^{19}$ W/cm^2 peak focused intensity[12]. At this intensity level, the contrast of 10^{-8} before the main pulse is required in many experiments.

Besides the ASE pedestal, the pre-pulses leaking from the regenerative amplifier still should be considered in the contrast measurement. After improving and optimizing the whole laser, we have ridden of the pre-pulses. Therefore, the contrast before the main pulse is due to the ASE pedestal in this case.

In our CPA laser, the ASE pedestal is produced mostly in the Ti:sapphire regenerative amplifier, which operates at the lowest fundamental transverse mode, TEM_{00}. The ASE pedestal level from the regenerative amplifier can be estimated by using the basic principles of quantum mechanics. For the higher seed pulse energy, the ASE pedestal level will be reduced and the ASE contrast will be improved respectively[13].

In order to experimentally study the influence on the level of ASE contrast resulting from different seed pulse energies, we measured the ASE contrast of the output pulse from our CPA laser with a commercial third-order cross-correlator (SEQUOIA, Amplitude Technology Inc.). The dynamic range of the third-order cross-correlator is $>10^9$, and the maximum scanning range of it can extend from −480 to 150 ps.

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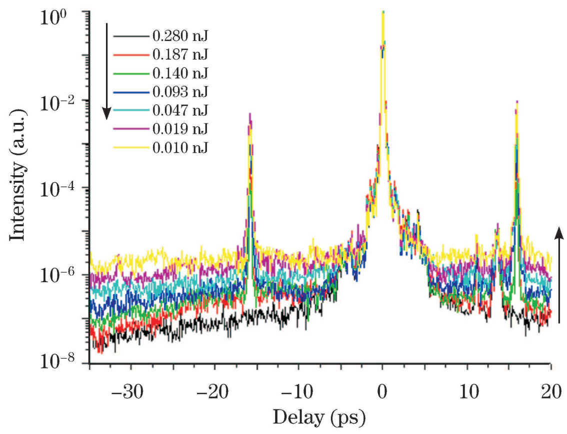

Fig. 1. Third-order cross-correlation traces with different seed pulse energies.

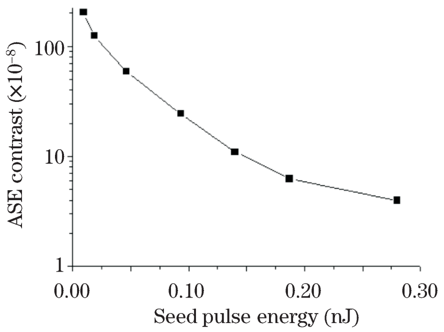

Fig. 2. ASE contrast around −35 ps before the main pulse with different seed pulse energies.

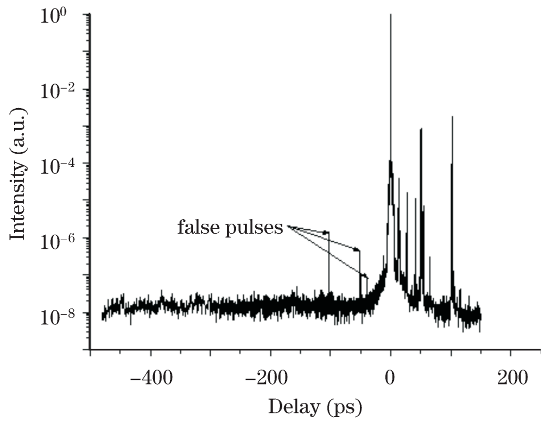

Fig. 3. Third-order cross-correlation trace of the 10-TW-level femtosecond CPA laser.

The energy of the seed pulse injected into the regenerative amplifier was changed from 0.28 to 0.01 nJ by a neutral attenuator, and the output energy from the CPA laser was almost invariable. A scanning range of −35 to 20 ps was used in the measurement. The measured third-order cross-correlation traces with the different seed pulse energies are shown in Fig. 1.

In Fig. 1, a compressed prior pulse before the main pulse can be found in the cross-correlation trace when the seed pulse energy changes from 0.01 to 0.28 nJ. The prior pulse is identified as an artifact coming from a real post-pulse generated at the neutral attenuator, which is due to the multiple-reflections of the main pulse on the optical components. Without the neutral attenuator, when we made the measurement with the seed pulse energy of 0.28 nJ, the prior pulse disappeared.

Within the range from −5 to 5 ps for the main pulse, the symmetric shoulders starting from the 10^{-6} level appear. The level of the shoulder does not change with the increase of the seed pulse energy. For this feature, the shoulder is clearly independent of the seed pulse energy, just because it does not originate from the ASE but from the uncompensated residual phase of the amplified pulse.

Outside the above range, the ASE pedestal level decreases with the increase of the seed pulse energy. Considering that the ASE background extends to several hundreds picoseconds and seed pulses are stretched to the duration of 220 ps, the ASE background will coexist with the seed pulse within the range of the stretched pulse duration. The fact that the ASE pedestal level decreases with the increase of the seed pulse energy has shown that the ASE pedestal can be better suppressed by the seed pulse with higher energy. In addition, a downward trend along the ASE pedestal can be found in the cross-correlation trace when the seed pulse energy is higher than 0.047 nJ. When the seed pulse energy is less than 0.047 nJ, we cannot observe an obvious downward trend and the ASE pedestal is almost flat. This feature has also been used to testify that the ASE pedestal can be better suppressed by the seed pulse with a higher energy. The experimental result is in agreement with the theory, and we can conclude that for the higher energy of the seed pulse injected into the amplifier, the ASE pedestal level will be reduced and the ASE contrast will be improved further.

In order to have a clear observation about the influence on the level of ASE contrast resulting from the different seed pulse energies, a curve of ASE contrast around 35 ps before the main pulse versus the seed pulse energy is shown in Fig. 2. We can observe that the ASE contrast changes nonlinearly with the increase of the seed pulse energy, and there exits a saturable tendency. From Fig. 2, the contrast should be improved with the higher seed pulse energy, but it is hard to be better than 10^{-8}. Therefore, the intrinsic ASE noise can be regarded as $\sim 10^{-8}$ in our 10-TW-level femtosecond CPA laser.

Finally, we optimized our CPA laser system, and a full measurement of $\sim 2\times 10^{-8}$ ASE contrast in the range of more than 50 ps before the main pulse was achieved in the 10-TW-level femtosecond CPA laser. The measured third-order cross-correlation trace is shown in Fig. 3. The pre-pulses before the main pulse in Fig. 3 are demonstrated as the artifacts generated in the third-order cross-correlator during the measurement.

It is shown in Fig. 3 that the contrast in the several hundreds picoseconds region is uniform and almost the same as the contrast around 35 ps before the main pulse. It means that the ASE is suppressed efficiently in the $\sim$220 ps time window of the chirped pulse. The post-pulses after the main pulse can be contributed to the optics reflection in the laser and the third-order cross-correlator, which can be neglected in most physic experiments.

In conclusion, the influence on the level of the ASE contrast resulting from different seed pulse energies has been experimentally studied in a 10-TW-level femtosecond Ti:sapphire CPA laser. The experimental results have shown that, with the energy of the seed pulse injected into the amplifier increasing, the ASE pedestal is suppressed more efficiently, and the ASE contrast is improved. However, it is found that there exists a saturable tendency with the increase of the seed pulse energy, which is due to the intrinsic ASE noise in the regenerative amplifier and the following multi-pass amplification stages in the CPA laser. With the optimization of the whole laser system, the measurement of 2×10^{-8} ASE contrast in the range of more than 50 ps before the main pulse is achieved in our 10-TW-level femtosecond CPA laser. The ASE contrast has satisfied the requirement of most experiments based on our laser and the focused intensity.

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