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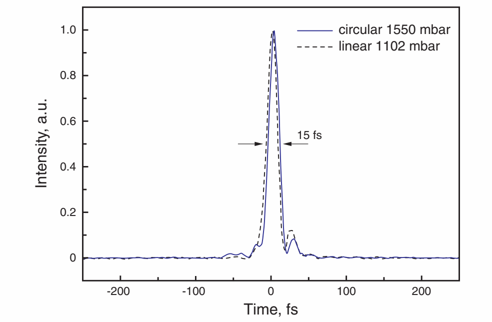
Abstract: Pulse compression through filamentation in an argon-filled cell was experimentally demonstrated by using circularly and linearly polarized pulses. A 53 fs circularly polarized pulse was successfully compressed to 15 fs. By using circularly polarized pulse input, the broadened spectrum was much wider and the incident energy in the gas cell can be increased by more than 3/2 times. Much shorter pulse could be compressed by using circularly polarized pulse input.



The temporal profile of the compressed pulse

Polarization-dependent pulse compression in an argon-filled cell through filamentation

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Over the past decades, the propagation of intense femtosecond duration laser pulses in bulk media [1], gases [2], and water [3] obtained great attention and development. Such study is important in many areas of high field science, such as generation of x-ray laser [4], laser-particle acceleration [5], and high harmonic generation [4]. Also pulse compression through nonlinear propagation has been widely studied in the past years [6–12]. The pulse compression technology is mainly based on spectrum broadening introduced by self-phase modulation (SPM) in the nonlinear medium and subsequently dispersion compensation by using an appropriate dispersive delay line.

Single mode optical fiber was used as the nonlinear medium to broaden the spectrum early in 1980's [6]. However, the incident pulse energy was limited to nJ level due to the low damage threshold of the fiber. Recently, pulses about 10 fs with mJ level energy were obtained by using hollow fiber filled with noble gas or hollow fiber with a pressure gradient as the nonlinear medium to broaden pulses spectrum [9–11]. The diameter of the hollow fiber used in the experiment was about several hundred microns and the hollow fiber must be strictly straightened, which made the experiment complicated, sensitive, and difficult to operate.

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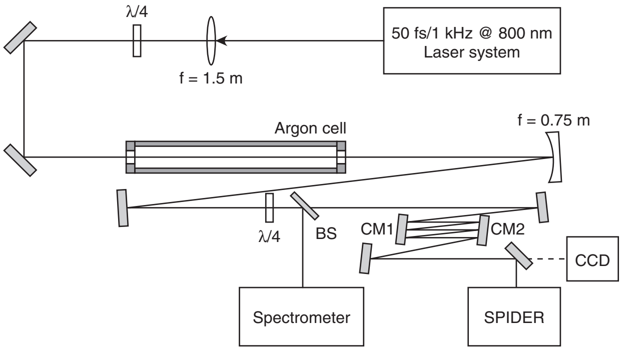

Figure 1 Schematic of the experimental setup. BS: beam splitter, CM1, CM2: chirped mirrors

More recently, a new method that through filamentation in the gas was used to obtain even shorter femtosecond pulses [11–14]. By using two succeeded argon cells, Hauri [11] obtained 5.7 fs pulses through filamentation in the argon gas and Trushin [13] obtained supercontinuum from >1000 nm to 250 nm. By using linearly polarized pulse input, 53 fs laser pulse also was compressed to less than 20 fs at lower energy input in one gas cell [14]. As is well known, the self-focusing takes place due to the optical Kerr effect when the laser power higher than the self-focusing critical power ($P_{crit} = \lambda^2/2\pi n_0 n_2$) in the propagation process of the intense femtosecond pulses in the argon cell. The pulse intensity gets stronger due to self-focusing as the pulse propagate in the medium. When the intensity is strong enough, multi-photon ionization (MPI) occurs and plasma formed, which acts as negative lens to defocusing the beam. The balance among the self-focusing, diffraction, and defocusing provides a stable formation of the filament, which maintains high peak intensity around 10^{13} W/cm^2 over a long distance. The filamentation self-guides the beam as a spatial filter and spectrum broadens the pulse due to SPM just like in a hollow fiber. Compared with the hollow fiber, this technique is robust and highly efficient. The unwanted energy fluctuations and the fluctuations of other pulse parameters of the output pulse can be avoided because there is no requirement of the incident pulse to be coupled into the hollow fiber accurately.

In this paper, by using an argon-filled cell, we compressed a 50 fs circularly polarized pulse to 15 fs. Compared with linearly polarized pulse input, it can increase the input pulse energy about 3/2 times by using circularly polarized pulse input. The compressed pulse had excellent pulse stability and the beam acquired a high spatial quality. Higher energy pulse could be compressed to much shorter by using circularly polarized pulse input.

The experiment setup used for pulse compression is shown in Fig. 1. The laser source used in the present experiment is a commercial chirped-pulse-amplified Ti:Sapphire laser system (Spectral-Physics, Spitfire) running at a 1 kHz repetition rate, producing ~ 0.7 mJ/pulse, and ~ 50 fs in duration with a central wavelength at 800 nm. Typically, the bandwidth (FWHM) of the pulse is about 22 nm, and the beam quality parameter M^2 is about 1.3 with 7 mm beam diameter (at $1/e^2$ of the peak intensity). A zeroth-order quarter waveplate is used to change the polarization of the pulse after the laser system. The beam is focused by an $f = 1.5$ m lens into an argon-filled cell. After passing through the argon-filled cell, the transmitted beam is then collimated by an $f = 0.75$ m sliver-coated concave mirror. A second zeroth-order quarter waveplate is used to change the polarization of the pulse back to be linear. A small fraction of the beam is then reflected by a 4% splitter to a grating spectrometer (SpectraPro-300i, Acton Research Corporation) to monitor the spectrum. The transmitted beam is sent to a chirped mirror pair (– 50 fs^2). After several bounces on the chirped mirror, the pulse is sent to the spectral phase interferometry for direct electric-field reconstruction (SPIDER) instrument (APE, Co. Ltd) to measure the spectral phase and temporal profile of the compressed pulse.

The temporal profile and spectral phase of the input pulse after the lens was characterized by using SPIDER to ensure the input pulse have no chirp. The length of the argon cell used in the experiment is about 77 cm. The incident and export windows are both 1-mm-thick fused silica glass plates, the incident side of which is anti-reflection coated. The argon cell was vacuum pumped at first and then filled with high pure argon gas. The input-pulse energy is 0.58 mJ. The optimum pulse shortening from 53 fs to 15 fs was achieved at the pressure of 1102 mbar of argon gas when the input pulse is linear polarization. For circularly polarized pulse, the optimum pulse shortening from 53 fs to 15 fs was achieved at the pressure of 1550 mbar of argon gas. There was about 8-cm long filament at the center of the cell near the focus of the lens, as estimated from the length of the scattered broadband continuum.

Fig. 2a shows the spectrum of the incident pulse after passing through the argon cell at different pressure with 0.58 mJ input. The outgoing pulse energy from the argon cell is 0.53 mJ with the transmitted efficiency about 90%. The spectral FWHM bandwidth increased from 22 nm to about 58 nm for linearly polarized pulse input at 1102 mbar gas pressure. For circularly polarized pulse input, the spectral bandwidth was narrower than that with linearly polarized pulse input at 1102 mbar gas pressure. It is because the nonlinear coefficient is much smaller for circularly polarized pulse at the same gas pressure. When the pressure of the gas increased to 1550 mbar, the linearly polarized beam after the gas clearly showed conical emission, but the spectrum of transmitting pulse show very small broadening. However, for circularly polarized pulse input, the spectrum broadening was greatly enhanced and the spectral bandwidth of the transmitting pulse broader than that with linearly polarized pulse input, shown in Fig. 2a. It is because the nonlinear coefficient is lower for circularly polarized pulse input that the self-focusing is much slow [15,16]. Furthermore, the multiphoton ion-

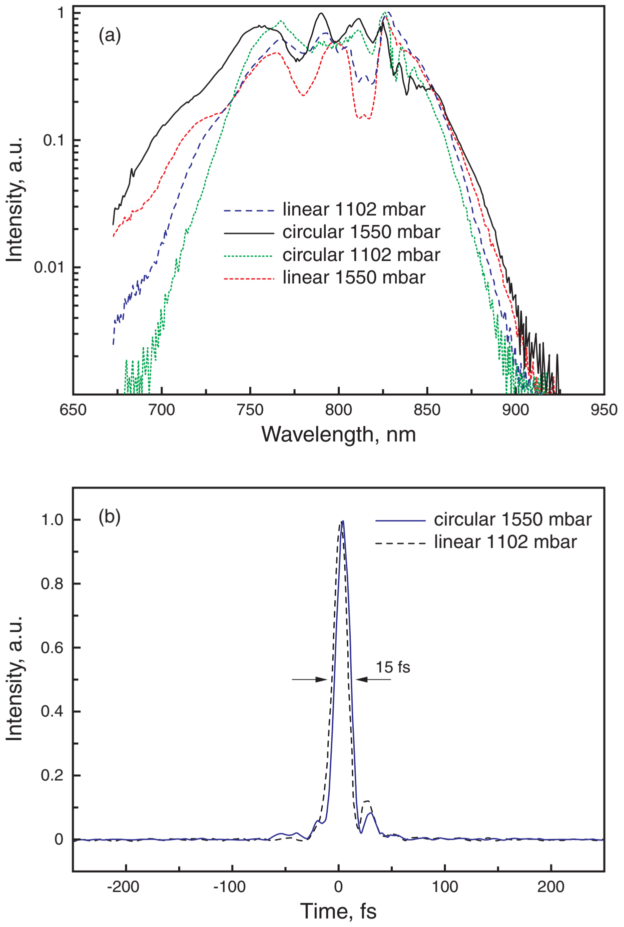

Figure 2 (online color at www.lphys.org) The spectrum (a) and the temporal profile (b) of the compressed pulse

ization (MPI) and multiphoton absorption (MPA) are less efficient [16,17] that the energy loss is smaller for circularly polarized pulse input. Then the filamentation in the gas cell could be thinner and maintained for much longer propagation distance. The thinner and longer filamentation induce broadening spectrum for circularly polarized pulse input.

Fig. 2b also shows the temporal profiles of the compressed 15 fs pulse. It is obvious that circularly polarized pulse could reach the good compression at a relatively higher gas pressure. It is also expected that much shorter compressed pulse could be obtained with better dispersive compensation owing to the broad spectral bandwidth for circularly polarized pulse input. For linearly polarized pulse, conical emission occurs when the energy of the incident pulse was about 0.40 mJ at 1800 mbar gas pressure. The incident pulse energy of the occurring the conical emission at 1800 mbar gas pressure for circularly polarized pulse was 0.58 mJ, which was about 3/2 times of that for circularly polarized pulse input. The multi-filamentation is a cause of limitation of the input pulse energy to be used for filamentation. It is known that by using circularly polarized pulse input, the multi-filaments can be suppressed [18]. Therefore it is expected that higher energy pulse can be compressed by using circularly polarized pulse input.

In conclusion, we compared a pulse compression technique by using circularly and linearly polarized pulse incident into an argon-filled cell. We have successfully compressed the intense pulse from 53 fs to 15 fs. By using circularly polarized pulse input, it is further expected that few cycle laser pulses with high energy are to be obtained in the near future. Such pulses obtained will enable us to explore soft x-ray as well as attosecond sciences.

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