ASE pulse compression using optical breakdown clipping technology in liquid medium

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Using the method of optical breakdown clipping on Krypton Fluoride excimer laser, ASE (Amplified Spontaneous Emission) pulse compression technology was studied in this paper. And the liquid medium breakdown depth on the ASE pulse compression effect was analyzed. The initial ASE pulse width was 16.8 ns; the shortest 8.4 ns ASE pulse was obtained in the experiment. The auxiliary beam induced luminescence breakdown was used to study on the law of optical breakdown clipping, and the short 7.3 ns ASE pulse was got. These experimental results proved that the auxiliary beams are useful to accelerating the plasma generation rate and duration. The results ASE pulse compression can be controlled in some degree.

Key words: optical breakdown; excimer laser; pulse compression.

Introduction

ICF (Inertial Confinement Fusion) and related physical experiments require different time shape of the laser pulses output from high power laser drive system. Especially in order to meet the need of the state equation, the optical pulse should be compressed to a specific time distribution [1, 2]. For the high energy, short wavelength, and high efficiency of the KrF excimer laser, it plays an important role in the research of the ICF [3–6]. But the technology of the KrF laser pulse compression is one of the factors to limit in application. However, the ASE pulses outputting from the KrF excimer laser have evident advantages in the spatial energy distribution, incoherent and natural bandwidth than the laser pulses [7, 8]. Recently, the combination of the SRS (Stimulated Raman Scattering) and SBS (Stimulated Brillouin Scattering) [9], the combination of the SRS and the fast Pocketls cell [10], the same frequency pulse amplification [11], the SRS [12] and other methods were used to compress the pulses of the KrF laser. These studies have some reference value to the ASE pulse compression.

To our knowledge, the ASE pulses compressions are rarely seen in the reports. They have many potential applications in the ICF studies. Therefore, this technology should become the focus of attention. In accordance with the characteristics of the ASE source, the method of the optical breakdown was employed to compress the ASE pulses output from the KrF laser. It proved a reference for the pulse output to meet the need of the state equation.

1. Theory and experimental setup

1.1. Theory

When the optical intensity reached the breakdown threshold, the optical breakdown phenomenon appears. Most energy of the incident pulse were absorbed, reflected or scatted by the plasma. Only a small part of the energy can pass through the breakdown region.

Accounting of the spatial and temporal distribution of the Gaussian beam,

$$I(z,t) = \frac{P_{\max}}{\pi r(z)^2}\exp\left[-4\cdot\ln 2\left(\frac{t}{\tau_p}\right)^2\right], \quad (1)$$

where γ_0 is the radius of the beam waist; $\gamma\ (z)$ is the radius of the Gaussian beam at the distance of z on the optical axis; $r(z) = r_0\left[1-(z/z_r)\right]^{1/2}$; $z_r = \pi r_0^2/\lambda$ is the confocal parameter; $P_{\max}$ is the peak power; τ_p is the pulse width. The zero point of t corresponds to the point of the pulse peak power.

The rate equation of the plasma density can be written as,

$$\frac{d\rho(t,z)}{dt} = \left(\frac{d\rho(t,z)}{dt}\right)_{mp} + \eta_{casc}(t,z)\rho(t,z) -$$
$$- g(z)\rho(t,z) - \eta_{rec}\rho(t,z)^2; \quad (2)$$

$$n_p = \left(1-\frac{\rho e^2}{\omega_0{}^2\varepsilon_0 m_e}\right)^{1/2}. \quad (3)$$

From Eq. (3), it can be seen that when the plasma density ρ becomes larger, the refractive index decreases. The plasma density reaching the breakdown threshold is approximately in the orders of magnitude 10^{26}

$$\frac{dI(t,z)}{dt} = c\frac{dW_1}{dt}\rho(t,z) =$$

$$= -c\left(\frac{e^2 I(t,z)}{cn\varepsilon_0 m_e}\right)\left(\frac{\tau}{\omega^2\tau^2+1}\right)\rho(t,z). \qquad (4)$$

Assuming the energy of the ASE pulse is fixed, another high intensity pulsed light was used to irradiate the breakdown region. It can be effectively improve the initial electron density. So that the plasma generating time can be shortened, the duration of the plasma can be extended, the width of the ASE pulse can be narrowed, the pulse trailing edge becomes smaller.

1.2. Experimental setup

The experimental setup is shown in Fig. 1. The optical elements are all quartz materials applicable for 248 nm light; L_1, L_2 are lens with 500.0 mm focal length; L_3 and L_4 are lens with 30.0 mm focal length; M_1 and M_2 are reflection mirrors; M_3 is a half reflection mirror; C is the quartz cuvette.

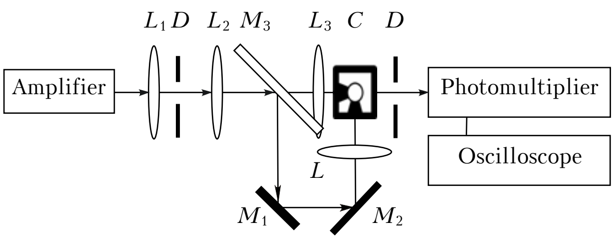

Fig. 1. Experimental setup

After removing the front mirror of the KrF laser, the output ASE pulses were collimated by the L_1 and L_2, focused by L_3 and L_4, finally located in the cuvette. C_2H_5OH and CS_2 mixed liquid is load in the cuvette. Adjusting the lens to coincide the two focal spots, the compressed ASE pulses are recorded by the photomultiplier. And the pulses waveform can be collected by the oscilloscope.

2. Analysis of experimental results

The ASE pulse waveform before compression is shown in Fig. 2. The rising time is 8.2 ns, pulse width is 16.8 ns.

The optical breakdown clipping experiments are operated by using the ethanol mixed liquid. When the spark can be observed at the focal spot region and breakdown sound accompany, it means that the optical breakdown was produced.

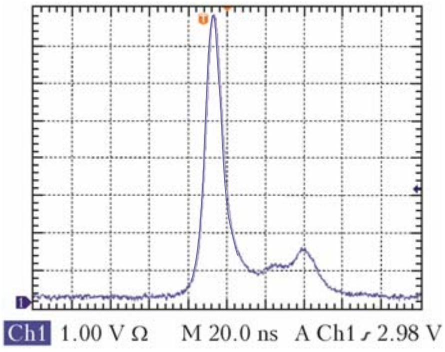

Fig. 2. ASE pulse waveform

2.1. Influence of different breakdown depth on the width of the transmittance ASE pulse

The size of the cuvette in experiment is 12.5 mm × × 12.5 mm × 45.0 mm. Selected breakdown depth too large or too small would make the pulse focal spots falling near the inner wall of the cuvette. So, the 3–6 mm depth was selected. After occlusion the ASE pulse focusing by L_4, the compressed ASE pulse waveform is shown in Fig. 3.

In Fig. 3 are respectively the ASE pulse waveform corresponding with the breakdown depth of 3, 4, 5, and 6 mm. And the corresponding pulse widths are 12.7, 10.4, 9.8, and 8.4 ns. It can be seen that the pulse width narrowing with the increase breakdown depth.

2.2. Influence of additional auxiliary pulse on the ASE pulse compression

Removing the block of the L_4 and adjusting the delay when the main ASE pulse arrives at the cuvette, the optical breakdown depth can be changed by moving the position of the cuvette.

When the breakdown depth id 3 mm, delay is 1 and 3 ns, the ASE pulse before compression is shown in Fig. 4, *a*. Its pulse width is 12.7 ns. The compressed results are shown in Fig. 4, *b* and *c*. Their pulse widths are 10.0 and 8.1 ns.

When the breakdown depth id 4 mm, delay is 1 and 3 ns, the ASE pulse before compression is shown in Fig. 4, *d*. Its pulse width is 10.4 ns. The compressed results are shown in Fig. 4, *e* and *f*. Their pulse widths are 9.5 and 7.3 ns.

3. Analysis and discussion

The experimental results show that the width of the ASE pulse is inversely proportional to the breakdown width, and the trailing edge becomes smaller. This is because when the breakdown width is small, the plasma can't fully absorb the reflected ASE pulse.

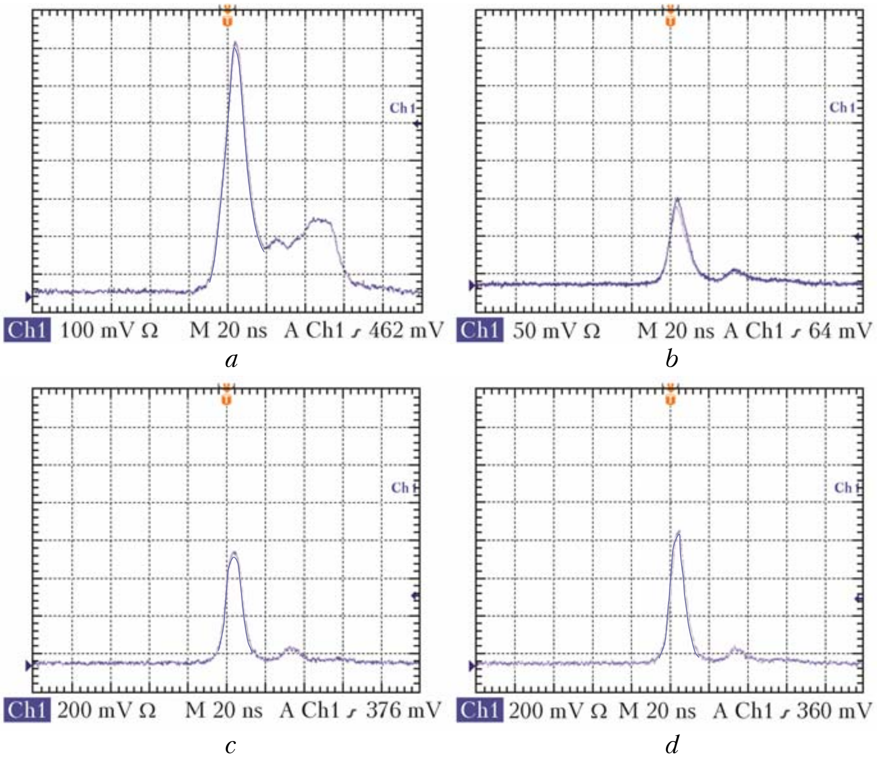

Fig. 3. Transmitted ASE pulse waveform with different breakdown depths

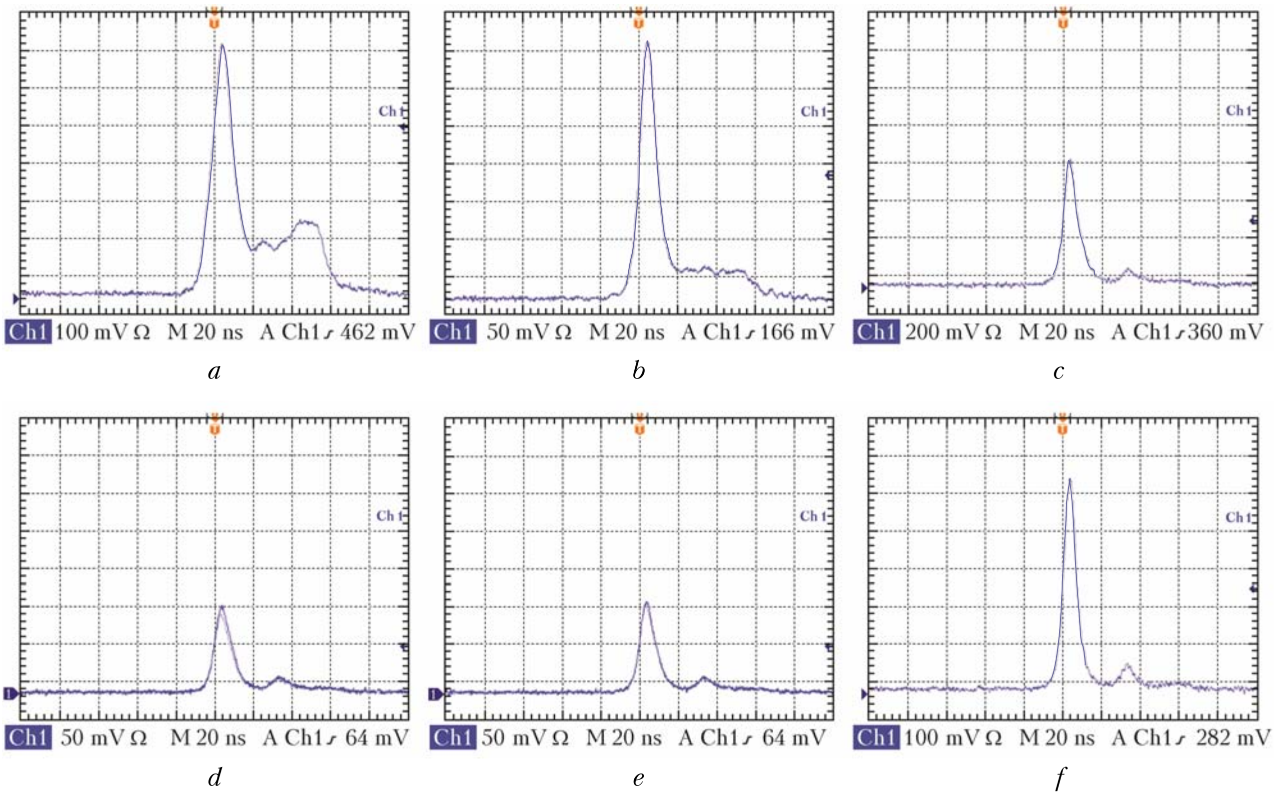

Fig. 4. Transmitted ASE pulse waveform with assisted breakdown

Therefore there is a small peak in pulse trailing edge. With the increase of the breakdown width, the plasma in liquid is fully absorbed, so that the ASE pulse width is narrowed.

Additional auxiliary pulse optical breakdown experimental results show that the auxiliary pulse can narrow the main ASE pulse at the same breakdown depth. This is because the auxiliary pulse improved the energy intensity of the ASE pulse focused area. This decreased the plasma generating time and increased its duration, so that the ASE pulse got better compression.

By controlling the breakdown depth and the related delay, the ASE pulse width can be compressed in a certain range.

Conclusion

Using the optical breakdown clipping method, the 248 nm ASE pulses compression was discussed in this paper. Changing the breakdown depth, Short pulses of 8.4 ns were obtained from the 16.8 ns initial pulses. The experimental results show that changing the breakdown depth of the ASE pulse has a pronounced effect on the ASE pulse compression. In addition, changing the related delay between the auxiliary breakdown beam and the main ASE pulse, a 7.3 ns ASE transmitted pulse was obtained. These proved that the auxiliary breakdown used for the optical breakdown clipping ASE pulse compression is feasibility. And it is accordance with the theory analysis.

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