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A Compact Femtosecond Ti:Sapphire/KrF Laser System

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Abstract

A compact femtosecond Ti:sapphire/KrF laser system which produces ultraviolet and ultrashort pulse has been developed. It consists of a mode-locked Ti:Sapphire laser, a regenerative amplifier , a frequency conversion system and a KrF excimer amplifier. The system can produce 50 mJ of pulse energy at a pulse width of 440 fs. The pulse width can be reduced down to 100 fs region using a prism pair compressor.

Keywords: ultrafast phenomenna, ultraviolet laser pulse

1 INTRODUCTION

The rapidly-developed femtosecond technology makes it possible to produce a table-top coherent X-ray source from laser produced plasma by terawatt ultrashort pulses ranging from IR to UV [1,2]. A high power UV and ultrashort pulse system contains an excimer amplifier (ArF, KrF, XeCl, etc.) and an ultrashort seed pulse generator at UV wavelength which is usually produced by frequency doubling or tripling from visible or IR laser pulses. Since KrF has a fully saturated gain bandwidth of 2 nm, it is found to show very good performance as a subpicosecond amplifier, and a potential pulse compression ability at the excimer wavelength of 248 nm [2,3], the generation and amplification of femtosecond pulses at this wavelength becomes our interest. There have been a few seed pulse amplification systems developed at KrF wavelength [3-6]. In those systems, the amplification of infrared seed pulse was done by a few multiple-pass amplifiers rather than by a regenerative amplifier, which makes the system complicted and less efficient. In our system, we used a wavelength controlled regenerative amplifier and a delay compensated frequency tripling kit to produce a 100 μJ seed pulse at 248 nm. This seed pulse energy is enough to be amplified to 50 mJ by 3-pass in a single excimer amplifier.

2 SYSTEM DESCRIPTION

The laser system is shown in Fig. 1. The self-mode-locked Ti:Sapphire laser is pumped by a Spectra-Physics model 2060 argon ion laser. The original pulse at 745 nm is generated from a modified mode locked Ti:Sapphire laser (Clark Instrumentation model NJA-3). The pulse is stretched to about 300 ps by a grating pair stretcher which has a net slant distance of 76.9 cm at a diffraction angle of 31.0°. The pulse is amplified by a regenerative amplifier to 2 mJ and compressed by a grating pair compressor which has a slant distance of 79.2 cm at a diffraction angle of 30.7° in order to remove both the second and third order dispersions, including the dispersions imposed by the amplifier. The wavelength of this pulse is converted by a tripling kit to 248 nm so that it can be amplified by a KrF excimer amplifier.

In this tripling scheme, two BBO crystals are used for the frequency doubling and tripling. The doubler BBO is cut at 31.2° and the tripler is cut at 48.9°, both for type I phase matching. The thinkness of the crystals are 0.4 mm and 1 mm respectively. After the frequency doubling, the fundamental and the second harmonic waves are separated by a harmonic beam splitter. The length of the arm for the second harmonic wave is adjustable so that the group delay between the fundamental and the second harmonic waves can be compensated. A halfwave plate is inserted in this arm to rotate the polarization of the second harmonic pulse consistent with that of the fundamanetal beam. Both fundamental and second harmonic pulses coincide at the tripling crystal by the second harmonic separator. Their overlaping in the crystal is obtained by adjusting the delay line. The advantage of the system is the compensation for not only the group delay but also for the walk-off angle, by adjusting the vertical position of the fundamental or second harmonic waves independently. The convertion efficiency is about 10%.

This seed pulse is amplified by 3-pass configuration in a Questek V_β excimer amplifier.

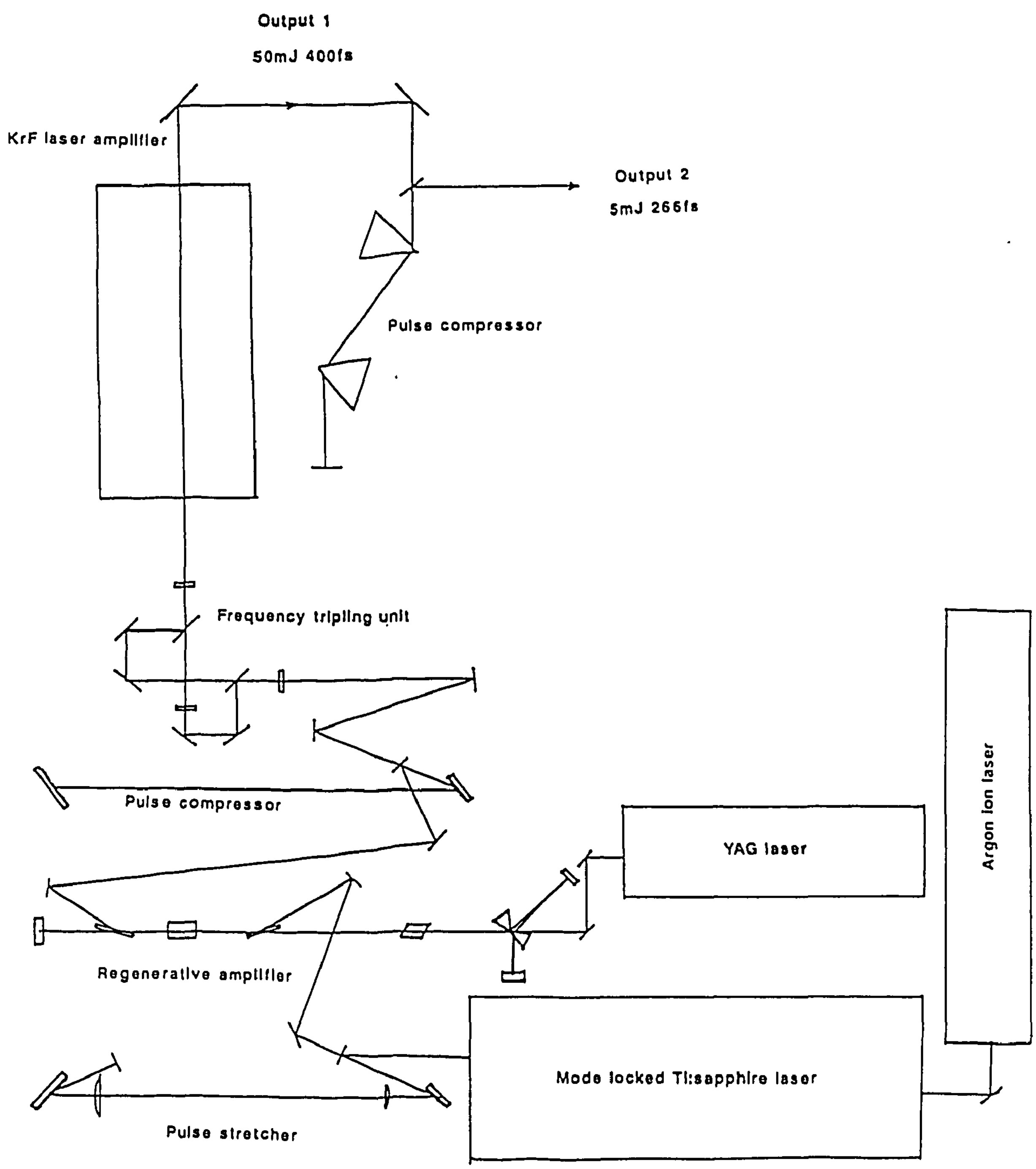

Figure 1: Schematic of the femtosecond KrF pulse generation system

After amplification, the pulse is compressed by a quartz prism pair. The distance between the prisms is adjustable. The whole system (except the KrF amplifier) is sitting in a 1.2×3 m^2 optical bench.

3 PULSE WIDTH AND SPECTRAL BANDWIDTH MEASUREMENTS

The pulse width and spectral width were measured during the amplifications. The seed pulse from the mode locked Ti:Sapphire laser was measured to be 46 fs at a bandwith of 13 nm. After the regenerative amplification, and compression, the pulse becomes 90 fs at a bandwidth of 12 nm. The pulse broadening is due to the uncompensated dispersions introduced in the pulse stretching and amplification. The sepctral bandwidth of the seed and amplified KrF pulse is shown in Fig. 2. The bandwidth of the third hamonic pulse is 0.45 nm. The excimer amplifier broadended the spectrum to be 0.68 nm The pulse width of the amplified KrF laser output was measured by an autocorrelator with the use of two-photon absorption in the BaF_2 crystal. Using BaF_2 other than CaF_2 or excimer gas is because the emission of BaF_2 is stronger than that of CaF_2 [7] and the device is simpler than the excimer gas chamber[8]. The measured autocorrelation trace of the amplified KrF pulse is shown in Fig. 3. The half width of this trace is 680 fs, corresponding to a pulse width of 440 fs, if a Gaussian profile is assumed. When the pulse passes a prism pair compressor, the minimum pulse width of 260 fs is obtained at a prism separation of 58 cm. The separation is different from our calculated 20 cm. The energy from the prism pair is 5 mJ. This low energy is due to the high reflection of the prism surfaces because the output is not a polarised beam anymore. Antireflection coated prism pair with one pass configuration is going to be used.

4 DISCUSSIONS

The pulse width of the KrF output has not been measured to as short as the seed pulse for some possible reasons. First, the autocorrelation trace we measured is the average of many pulses, because the single shot autocorrelation signal is too weak to be de recorded. Due

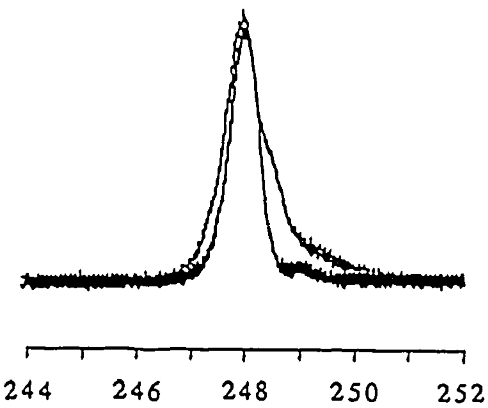

Figure 2: Spectra of the seed and the amplified pulses at 248 nm. seed pulse (third harmonic wave of 745 nm): 0.45 nm; amplified pulse: 0.68 nm.

to our poor switch characteristics of Pockels cell driver, there are sometimes double pulses in the output of the regenerative amplifier and the pulse width may vary from pulse to pulse and shot to shot. The second reason is that the higher order dispersions during the amplifications have not been well compensated. In the caululations only the dispersions in the CaF_2 windows were included. The other dispersions such as the dispersions in the frequency tripling crystals have not been taken into account. One difficulty in compression is that the high order dispersions can not be fully compensated by adjusting the prism separation or prism insertion, unlike the case of the grating pair in which the second and third order dispersions can be simultaneously compensated by adjusting the difraction angle. To obtain a shorter KrF pulse, the spectral width of the seed pulse should be as wide as possible. We have developed a broadband third harmonic wave generation scheme which increased the bandwidth of the seed KrF pulse to 1.3~1.5 nm. We expect to amplify and compress this pulse to sub 100 fs.

5 CONCLUSIONS

We have developed a femtosecond KrF laser pulse generation and amplification system. With the use of the regenerative amplifier and the delay compensated frequency tripling

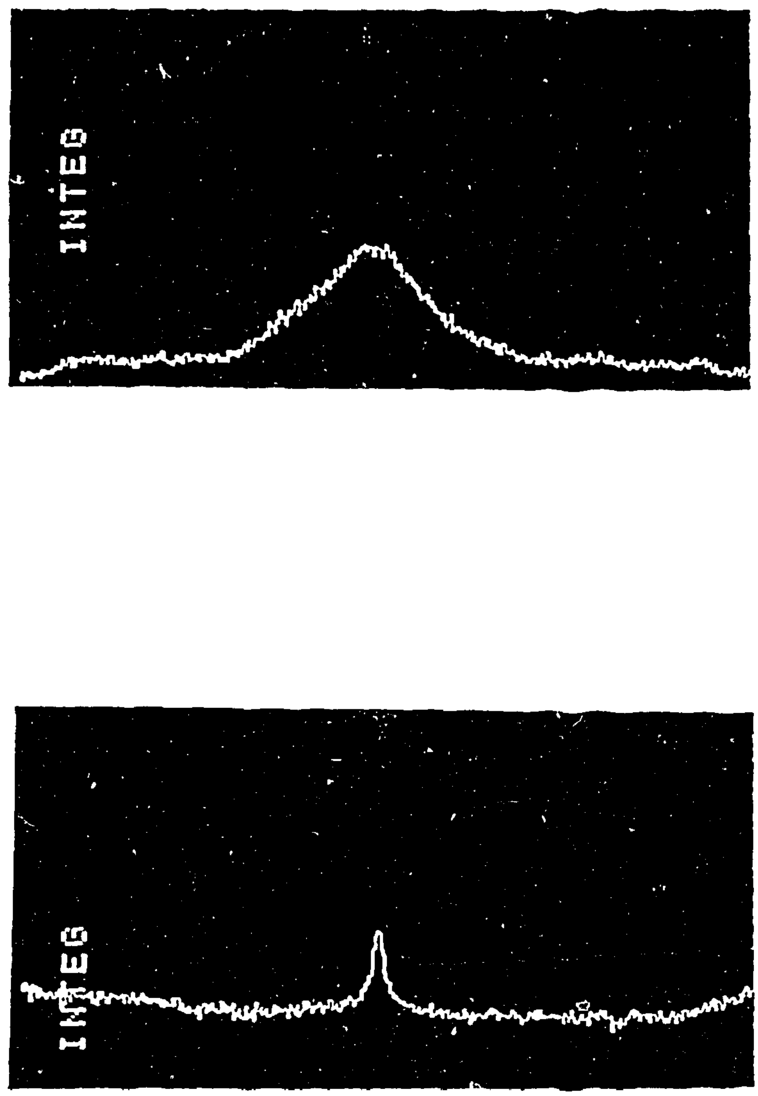

Figure 3: Autocorrelation traces of the amplified KrF pulses. a) measured directly from the amplifier (FWHM=680 fs, τ_p=440 fs); b) measured after compression (FWHM=400 fs, τ_p=260 fs). Note that the autocorrelation traces are not plotted in the same scale.

system, we can produce 100 μJ seed pulse at 248 nm. This seed pulse is amplified to 50 mJ in a single KrF excimer amplifier. The minimum pulse width is 260 fs. Further compression is under progress. Such a laser pulse is going to be used to produce high temperature and high density plasma for soft X-ray generation and to trigger the lightning discharge.

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