High Repetition Rate Amplification of Femtosecond Pulses in the Ultraviolet Spectral Range

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Abstract. UV optical pulses at 248 nm and 193 nm generated by frequency conversion of high-repetition rate Ti: sapphire laser pulses are amplified in commercial excimer amplifiers at up to 500 Hz repetition rate. At 248 nm maximum pulse energies exceeding 10 mJ at pulse durations of 350 fs have been obtained. At 193 nm average powers of 290 mW at 400 Hz with pulse durations of 300 fs have been generated.

Introduction

There is considerable interest in the development of excimer laser systems emitting high intensity, ultrashort optical pulses in the ultraviolet (1-3) for a variety of potential applications. All these systems are based on amplification of ultrashort seed pulses in excimer gain modules. Until now all fs amplification systems were restricted to rather low repetition rates (<30 Hz) which results for many applications in a decrease in signal-to-noise-ratio due to the low data acquisition rate. Here we report on the amplification of fs pulses in commercial KrF and ArF amplifiers at repetition rates up to 500 Hz resulting in femtosecond pulse trains with single pulse energies above 10 mJ at 248 nm and 1 mJ at 193 nm.

Experimental

The generation of the femtosecond UV seed pulses from the Ti: sapphire regenerative amplifier system by frequency tripling and quadroupling has been reported earlier (4). The experimental arrangement is shown in Fig. 1.

The stable operation of the oscillator/amplifier system critically depends on the timing synchronization of its different components. The 41-MHz output of the driver electronics for the acousto-optic modulator of the fs-Ti:sapphire oscillator is divided down to the desired repetition rate (50 Hz-1 kHz) by the MEDOX-Pockels cell driver DR85-A. This TTL-signal is used for direct triggering the Q-switch of the Nd:YLF pump laser. Two programmable delays of the pockels cell driver define the moments to switch the stretched fs-pulse into the amplifier laser cavity and to switch out the amplified pulse. Additionally to this "normal" timing circuit the TTL-pulse also starts an adjustable electronic delay which triggers the amplifier gain module with the excimer controller used to stabilize the time between the start pulse and the discharge of the excimer gain module. The timing jitter between the seed pulses and the gain maximum is typically less than 1.5 ns r. m. s. This is considerably shorter than the temporal width of the gain profile allowing stable amplification of the seed pulses.
Femtosecond Pulse Amplification at 248 nm

The UV seed pulses at $\lambda = 248$ nm are generated by frequency tripling of the 745 nm radiation in two subsequent phase matched BBO crystals. The energy of the seed pulses is typically 4 $\mu$J. Amplification of these pulses was performed in a commercial femtosecond KrF amplifier (based on the Lambda Physik excimer laser LPX 140i).

In single pass geometry at repetition rates up to 500 Hz, the average power of the amplified femtosecond pulses increases linearly with the repetition rate. A maximum average power of 1.0 W was achieved at 500 Hz corresponding to a single pulse energy of 2 mJ.

Off-axis amplification (5) in a double pass geometry has been employed to reach energy levels above 10 mJ with ASE background of less than $10^{-4}$.

To determine the pulse duration of the amplified pulses the cross correlation function was measured. To this aim the pulse energy of the difference frequency signal at $\lambda = 372$ nm generated by mixing the amplified pulses at 248 nm and the fundamental at $\lambda = 745$ nm in a 0.3 mm thick BBO crystal has been determined. The duration of the amplified UV pulses was measured to 350 fs.

Amplification at 193 nm

The seed pulses were first tuned to the peak gain wavelength of ArF (193.4 nm) by tuning the Ti:sapphire system to a wavelength of about 774 nm and adjusting the BBO conversion stages (crystals) for optimum second, third and fourth harmonic generation. The energy of the seed pulses was measured to be about 0.8 $\mu$J and the pulse duration was determined to be 170 fs by a cross-correlation technique (4). Pulse energies up to 110 $\mu$J at 100 Hz repetition rate could be obtained after a single pass which corresponds to a small signal gain of about 140.