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TITLE: SUBPICOSECOND, HIGH-BRIGHTNESS EXCIMER LASER SYSTEMS

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Subpicosecond, High-Brightness Excimer Laser Systems

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Subpicosecond, high-brightness excimer laser systems are being used to explore the interaction of intense coherent ultraviolet radiation with matter. Applications of current systems include generation of picosecond x-ray pulses, investigation of possible x-ray laser pumping schemes, studies of multiphoton phenomena in atomic species, and time-resolved photochemistry. These systems [1,2], based on the amplification of subpicosecond pulses in small aperture (~1 cm^2) XeCl or KrF amplifiers, deliver focal spot intensities of ~10^{17} W/cm^2. Scaling to higher intensities, however, will require an additional large aperture amplifier which preserves near-diffraction-limited beam quality and subpicosecond pulse duration [3]. We describe here both a small aperture KrF system which routinely provides intensities >10^{17} W/cm^2 to several experiments, and a large aperture XeCl system designed to deliver ~1 J subpicosecond pulses and yield intensities on target in excess of 10^{19} W/cm^2. We also discuss the effects of two-photon absorption on large-aperture, high-brightness excimer lasers.

The small aperture KrF system consists of a "front-end" which generates 248-nm seed pulses, followed by two KrF amplifiers. The seed pulses are initially generated at 648 nm with a mode-locked dye laser that uses DCM as the gain dye and DTDCI as the absorber dye. The dye laser is synchronously pumped with the frequency-doubled output of a cw mode-locked Nd:YAG laser. The pulses are then amplified at a 3 Hz repetition rate and frequency-doubled in a 2-mm-thick BBO crystal. The resulting pulses at 324 nm are finally sum-frequency mixed with amplified 1064-nm pulses in a second 2-mm BBO crystal to produce 5- to 10-μJ subpicosecond seed pulses at 248 nm. These pulses are then amplified by two Lambda Physik EMG 200 Series KrF amplifiers, separated by a vacuum spatial filter to suppress ASE and improve beam quality. The output beam diameter is 17 mm and the final output energy at 248 nm is 25 ± 3 mJ with <5% ASE. The pulsewidth, measured using two-photon ionization in NO, is 700 fs. The focused spot size achievable with this system has been determined indirectly by measuring the confocal parameter of a beam focused by f/3 optics. The inferred focal spot diameter is 3.6 μm (twice the diffraction limit), which implies an intensity at the focal plane of 3.5 x 10^{17} W/cm^2. For all experiments parabolic mirrors are used as the focusing optics to preserve pulsewidth, minimize aberrations, and avoid nonlinear absorption and refraction.

This system is routinely operated as a source for several physics experiments [4]. An x-ray spectroscopy experiment has shown that multiphoton processes in a solid aluminum target produce an aluminum ion plasma exhibiting line radiation at energies exceeding 2 KeV. Another experiment has shown that highly charged ion states can be produced by multiphoton ionization. In xenon, for example, absorption of 213 248-nm photons yields a Xe^{+11} ion.

We are currently building a second high-brightness system based on amplification in XeCl, that uses a large aperture (100 cm^2) final amplifier designed to deliver pulse energies approaching 1 J at a maximum repetition rate of 1 Hz. The seed pulse generator scheme is sketched in Fig. 1. Pulses of 175 fs duration at 616 nm are initially generated in a linear-cavity, dispersion-compensated dye laser (Rhodamine 6G/DODCI) that is synchronously pumped by a cw mode-locked Nd:YAG laser. The Nd:YAG laser also provides 1.06-μm seed pulses to a regenerative amplifier, whose frequency-doubled output longitudinally pumps a three-stage amplifier for the dye laser. This synchronous amplification scheme has the advantages of low amplified spontaneous emission, good beam quality, and the elimination of a separate pump laser for the dye amplifier. We observe no temporal broadening of our 175 fs pulses through this amplifier. The amplified 616-nm pulses are then frequency doubled to 308 nm in a BBO crystal. Pre-amplification of these 30-μJ uv pulses to the 3-mJ level is accomplished with a single small aperture commercial XeCl discharge amplifier. The beam is then expanded in a vacuum spatial filter before entering the final amplifier. This 10 x 10 cm^2 aperture device consists of two independently pumped discharge gain regions which share a common x-ray preionizer. The small signal gain, g_0l, in each discharge region is five. The amplifier is triggered by low-jitter, thyratron-switched pulse modulators with three-stage magnetic pulse compression. The resultant jitter is less than 5 ns over a ~50 ns gain time. In order to maintain near-diffraction-limited beam quality at a sustained 1-Hz repetition rate, a transverse gas flow system is used. The wave front distortion is less than λ/20 over 80% of the aperture and the hot gas clears within 30 ms after a shot. Barring additional distortion due to nonlinear refraction in the output window, focal-spot intensities $>10^{19}$ W/cm^2 should be obtained with this system.

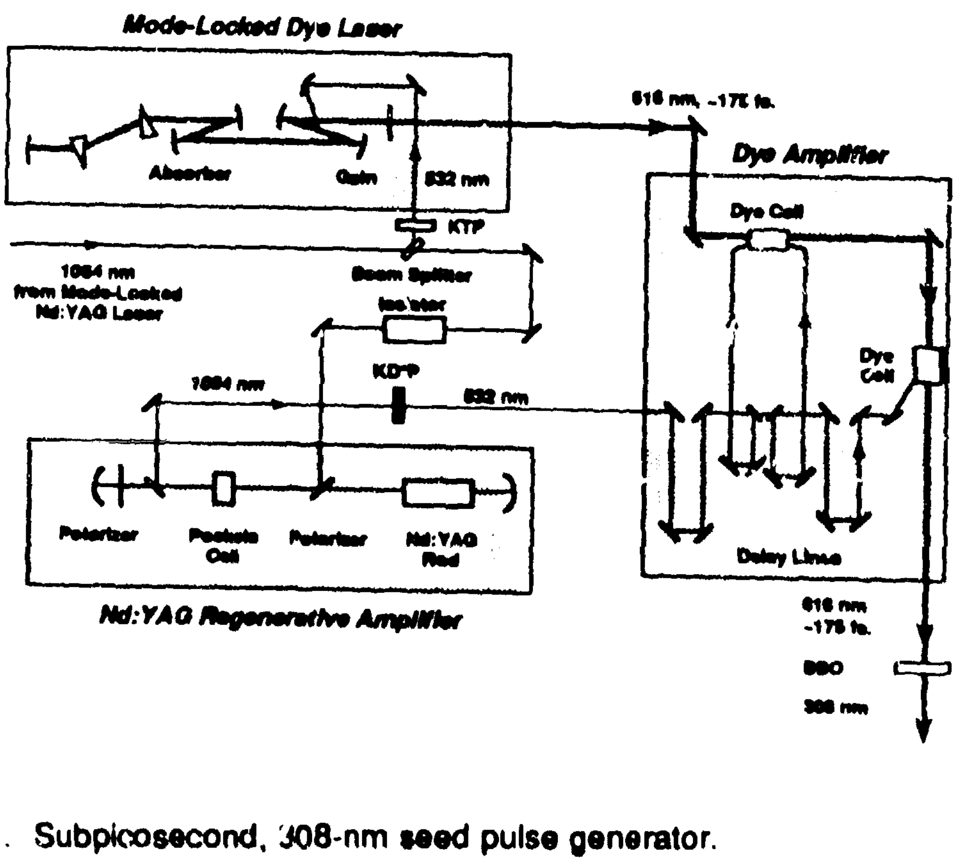

Fig. 1. Subpicosecond, 308-nm seed pulse generator.

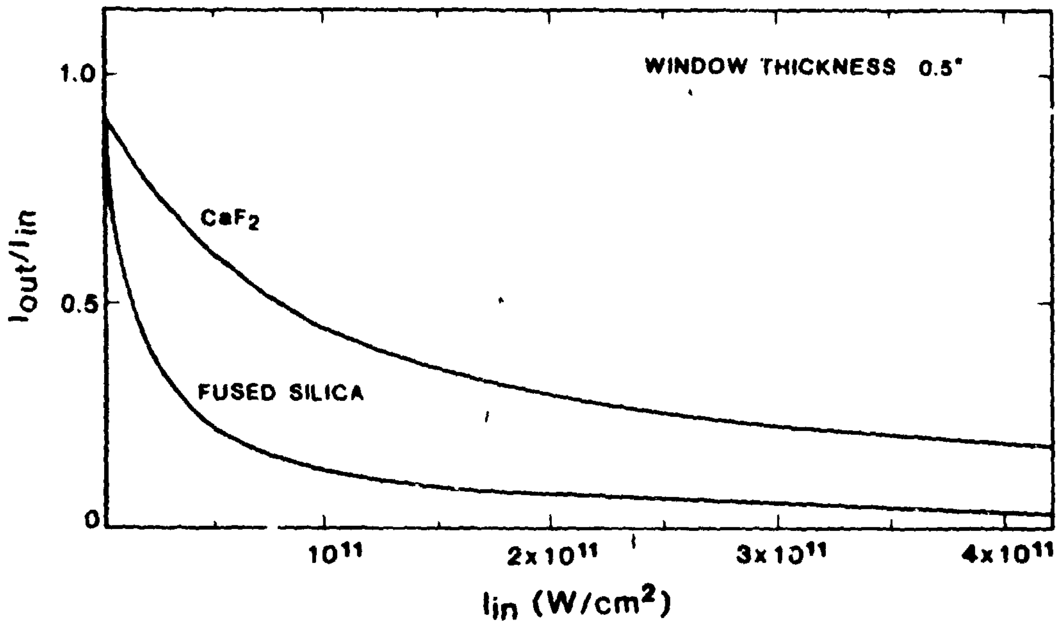

Fig. 2. I_{out}/I_{in} versus I_{in} for 0.5-inch-thick CaF_2 and fused silica samples.

An understanding of nonlinear optical phenomena such as two-photon absorption and nonlinear refraction in ultraviolet window materials at excimer wavelengths is essential for the design of large aperture amplifiers. We have measured the two-photon absorption coefficients at 248 nm for those materials (fused silica and CaF_2) which can be obtained in large apertures. For fused silica $\beta = 4.5 \pm 2.2 \times 10^{-11}$ cm/W, while for CaF_2, $\beta = 8.3 \pm 4.1 \times 10^{-12}$ cm/W. To evaluate the implications of these values of β for KrF laser systems, we plot, in Fig. 2, I_{out}/I_{in} versus I_{in} for 1.27-cm-thick windows of fused silica and CaF_2 at 248 nm. Both two-photon absorption and its associated pulsewidth broadening are included in the calculation of I_{out}. At $I_{in} = 3 \times 10^{10}$ W/cm^2, a typical intensity for current systems, $I_{out}/I_{in} = 0.33$ for fused silica and $I_{out}/I_{in} = 0.66$ for CaF_2. Therefore, for large aperture, KrF-based, high-brightness lasers, the material for the output window, as well as for any subsequent windows should be carefully chosen and the total thickness after the gain medium minimized. In contrast, XeCl-based high-brightness lasers, where the photon energy is 4 eV, become attractive since two-photon absorption in CaF_2 is not possible.

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