converted to the third harmonic with an energy of 700 µJ. The third harmonic pulse is divided to 4 pulses with a interval of 2.5 ns by using two pairs of thin film polarizers in the third stage, then is sent to the fourth stage of a KrF amplifier with 4-pass configuration in which the separations of the folding mirrors are set to about 2.5 m. As it takes 8.3 ns each pass, the 4 pulse-train with a separation of 2.5 ns can cover the duration of 33 ns, which is almost equal to the gain duration of the KrF amplifier.

We measured ASE in the backward light from the amplifier. Typical ASE signals are shown in Fig. 2(a).

ASE is dramatically suppressed by the injection of the seed pulse. The hatched area shows the remaining ASE and the groups of four pulses shows the scattering of amplified pulses. We can estimate ASE level by comparing the hatched area with ASE area without injection in Fig. 2(a). The net average power is obtained by substituting the ASE from the total output power. The net average power written by circles in Fig. 2(b) almost linearly increases to 36 kV but saturates above this voltage. This is clearly because of increasing ASE ratio of the output beam as written by squares. As a result, we obtain a 55-W average power of the net amplified pulses with a 12-W ASE at a 40.5-kV discharge voltage, and a 49 W with a 3-W ASE at 36 kV. The output pulsewidth is measured by the third order autocorrelation by the 3-photon fluorescence of XeF[6] resulting a 480-fs pulsewidth in the full width of half maximum by a assuming *sech*^{2} pulse shape.

We developed a high-average power ultrashort-pulse KrF laser at a 200-Hz repetition rate by using the method of GGA. The 50-W average power is the highest ever obtained in any femtosecond lasers. We will apply this laser to develop a high-power soft X-ray sources from the Xe cluster target.

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CMT4 4:30 pm

High-energy broadband regenerative amplifier for chirped-pulse amplification

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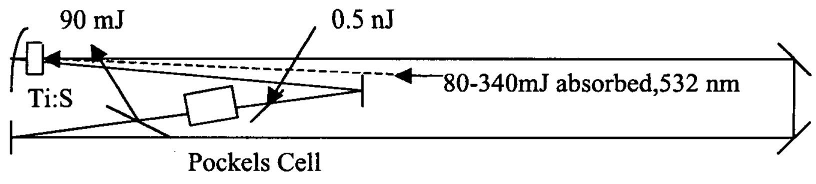


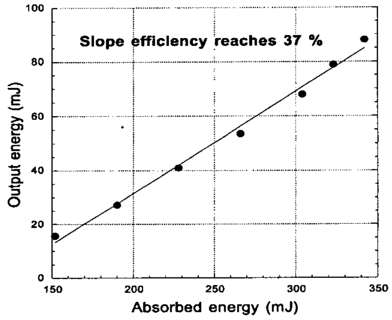
CMT4 Fig. 1. Regenerative amplifier layout

In modern short pulse terawatt power lasers a femtosecond pulse of a master oscillator is stretched to subnanosecond pulsewidth and is subsequently amplified to joule scale energy by using either several stages of multipass amplifiers or a combination of a regenerative amplifier and multipass amplifiers. Regenerative amplifiers, used preferably in the first amplification stages, provide for diffraction limited beam quality, large number of passes leading to a high total small signal gain. Multipass amplifiers are preferred for the output stages as they have better extraction efficiency comparing to regenerative amplifiers. A typical meter size linear Ti:sapphire regenerative amplifier has submillimeter mode size and output energy of 1–10 mJ limited by saturation fluence of Ti:sapphire (0.9J/cm^2) and intracavity losses. Subsequent amplification to joule scale energy requires a saturated gain of 100–1000 which is hard to reach with a single multipass amplifier so multiple stages of multipass amplifiers are used resulting in beam quality degradation and overall complexity of the laser system. A ring resonator with an intracavity lens was used[1] in a high-energy/large-mode regenerative amplifier as such a cavity has a larger mode size compared with a linear one with the same footprint. However, for broadband 20–30 femtosecond lasers, only reflective optics can be used to avoid chromatic aberrations.

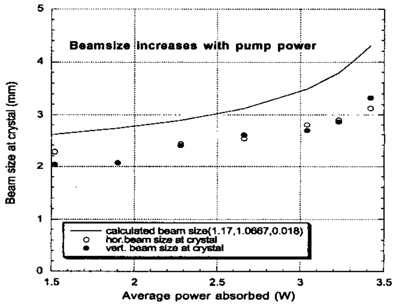
We developed a ring all-reflective-optics regenerative amplifier for the high power (>100TW) Ti:sapphire laser we are currently building. The resonator roundtrip length (7.5m) is less than double the radius of curvature of the curved mirror (4m) providing for cavity stability (Fig. 1). Ti:sapphire crystal is located close to the curved mirror where the beam size is the largest. This arrangement allows the amplified beam to double pass the gain region eliminating the common disadvantage of a ring cavity (one gain-length per roundtrip). The beam waist is far from optical elements to insure high damage threshold. A double peak Pockels cell injects the pulse in the cavity and ejects it after gain saturation is reached. Round trip cavity losses are 16%. By pumping the regen with 80–340 mJ absorbed energy of the green pump laser we are able to reach output energy up to 90 mJ at 37% slope efficiency (Fig. 2). Allowing for 80% output polarizer efficiency for the rejected polarization, the intracavity energy is 110 mJ. The calculated slope efficiency, with cavity losses and population inversion lifetime taken into account, is 39%. The injected stretched pulse width is ~1 ns, output bandwidth is 45 nm (FWHM). The output energy stability is 0.5% (RMS) exceeding the pump laser stability.

The thermal lens induced by pumping increases the beam size (Fig. 3) and moves the resonator closer to the stability limit increasing its sensitivity to aberrations and causing some astigmatism of the TEM 00 mode of the laser at highest pump powers.

A very simple terawatt scale laser consisting only of an oscillator and a regenerative amplifier can be built using the described design.



CMT4 Fig. 2. Regenerative amplifier output energy *vs.* pump energy



CMT4 Fig. 3. Beam size dependence on the average pump power.

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CMT5 4:45 pm

Electro-Optic Deflector Isolator for Short Laser Pulse Contrast Enhancement

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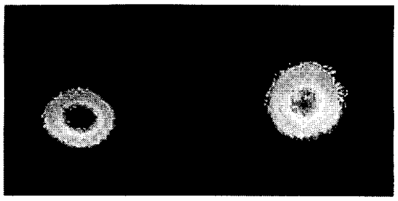
A common limitation in high intensity ultrashort laser-matter investigations is the generation of pre-pulse emission, and occasionally also post-pulse emission in the laser system of sufficient intensity that it can affect the interaction conditions. For instance, focused pre-pulse laser emission of intensities ≥10^{10} W/cm^2 incident on solid density material can create plasma densities higher enough to alter the interaction regime, and the x-ray radiation characteristics of ultra high intensity laser plasmas. This pre-pulse and post-pulse emission can originate from several sources, such as amplified spontaneous emission within the amplifiers, uncompressed laser light, scattering and reflection sources within the laser, and incomplete electro-optical switching. As the development of ultra-high intensity lasers goes beyond 10^{20} W/cm^2, the requirements on pulse-shape fidelity become more severe, demanding pulse-contrast ratios in excess of 10^{10}. Up to the present time these high contrast ratios have not been achieved without resorting to frequency upconversion, with the concurrent loss in laser energy and change in wavelength. The most serious source of pre-pulse emission results from leakage pulses through electro-optic pulse switching devices, such as Pockels cells, located within the laser chain. Although in principle, this emission can be reduced by the inclusion of more Pockels cells, this approach becomes self-defeating beyond the use of ~2 electro-optical devices, limiting the maximum contrast ratio to values at best of $10^6 - 10^7$. There is therefore a growing need for approaches that will augment or improve the pulse contrast of high intensity laser systems.

In this paper we describe an electro-optic deflection isolator (EODI) system that in principle could increase the contrast ratio of selected single pulses in a ultra-high intensity laser by as much as 10^7. The EODI utilizes the well-known transverse gradient in refractive index produced in a birefringent material by an electric field.[1] Electro-optic deflection has most commonly been used to deflect cw laser beams.[2] Its use with pulsed laser beams has been very limited. It has been used to cut pulses of arbitrary length from a Q-switched solid-state laser.[3,4] The deflection angle per unit length of passage of a beam through the material is given by $d\theta/dL = n^{-1}(dn/dw)$, where dn/dw is the variation of the refractive index n across the width of the beam w within the material. In the EODI, the deflector is configured with a lens pair and an aperture, asa spatial filter, (Fig. 1). A high voltage step pulse, with a prescribed ramp speed, and a transient bias potential is applied to the crystal at the same time as the high intensity short pulse. The ramp voltage pulse applied to the EODI is synchronized to the laser pulse so that the deflected beam is transmitted through the aperture just as the main pulse passes through it. Earlier pre-pulse emission, and later post-pulse emission is effectively blocked by the aperture. The opening, or gate time of this isolator is thus defined by the diameter of the aperture and the sweep velocity of the ramp voltage. This device was demonstrated by inserting it in the beam line of a CPA, 10 TW, 100 fs duration high intensity laser,[5,6] at a position just following the output of a regenerative amplifier, where the stretched, 230 ps pulse had an energy per pulse of ~3 mJ. A 18 mm long specially-designed $LiNbO_3$ electro-optic deflector crystal was used, the lenses had a focal length of 1.5 m and the 300 µm aperture adjusted to accommodate the 260 µm diffraction limited beam waist. As can be seen no deformation of the beam shape was evident on the transmitted beam. Moreover, subsequent compression of the stretched laser pulse back to its original 100 fs duration confirmed that the EODI had no undesirable effects on the chirped pulse. The effective contrast enhancement measured with this configuration was ~2200, and was limited by residual scattering in the $LiNbO_3$ crystal. Experiments are now underway to eliminate this problem, and to demonstrate the full potential of the EODI in improving the contrast ratio of high intensity ultra-short laser pulses.



CMT5 **Fig. 2.** Beam profile at the output of (a) the EODI, and (b), the second collimating lens.

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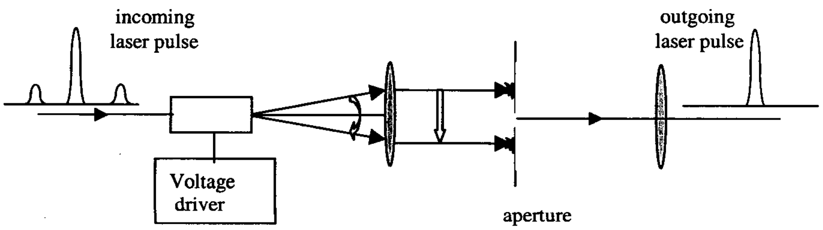

CMT5 **Fig. 1.** Schematic of the Electro-Optic Deflection Isolator.

CMT6 **5:00 pm**

Improved Damage Threshold and Diffraction Efficiency of Gratings for Ultra-Bright Lasers in Sub-Picoseconde Regime

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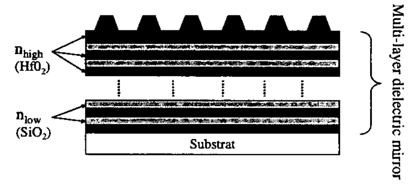
For the last 15 years, diffraction gratings have been the key critical components of the chirped pulse amplification (CPA) technique. They can introduce a large dispersion on an optical short pulse without propagating through a dispersive medium. However, their limited damage threshold has led to limited compressed energy. Furthermore, all present diffraction gratings used in CPA laser chains have a limited diffraction efficiency (typically 60% in a four-pass scheme).

Current diffraction gratings are made by etching a silicate substrate before evaporating a thin gold layer on the top. This means that the diffraction occurs at the surface. The energy is thus concentrated in a very thin layer. Consequently, a way to improve the damage threshold is to let the electro-magnetic field diffract in the material bulk, for instance, in a multi-layer dieletric material. The grooves of the diffraction gratings can be produced by ion-etching dielectric coated mirrors.[1] Jobin-Yvon Horiba studied this technique, using SiO_2/HfO_2 layers (see Fig. 1). The SiO_2 top layer samples exhibited larger damage threshold than the HfO_2 ones, which is in agreement with the bulk measurements.[2]

Simulations on the diffraction efficiency were made for λ = 1057 nm and can be extended to λ = 800 nm. They showed that the shape of the etched diffraction function can be optimized leading to very high theroritical efficiencies up to 100%, over a large spectral bandwidth (>30 nm). Moreover, the produced etched profiles can also be optimized and efficiencies over 98% were measured.

Samples from this technique were tested at the



CMT6 **Fig. 1.** Ion-etched multi-layer dielectric grating. A multi-layer dielectric mirror is deposited onto a silicate substrate. The top layer is thicker than the other and is ion-etched. It can be either HfO_2 (High index) or SiO_2 (Low index).