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ABSTRACT

We describe our work on the amplification of short pulses in tunable solid state materials; specifically alexandrite and Ti:sapphire. Our goal is to amplify femtosecond range pulses to the joule level in a table top size laser. We will describe our results which show that such a laser is now feasible.

INTRODUCTION

A laser with the peak power of its output similar to that of one arm of the NOVA laser system but which is small enough to fit in the normal laboratory would lead to new developments in high field physics. We are building a laser for this purpose. It utilizes chirped pulse amplification (CPA).[1] The concept of CPA is to temporarily stretch a short laser pulse prior to amplification. The purpose is to lower the intensity of the pulse without lowering the energy. The reason for this is that the amplifiers are intensity limited rather than energy limited due to the intensity dependent nonlinear refractive index and optical damage. After amplification, the pulse is compressed. Stretching and compression are based on frequency chirping our source.

The laser we are building has four major sections. The first is the oscillator which generates the femtosecond range pulse. We first used a synchronously pumped dye laser. However this laser required continuous attention. Also, our intention is to have a totally solid state laser system. We are now working with a tunable solid state source. This is a frequency doubled, additive pulse modelocked (APM) color-center laser.

The second section consists of two sets of gratings used to temporarily expand and then compress the pulses for chirped pulse amplification. The first pair of gratings is used to stretch the output from the fsec-range oscillator to a chirped ≥ 100 psec pulse. This pulse is injected into the third section of the system, a regenerative amplifier. Here, we report our results with a 10 mJ, alexandrite regenerative amplifier, a 1 mJ, Ti:sapphire regenerative amplifier and a 100 mJ, alexandrite regenerative amplifier which utilizes an unstable resonator design.

The forth and final stage of our laser system is the high-energy alexandrite amplifiers. We will present results on two pass and four pass amplifiers.

OSCILLATOR

The first oscillator which we used was a dye laser of a synchronously pumped, passively mode-locked design, utilizing LDS 722 (Pyridine 2) and cryptocyanine as the gain and absorber media, respectively. A layout of the dye laser cavity is illustrated in Fig. 1.

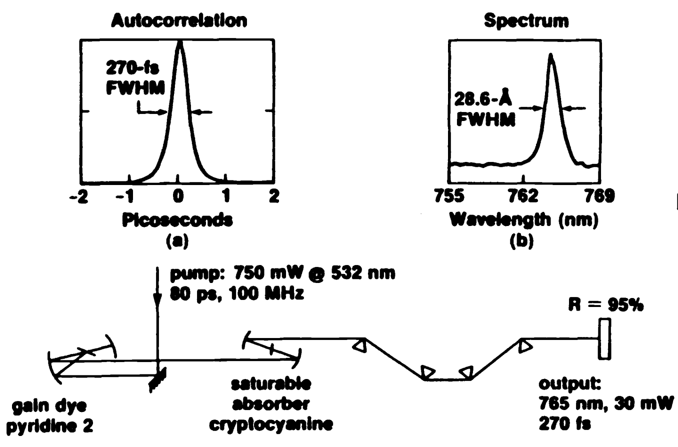


Fig. 1: Dye laser cavity. (a) CW autocorrelation. Pulse FWHM = 270 fs ($sech^2$ pulse shape). (b) Laser spectrum FWHM = 28.6Å. The time bandwidth product $\Delta\nu\Delta t$ =0.40.

Careful matching of the cavity length (<1 μm) resulted in the formation of stable pulses of less than 0.5 psec duration at 765 nm in a nondispersion-compensated cavity. Optimization of the cavity dispersion with the addition of four prisms yielded pulses as short as 197 fsec. Typical day-to-day operation of the laser yielded pulses of ~270 fsec with a spectral width of 29 Å, for a time bandwidth product of $\Delta\nu\Delta t = 0.40$. Spectral and autocorrelation measurements are also shown in Fig. 1.

However, for experiments with pulses significantly shorter than 300 fsec, this laser had to be modified. In order to provide sufficient bandwidth for the generation of 100 fsec pulses, the dye-laser output was amplified in a 1 KHz dye preamplifier, and coupled into a 20-cm-long section of polarization-preserving, single-mode fiber. The spectrum was increased to ~25 nm through self-phase modulation; consequently, the pulse width broadened to ~1 psec. The pulse was again amplified in another dye preamplifier and temporarily expanded by a pair of gratings before injection into the regenerative amplifier. This is the laser we used with an alexandrite regenerative amplifier to obtain 5 mJ, 100-fsec pulses.[2] However, as is shown by the streak camera measurement in Fig. 2b, the expanded pulse is modulated in time and in frequency [Fig. 2(a)].

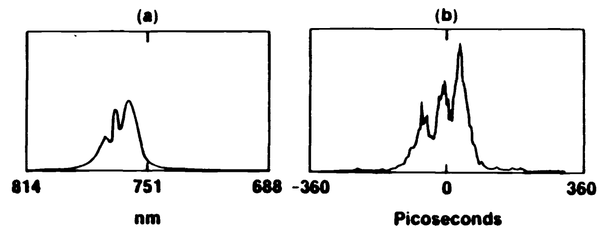


Fig. 2: (a) Self-phase modulated spectrum from the fiber. (b) Streak-camera image of the expanded pulse.

The low repetition rate pre-amplifier system, located before the fiber, was found to be extremely alignment sensitive. Because self-phase modulation in the fiber is intensity dependent, the output spectrum could change for a variety of reasons. For instance, any drift in amplitude from the oscillator due to a change in energy output. A varying pulsewidth, or instabilities in the preamplifier located before the fiber could result in a change in the output spectrum. Due to this instability, it was not possible to correct for the dispersion in the alexandrite regenerative amplifier over long periods of time. This led us to search for a more suitable source. Modelocked dye lasers which are capable of generating 100-fsec pulses at 750 nm have been built. However, it has also been our goal to build an all solid state system.

We have built an Additive Pulse Modelocked (APM) color-center which is similar to that reported by Pollack.[3] A diagram of the laser is shown in Fig. 3. The laser is pumped with 3.7 Watts of modelocked output at 1.06 μm from a modelocked Nd:YAG laser. A milliwatt of green is generated for alignment purposes and for color-center stability. A NaCl crystal is used as the color-center host. The tuning curve of the laser is shown in Fig. 4. We will operate this laser at 1500 nm and then double it to 750 nm. The output power is 150 mW and the pulse width is measured from the autocorrelation trace (Fig. 5a) to be 164 fsec (FWHM) assuming a gaussian shape. Figure 5b shows the spectrum of the pulse which is reproducible and thus much more suitable for our dispersion compensation techniques.

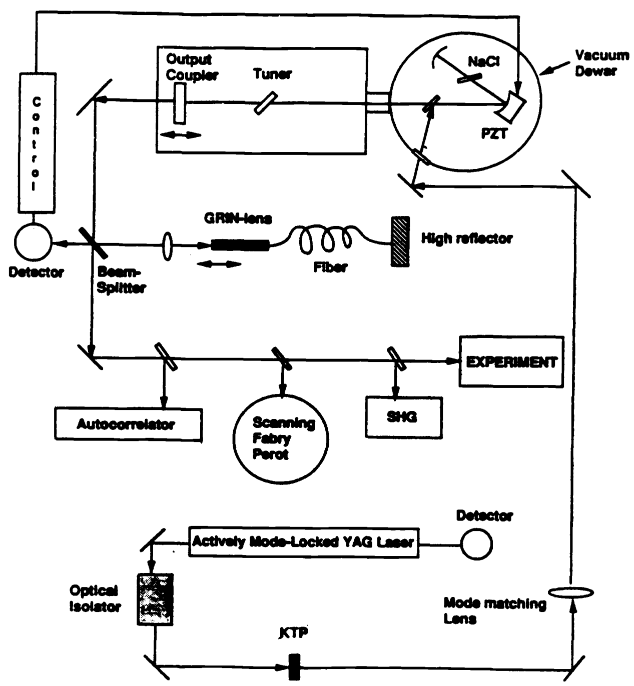


Fig. 3: Layout for the color-center APM laser.

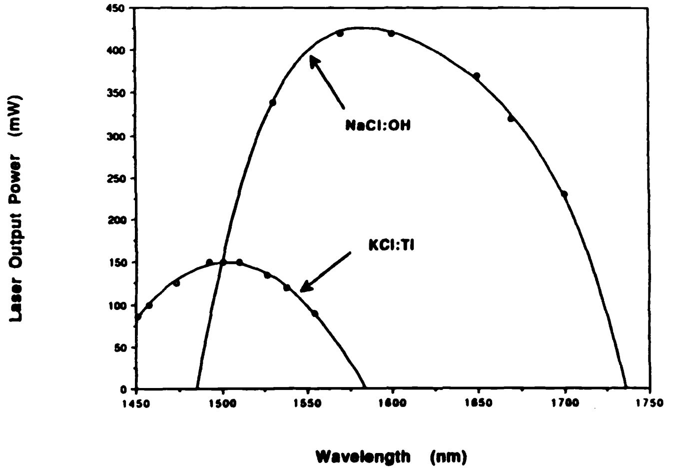


Fig. 4: Tuning curves of KCL and NaCl color center laser

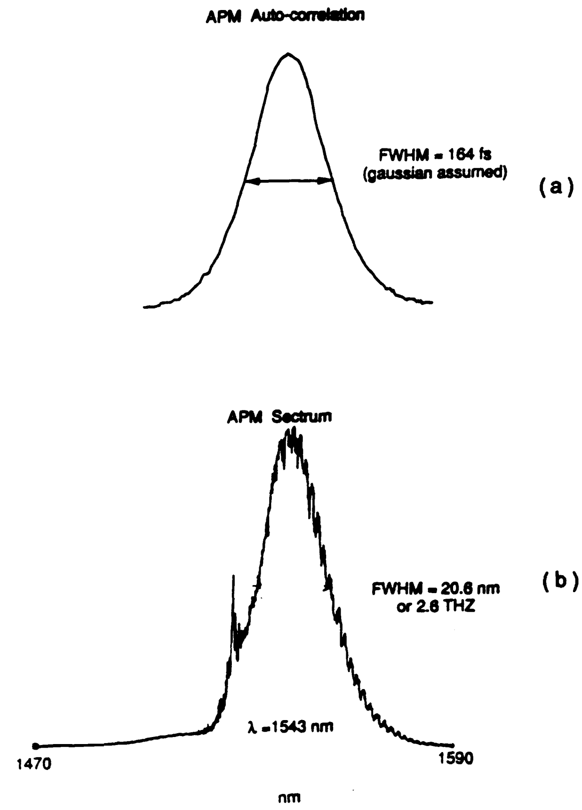


Fig. 5: Autocorrelation (a) and spectrum (b) of APM laser.

CHIRPED PULSE AMPLIFICATION

As stated previously, the first pair of gratings stretch the pulse temporarily. A second pair of gratings located after the final stage of amplification is used to recompress the pulse to the original pulsewidth. The pulse expansion system consists of two 1800 lines/mm gratings in an antiparallel configuration. Between the gratings are two lenses forming a unit magnification telescope. This grating configuration provides a net positive group velocity dispersion. This system is used in double pass to avoid any transverse chirp on the output beam. To recompress the pulse, two gratings are used in parallel configuration without lenses. The dispersion of the expansion can be completely compensated. This has been shown previously for a 1000x expansion-compression system with 80 fsec pulses.[4]

REGENERATIVE AMPLIFIER

We have built several solid-state regenerative amplifiers. Most experiments have been performed with a 10 mJ alexandrite regenerative amplifier based on a stable resonator.[5] Some of the work reported here on regenerative amplifiers use a 100 - 300 psec gain-switched laser diode as the oscillator. This type of oscillator is preferred for amplifier development since it is much more stable and reliable than a 100 - 300 psec chirped pulse from a subpicosecond-pulse-range laser.

The regenerative amplifier shown in Fig. 6 consists of two high reflectors, the alexandrite gain medium, a broadband thin film polarizer, a static quarter wave-plate, one or two apertures, and a Pockels cell. For wavelength tunability off gain center, the alexandrite regenerative amplifier often incorporates a birefringent tuner or a pellicle. The 1.5 meter long resonator is designed with a large TEM_{00} beam and to be insensitive to some variation in the laser rod's thermal lensing at the operating repetition rate. Resonators have been designed for operation between 4 - 30 Hz. The design and the merits of thermal insensitive resonators are well described by De Silvestri et al.[6] Essentially, the resonator is designed to operate where the size of the laser beam in the rod is insensitive to the thermal lensing of the laser rod from optical pumping. We also added two apertures which introduce significant losses and strongly affect the beam profile. There are four reasons for the use of these apertures. The apertures reduce the beam wander to less than ±50 μradians. The apertures determine the beam shape. In spite of using a thermally insensitive resonator to reduce the sensitivity of beam radius to changes of thermal lensing the apertures add additional control of the beam diameter. The design point for the thermal insensitive resonator is also the point of minimum beam diameter for any value of thermal lensing so any change of thermal lensing doesn't reduce the size of the beam, it just adds loss from the aperture. Finally, to obtain good pulse-to-pulse stability the threshold for switchout should be at the point where the gain has saturated and the pulse to pulse energy difference is minimal. However, alexandrite stores significant energy so that normally the energy in the pulse to saturate the gain is greater than the damage threshold of the intracavity elements. Thus, the intracavity loss of the apertures allows the regenerative amplifier to be operated sufficiently above threshold for good pulse stability and with gain saturation without introducing intracavity damage.

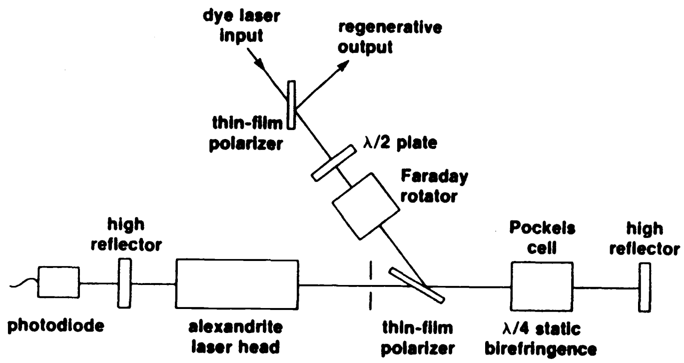


Fig. 6: Design of the alexandrite regenerative amplifier.

A single Pockels cell controls the injection of the seed pulse and the cavity dumping after amplification. The Pockels cell driver is described elsewhere.[7] The intracavity polarizer has a broad-band coating (50 nm) and can be used in transmission or in reflection. For some experiments, the static quarter-wave plate was found to produce a strong etalon effect. To overcome this, the Pockels cell alignment was adjusted to provide a quarter wave of static birefringence, removing the need for a separate quarter-wave plate.

Switching the Pockels cell to its quarter-wave voltage (double-pass retardation equal to half wave) injects a single pulse inside the cavity. The pulse is trapped between the two high reflectors and is amplified for ~50 roundtrips. The pulse remains in the resonator until the signal from a photodiode which detects light transmitted through one of the end reflectors reaches a predetermined threshold value. A second voltage step is applied to the Pockels cell to cavity dump the amplified pulse.

This regenerative amplifier has been used to amplify 270 fsec,10 pJ to 1 nJ pulses from the synchronously modelocked dye laser.[8] The pulses were stretched by a grating pair to 50 psecs which were then amplified by this regenerative amplifier to 2 mJ. From the ~50 round trips through the regenerative amplifier the pulse spread from 50 to 60 psec due to the dispersion of the intracavity components. By altering the distance between the compression gratings, the pulse was compressed to 305 fsec pulses. However to amplify pulses in the 100 fsec range with this regenerative amplifier the intracavity dispersion becomes a significant problem.

In order to determine the limitation on the minimum achievable pulsewidth from this system, we modeled the dispersive properties of the alexandrite regenerative amplifier. An input Gaussian pulse is Fourier transformed, multiplied by the appropriate phase shift, and inverse Fourier transformed to find the output pulse shape. The frequency-dependent phase shift from the diffraction gratings can be written to third order as

$$\Phi_{DG}(\lambda_o + \Delta\lambda) = -\frac{\pi b}{\lambda_o d^2}\frac{1}{\cos^2\Theta_d}(\Delta\lambda)^2 - \frac{\pi b}{\lambda_o{}^2 d^2 \cos^2\Theta_d}\cdot\left[1 + \frac{\lambda_o}{d}\frac{\sin\Theta_d}{\cos^2\Theta_d}\right](\Delta\lambda)^3 \qquad (1)$$

where d is the line spacing, Θ_d is the diffraction angle, and λ_o is the center wavelength. For the compression stage, b is simply the (double-pass) grating separation; for the expansion gratings, b=2(z-4f) where z is the separation distance and f is the focal length of the lenses forming the telescope.

The material path in the cavity contributes an additional phase shift which can be written in terms of a quadratic and third order term such as

$$\Phi_{mat}(\lambda_o + \Delta\lambda) = \Phi_1(\Delta\lambda)^2 + \Phi_2(\Delta\lambda)^3 \qquad (2)$$

(note that in Eqns. (1) and (2) the term linear in wavelength has been neglected since this term has no effect on the dispersion.) Four components contribute to the optical path length: an alexandrite rod, a KD*P Pockels cell, a thin-film polarizer substrate and the pockels cell windows. The contribution of each of these elements to the first- and second-order dispersion for a single round trip is shown in Table I.

Table 1

Component	Length/Round Trip	Φ_1	Φ_2
Alexandrite	20 cm	5.80×10^{-2} nm^{-2}	-7.62×10^{-5} nm^{-3}
KD*P	4 cm	8.26×10^{-3} nm^{-2}	-8.12×10^{-6} nm^{-3}
BK-7	0.8 cm	1.97×10^{-3} nm^{-2}	-1.50×10^{-6} nm^{-3}
Quartz	2.2 cm	4.50×10^{-3} nm^{-2}	-3.25×10^{-6} nm^{-3}

Ideally, the compression gratings are a perfect match to the expansion gratings and cancel the phase shift to all orders. This is only true, however, if both sets of gratings are used at the same separation and at the same angle of incidence. In practice, the compression grating spacing is adjusted to minimize the output pulse width and thus the dispersion introduced by the intracavity elements. If the ratio of the second and third order terms are not fortuitously correct so all terms cancel, then we are left with a residual chirp which contains both material and grating contributions. Figure 7 is a plot of the calculated output pulse duration for a given pulse as a function of the cavity build-up time (i. e., for a given material path). For the numerical calculations, the compression grating spacing was optimized so that no linear chirp remained on the output pulse. At a given cavity build-up, as the input pulse gets shorter, the higher-order dispersion plays a more and more dominant role. In the absence of any higher order compensation, this leads to a minimum achievable output pulse width. Our experimental results with a 600 nsec buildup agree with the calculated values for a cavity buildup of 640 nsec.

From Fig. 7, it becomes clear that in a multipass configuration such as in our regenerative amplifier, some control over the higher-order dispersion becomes necessary if amplified with duration pulses significantly shorter than 200 fsec are desired. This can be accomplished by using a combination of prisms and gratings for cubic phase compensation. For example, by including a sequence of four Brewster angle TeO_2 prisms inside the cavity, the prism and compression grating spacings can be adjusted to compensate simultaneously both the quadratic and cubic phase terms. TeO_2 is a highly dispersive crystalline material, equivalent in dispersion to a 1200 lines/mm grating. Using the prisms inside the cavity results in a quite manageable prism spacing of only 5 cm (again, for a 600 nsec build-up). The calculated output pulse duration of the prism-compensated system is also shown in Fig. 7. The curve is not continued to the origin, as when the pulsewidths reach a few femtoseconds it becomes necessary to include additional terms to model the dispersive properties of the system accurately. With this additional phase control, it is possible to amplify and recompress pulses well into the femtosecond domain.

Thus, we have modified our alexandrite regenerative amplifier to incorporate a prism sequence to provide the necessary higher-order compensation (Fig. 8).[2] Placing the prisms internal to the cavity allows us to take advantage of the large number of transits that the pulse makes to accumulate the required amount of compensation. External to the cavity the required prism spacing is not feasible.

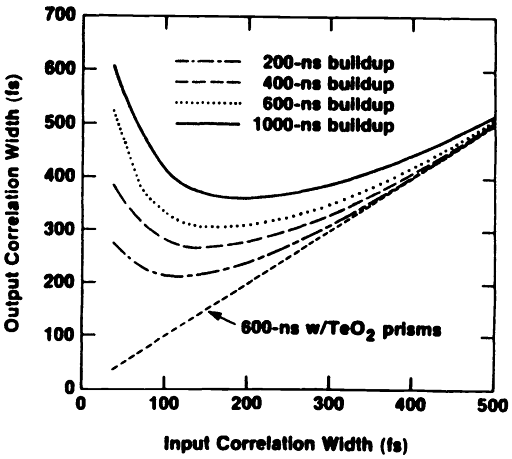


Fig. 7: Calculated output pulse duration versus input pulse for various cavity buildup times. Also shown are numerical results for a 600 ns buildup with TeO_2 prisms and gratings used to compensate both quadratic and cubic phase terms.

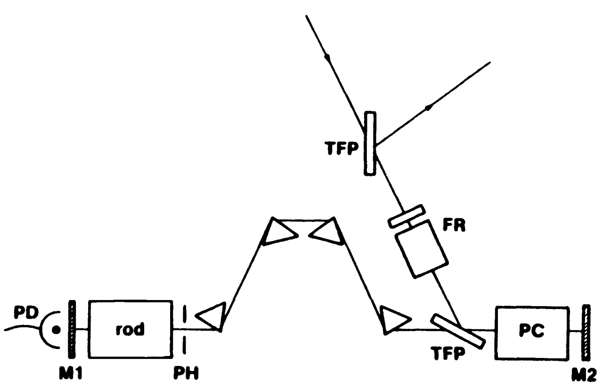


Fig. 8: Alexandrite regenerative amplifier with four Brewster prisms for cubic phase compensation. PD, photodiode; TFP's thin-film polarizers; M1, M2, high reflectors; PH, pinhole, FR, Faraday rotator and half-wave plate; PC, Pockels cell.

The prism separation was chosen on the basis of calculations of the contributed phase shift from all dispersive elements both internal and external to the cavity. The prism and grating separations were used as the two degrees of freedom to find some point at which the quadratic and cubic phase shifts would cancel. Strictly, this cancellation holds only for a unique number of transits within the cavity. This was performed in practice by setting the cavity dumper to fire at a specific time interval after the Q-switch, rather than cavity dumping on the basis of a threshold detector's monitoring the energy build-up of the pulse. With the prism sequence included, the compression gratings were then varied to optimize the compressed pulse. Some further optimization was possible by translating the prisms in the beam path.

Single-shot, background-free autocorrelation measurements were used to monitor the compressed pulse width. Figure 9 shows a 106 fsec pulse, assuming a $sech^2$ pulse shape for deconvolution. The 40% (double-pass) diffraction efficiency of the gratings reduce the pulse energy from 5 to 2 mJ. When the prism sequence was not included within the cavity, the shortest compressed pulse observed was 170 fsec. This is in reasonable agreement with the minimum pulse width expected from the limitations described above, indicating that we have achieved a partial cancellation of the cubic phase.

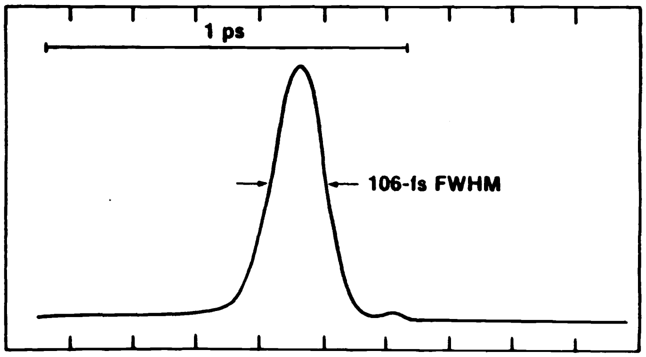


Fig. 9: Single-shot autocorrelation of the compressed pulse. The FWHM is 106 fsec, assuming a $sech^2$ pulse shape for deconvolution.

Another possible means of correcting for both quadratic and cubic dispersion is to use different angles, Θ_d, for the expansion and compression gratings. This and different spacings give sufficient degrees of freedom to correct for cubic and quadratic dispersion completely. Another possible solution is to use Ti:sapphire which has greater gain so fewer round trips are necessary and the crystals used are usually only 1 cm long rather than 10 cm long. Both of these properties would reduce the overall dispersion. Ti:sapphire is also interesting with its broader gain and should be able to amplify pulses even shorter than 100 fsec.

Figure 10 shows the Ti:sapphire regenerative amplifier which we have reported earlier.[9] Its operation is the same as the alexandrite regenerative amplifier described earlier. The short pulse oscillator we have used with this regenerative amplifier is a gain switched diode operating at 750 nm. The pulse width from the diode can be changed from 35 - 200 psec by varying the RF amplitude going to the comb generator or the DC bias. The laser diode pulses during these experiments were ~100-psec long with ~2 pJ per pulse. The pump laser is a Q-switched doubled Nd:YAG laser with 20-30 mJ incident on the crystal in a 1 mm diameter beam. Some effort had been made to clean up the spatial profile from the Nd:YAG unstable resonator but the beam profile was still irregular. The output energy in a single pulse from the regenerative amplifier was high as 2 mJ for an amplification of 10^9. The measured extraction efficiency was 22%. This is close to that expected with the large Fresnel losses we had from the uncoated Ti:sapphire crystal.

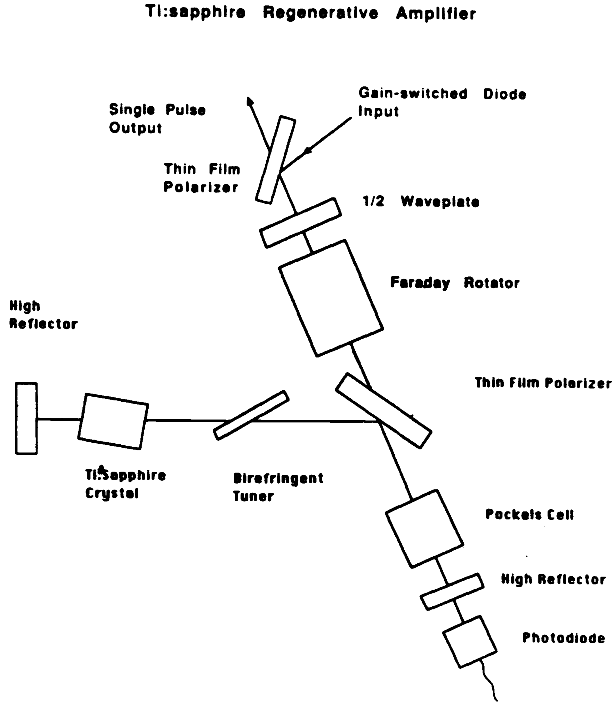


Fig. 10: Ti:sapphire regenerative amplifier.

This regenerative amplifier showed a very interesting phenomenon at first. 100 - 200 psec pulses were obtained without any input! The cause of this phenomenon was found to be from the Ti:sapphire initially lasing off the parallel uncoated surfaces of the crystal. This occurred during the pump pulse. The pulse duration is so short due to the short cavity (crystal length is 5.5 mm), the low Q of the cavity (8% reflectivity per surface) and the high gain. The pulse bandwidth was approximately 40 nm centered at 810 nm. A fraction of this pulse is scattered into the regenerative amplifier. The generation of this pulse could be controlled by rotating the crystal. The gain for the short pulse generated in the crystal is decreased as the angle between the axis of the long cavity and the crystal cavity is increased. An angle of approximately 30° is sufficient to suppress the generation of this pulse.

AMPLIFIERS

The regenerative amplifier provides a pulse output in the 10 mJ range. To amplify this to the joule level, we use alexandrite double pass amplifiers.[10] We selected alexandrite since the pump laser for the Ti:sapphire would need to be quite large and more complex than the alexandrite amplifiers themselves. The double-pass amplifier for alexandrite uses a Faraday rotator for polarization rotation rather than the conventional 1/4 wave plate since alexandrite exhibits gain for only one polarization. The rod sizes used for the amplifiers are 1/4 ", 3/8", and 1/2" diameter. The size used is determined by the damage threshold of the rod surfaces. The 1/4" rod double pass amplifier has a double pass gain of 8 - 22 depending on pumping energy. The 3/8 inch double pass amplifier is usually operated at an overall gain of 4 - 6 and the 1/2 inch is operated at a gain of 4. Figure 11 shows a one-joule, 350-psec laser being built for the Joint European Torus (JET) by Allied-Signal Inc. It could be used for short pulse amplification if the source was a stretched femtosecond laser pulse rather than a pulse from a gain switched diode. It uses a conventional regenerative amplifier and 4 - 5 double pass amplifiers. Thus far, 300 mJ have thus been obtained from this laser.

COMPACT LASER DESIGN

The JET laser shown in Fig. 11 is a table top laser and is more compact than NOVA but by no means would this laser be found in numerous laboratories for high peak power experiments. We will now describe our work at building a short pulse, one joule laser which is closer to the size of a commercial Nd:YAG, Q-switched, one-joule laser. This laser is shown in Fig. 12. It consists of an unstable resonator which has an output of around 100 mJ, followed by a four pass amplifier which has sufficient gain to obtain the desired one joule output.[11]

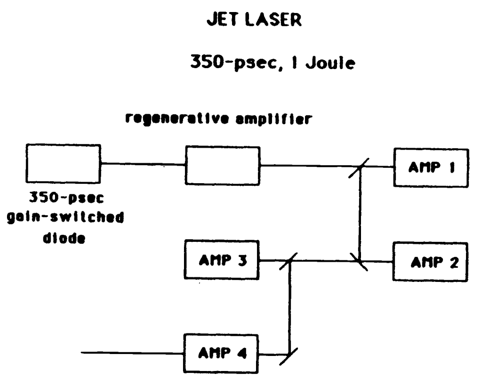
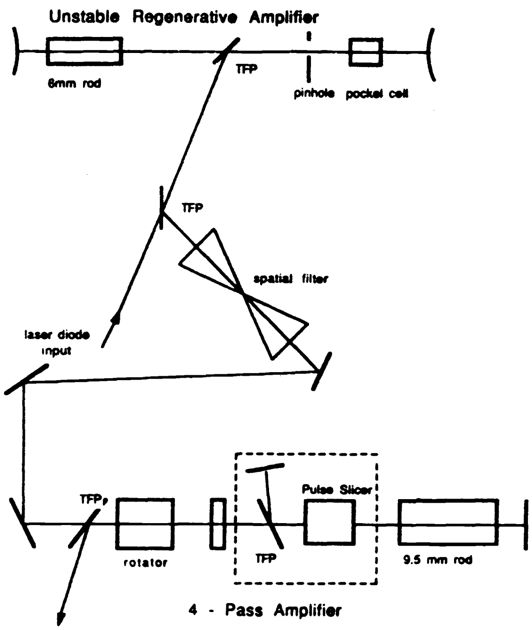


Fig. 11: One joule, 350 psec. laser built by Allied-Signal for the Joint European Torus (JET).



Amplifier Schematic

Fig. 12: An unstable regenerative amplifier and a four pass amplifier for a compact one joule laser.

The first unstable resonator regenerative amplifier which we built was a negative branch self-filtering unstable resonator (SFUR).[12] The SFUR is confocal in configuration and has the internal focus characteristic of negative branch unstable resonators. If an aperture is placed at the internal focus it acts as a spatial filter since it is located at the Fourier transform plane. If the aperture size is carefully chosen to transmit the first zero of its own Airy pattern. Under these conditions, a very clean diffraction-limited beam is obtained as the output. For alexandrite, a magnification of 1.5 - 2.0 is reasonable for the achievable gain. The relationship among cavity length, L, magnification, M, and the beam diameter after amplification , d, is;

$$L = \frac{d^2}{.61\lambda\ M^2}(1-M) \tag{3}$$

where increases in the beam diameter due to diffraction have been ignored. The intracavity fluence we operate at is 0.5 - 1.0 J/cm^2. For a reasonable length cavity, our beam diameter is limited to about 2 mm and the output is thus limited to about 20 - 30 mJ.

In order to obtain higher pulse energy, we built a positive branch unstable resonator. This was operated with a hard aperture to define the mode. With these resonators, up to 200 mJ in a 100 psec pulse have been obtained before the onset of optical damage resulted. The hard aperture used in these designs produces Fresnel rings which must be cleaned up in order to obtain a diffraction limited output. Fifty-five to 70% throughput is obtained when the beam is spatially filtered. As with conventional unstable resonators, it appears clear that the use of a radially varying reflector would improve the performance of this laser.[13,14] Better spatial throughput is expected from the lack of high frequency components from sharp edges in the cavity. Higher energy output is expected since the Fresnel zones in the cavity give amplitude peaks four times higher than the average. This imposes a low average cavity fluence in order to avoid optical damage. Finally, better pulse-to-pulse stability would be expected. Without the Fresnel hot spots in the cavity, the intracavity fluence can be increased and operated closer to saturation. The importance of this was discussed previously in the description of the stable alexandrite regenerative amplifier.

The four pass amplifier to be used with the unstable resonator is also shown in Fig. 12. Normally, a four pass amplifier can be built using 1/4 wave plates, polarizers and mirrors. This method cannot be applied to alexandrite as this material exhibits gain along only one polarization. Thus, for alexandrite we use a pulse slicer which is a Pockels cell that is switched from 0 to 1/2 wave retardation for approximately 4 nanoseconds and then back to 0 wave retardation. The sequence of operation is shown in Fig. 13. Essentially, the second round trip is obtained by switching to 1/2 wave retardation so that the pulse is switched to reflect off the second mirror. The gain of this device has been measured and as expected is equal to four times the single pass gain.

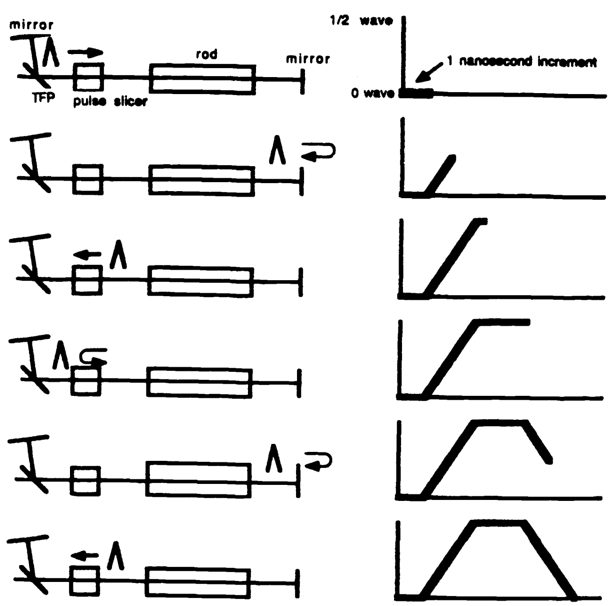


Fig. 13: Diagram illustrating operation of four pass amplifier. Position of the short pulse is shown on the left and the voltage on the pulse slicer is on the right.

4 - Pass Amplifier Schematic

FURTHER DESIGN ISSUES

An important specification for high peak power, short pulse lasers, is the absence of any prepulse. The experimental set-up used for measuring prepulse amplitude is shown in Fig. 14.[15] The set-up primarily consists of a gated photomultiplier and a voltage limiting circuit with neutral density filters which provide 10^8 reduction of the source. The light from the laser is directed into the photomultiplier with a fiber. The photomultiplier is set up in a separate room since scattered light within the room can be a large source of signal. The pulse is first observed with the filters in place. The filters are then removed and the level of signal before the pulse can be observed. In order for the laser to operate with 10^8 discrimination, reflections from surfaces into the beam had to be eliminated. Wedged surfaces were necessary in the regenerative amplifier. Another problem was to get the pulse to be 10^8 greater than ASE in the regenerative amplifier. Ten - 100 picojoules is not sufficient energy in the source to obtain this ratio of signal-to-noise without the alignment of the source into the regenerative amplifier being critical. A ratio of signal-to-noise of 10^4 was more common. To solve this problem, we used an intracavity saturable absorber. A discrimination of 10^4 can not be obtained from a single pass through the saturable absorber but with about 100 passes through the saturable absorber very good discrimination is obtained. The final source of prepulses from the regenerative amplifier is the leakage of the pulse for each round trip though the thin film polarizer. A ratio of this signal to the main pulse is ~10^5. Since these pulses are separated from the main pulse by the cavity round trip which is ~8 nanosecond, an external pulse slicer is used to remove these prepulses.

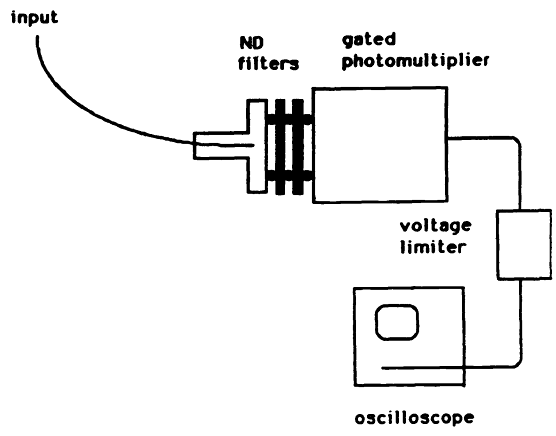


Fig. 14: Experimental set-up for measuring the prepulse suppression.

Gain narrowing becomes an important factor if pulses that are shorter than 100 fsec or that are tuned off the gain peak of the laser medium are desired. For example, alexandrite cannot amplify pulses centered at the peak of its gain curve and which are broader than 15 nm by more than 10^9 without significant spectral distortion. For the same criteria, Ti:Sapphire is limited to amplifying 46 nm bandwidth pulses. However, off-gain center and at 750 nm, Ti:Sapphire can only amplify a 4 nm bandwidth pulses under this criteria. As with dispersion, gain narrowing can be corrected. However, to correct gain narrowing, energy is normally lost from the pulse. One means to correct gain narrowing is to proportionally attenuate different parts of the input pulse spectra to compensate for the spectral difference in gain. Because the grating pair used for pulse stretching linearly disperses the spectrum, an attenuator varying across the beam between the gratings can compensate for uneven spectral gain. Using gratings pair to modify the spectrum of a short pulse was first recommended by DeBois et al[16] and is now being actively pursued by Weiner et al.[17] Another method to correct for gain narrowing is to put an attenuator which varies with wavelength in the cavity of the regenerative amplifier. This would work well with the alexandrite where energy loss is not important since the energy stored is more than sufficient. Possible loss elements for this task could be broadband tuning elements or dyes. For example, the HITC dye used as the saturable absorber in the alexandrite regenerative amplifier changes the overall gain as a function of wavelength significantly since it is used on the edge of its absorption curve.

CONCLUSIONS

We have described our work to produce femtosecond-range pulses at the one joule level based on chirped pulse amplification with tunable solid state materials. We have demonstrated the major components of such a source. Our laser source, based on alexandrite, is capable of amplifying 106 fsec pulses and has already amplified short pulses to the 300 mJ level. Ti:sapphire regenerative amplifiers have been demonstrated and could amplify even shorter pulses. From our experience, we find that a combined Ti:sapphire and alexandrite system would be optimum. Ti:sapphire, with its greater bandwidth, would be used in the initial amplifiers where most of the amplification is obtained. Alexandrite, with its larger energy storage capability, would be used in the final stages for obtaining the greater pulse energies. Such a system should be capable of generating very short pulses (<100 fs) beyond the joule level.

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