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1.B Laser Design and Performance

As discussed in article 1.A, important ignition physics issues could be investigated with a laser system capable of uniformly targeting 30 kJ of ultraviolet (UV, 351-nm) light with the temporal pulse shape illustrated in Fig. 38.10. The design of such a laser system presents several challenges. The first challenge is to generate the required energy at the lowest possible cost. As discussed below, while the implosion experiment utilizes 30 kJ of UV energy on target, the overall laser output, because of inherent system losses and red-to-blue conversion efficiencies, must be in excess of 60 kJ in the infrared (IR, 1054 nm). Production of such energies will be facilitated by the design, testing, and implementation of the multisegmented amplifier (MSA). This new amplifier,[1] a joint effort between Lawrence Livermore National Laboratory (LLNL) and the University of Rochester Laboratory for Laser Energetics (LLE), will be discussed in detail below.

The next important challenge is the generation of the desired on-target temporal pulse shape. The target design group has determined a set of basic requirements for the general pulse shape. The on-target pulse shape will be synthesized from two independent sub-pulses. Special attention must be given to minimize the damage threat associated with each of the sub-pulses. Such considerations will determine the location and size of certain optical components in the chain as well as many of the materials used.

The final challenge is to meet the stringent uniformity requirements of the implosion dynamics. It has been shown that the overall illumination uniformity of a laser system improves significantly as the number of incident beams is increased.[2] To take advantage of this, it

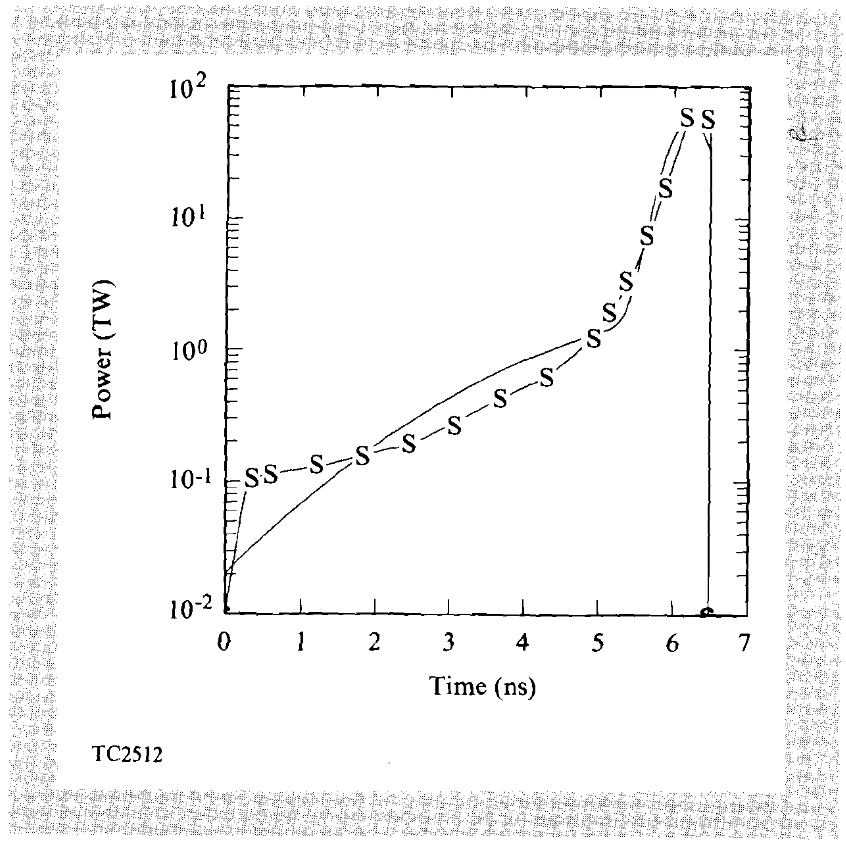

Fig. 38.10
Required on-target temporal pulse shape(s) scaled from MJ pulse shape and double-Gaussian approximation to it.

is planned to increase the number of beams on the OMEGA system (currently 24 beams). By comparing the increasing cost associated with handling larger number of beams with the improving uniformity, it was determined that the OMEGA upgrade would place 60 beams on target. This decision is complicated by two additional issues. First is the issue of producing both sub-pulses in each of the 60 beams. Second is the requirement that maximum use be made of the existing OMEGA hardware and laser-bay floor space. The easy solution of building two independent, 60-beam laser systems and combining them on target was rejected because of prohibitive costs and insufficient laser-bay area. The solution we have adopted is the co-propagation of two pulses in physically separate regions of the same beamline. This concept is the most cost-effective method (one laser system that can occupy the existing laser bay) of achieving the given uniformity requirements while still providing for all other parameters essential to the upgrade.

Laser Output Requirements

Although the designed, on-target energy is 30 kJ, the losses associated with the laser components between the target and the final amplifier must be accounted for in determining the final amplifier output energy. An output-energy budget for the proposed system is shown in Fig. 38.11. The output of the amplifier must be transported, frequency converted, diagnosed, focused, and phase converted. Nonlinear effects in air and the paucity of high-damage-fluence, 351-nm, high-reflector coatings dictate that frequency conversion take

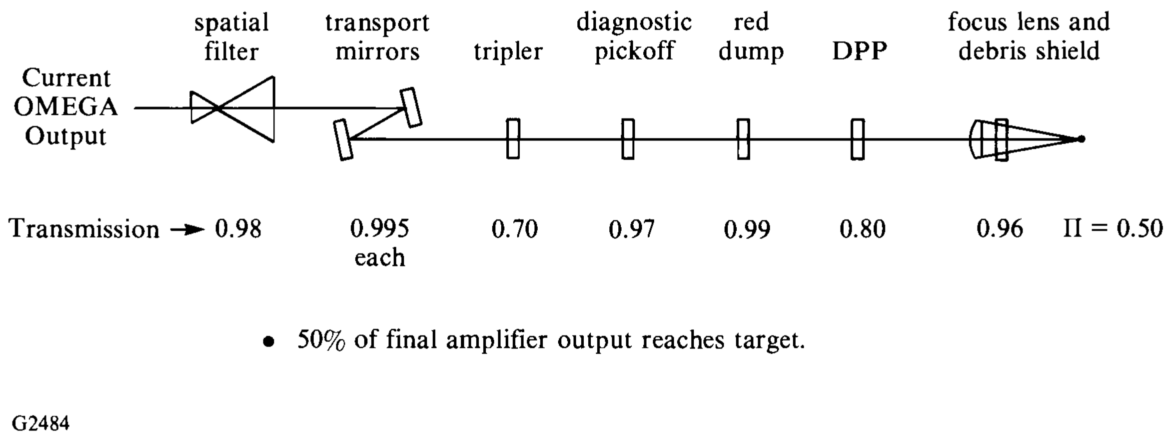

Fig. 38.11
Output energy budget.

place at or near the target chamber. The collective transport losses of the final spatial filter, transport mirrors, diagnostic, and focusing lens at 1054 nm are typically 10%. The target is placed in the central focal spot of a distributed phase plate (DPP), a phase mask located after the focusing lens, which contains 80% of the energy incident on the DPP. The frequency-conversion process can achieve a theoretical maximum of 80% efficiency for these temporal shaped pulses. Since a number of effects can degrade tripling efficiency,[3,4] a conservative 70% tripling efficiency has been assumed. The product of these effective transmissions is 50%, i.e., the energy output of the final amplifier must be twice the target requirement. If the foot and main pulses are delivered by separate beamlines, the energy per beam for the main pulse is 800 J and 200 J for the foot pulse, or 1000 J for a combined beamline.

MSA Amplifier

The MSA proposed for the OMEGA Upgrade is shown in Fig. 38.12. Because of the very close packing of adjacent beams in the MSA architecture, magnification and injection into the next amplifier stage requires either special handling optics after the amplifier to separate the beams or a very large, clear-aperture spatial filter. This problem can be avoided by using the MSA in an angularly double-passed configuration. This configuration allows amplification of the output of a current OMEGA beamline to the required levels in one stage. The angular offset may be taken on the output beam to provide the necessary beam separation for subsequent magnification. An increase in the amplifier clear aperture is necessary in order to accommodate the beam offset. If the required beam separation at the end of the stage is set equal to the amplifier's (not the beam's) clear aperture, than a relation may be derived between the required propagation distance for beam separation and amplifier clear aperture

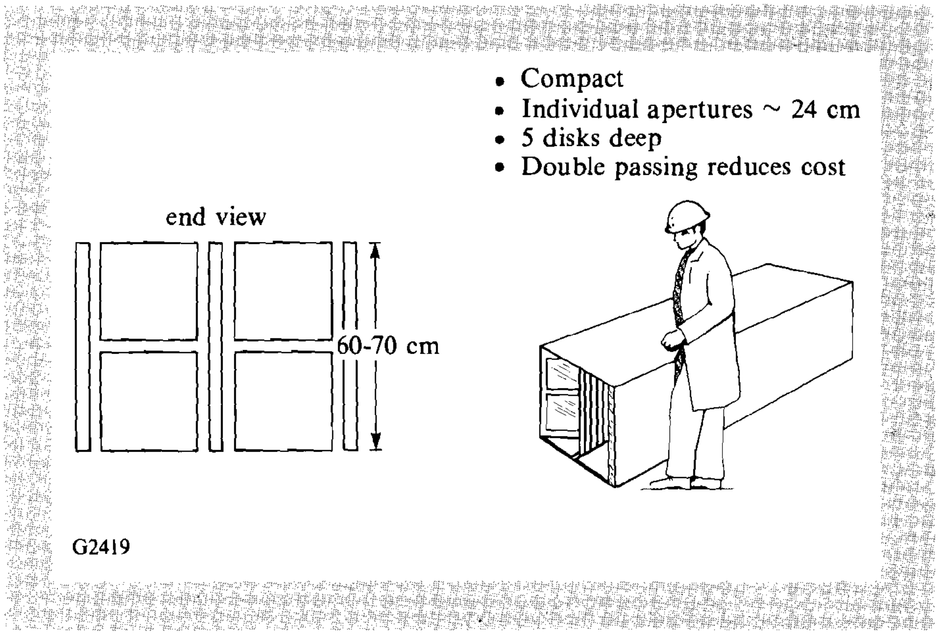

Fig. 38.12
Proposed MSA amplifier for the OMEGA Upgrade. It will be a 2 × 2 unit, 5 disks deep, and double passed.

parameterized in beam diameter. Since spatial filters and, consequently, propagation distance are relatively inexpensive compared to amplifier clear aperture, it is advantageous to use the maximum practical propagation distance. An upper limit of approximately 11 m is set by building-size limitations. Plan and elevation views of the proposed booster stage are shown in Fig. 38.13.

Pulse-Shape Requirements

The OMEGA upgrade must be capable of producing a shaped pulse consisting of a long (5-ns), low-intensity "foot" smoothly transitioning into a short (0.5-ns), intense, main pulse. While the main-pulse shape is fixed, the shape of the foot pulse must remain flexible [3 ns to 5 ns (FWHM) containing 2 kJ to 6 kJ] in order to accommodate various target designs under consideration. The foot pulse has rapid turn-on (0.1 ns) followed by a smooth rise to a peak power that is ~4%-5% of the main pulse. "Frozen-wave," transmission-line-driven Pockel cells[5] are capable of generating the system input required for the foot. The main pulse contains 24 kJ of energy and is a simple truncated 0.55-ns to 0.75-ns FWHM Gaussian. The truncation point can vary but is envisioned to be at the 80% integrated energy time. Main-pulse truncation can be done at the main-pulse oscillator output using Si-switch-driven Pockel cells.

Beam Modulation and Damage Fluences

The peak expected beam modulation, damage fluences, and fill factor, regardless of amplifier geometry, determine the clear apertures of the system. A 1.8:1 beam modulation is postulated for both the

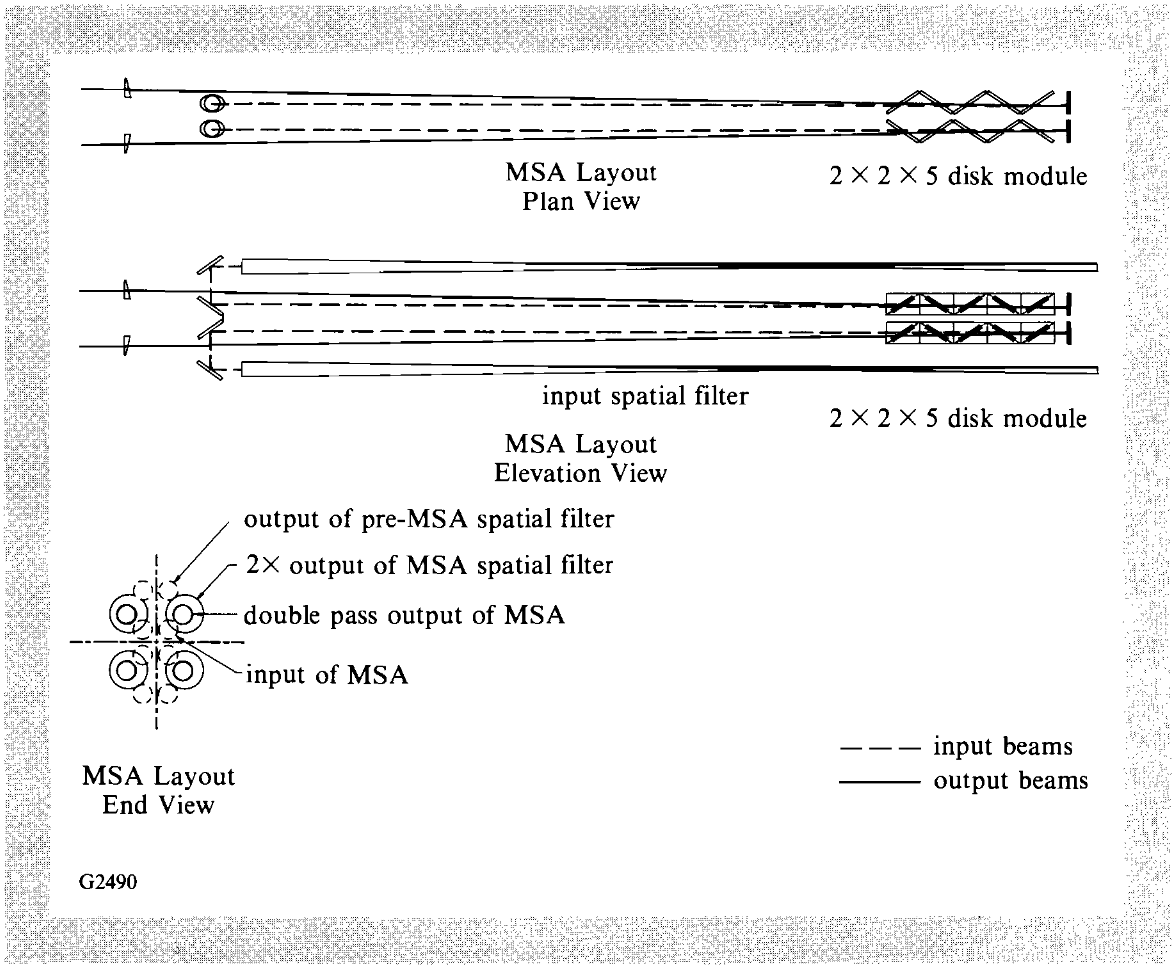

Fig. 38.13
Plan and elevation views of the double-passed amplifier stage.

351-nm and 1054-nm final stages. This modulation is conservative with respect to the OMEGA[6] experience and comparable to experience elsewhere[7]. Calculations are underway to verify this modulation estimate.

Damage fluences are a function of the type of coating, the wavelength, and the pulse width. The greatest damage threat for the main pulse occurs at the shortest pulse width. Because of the sliding energy scale for the foot pulse, it is not as clear where the greatest damage threat for the foot pulse occurs. The energy requirement for the foot varies linearly with the pulse width. The damage fluence for AR-coated optics tends to vary as the square root of the pulse width at 1054 nm and the fourth root of the pulse width at 351 nm. Thus, the greatest damage threat for the foot occurs, counter-intuitively, at the longer pulse width. Since only AR coatings will be used in the frequency-converted subsystem and the beam size in this subsystem is constant, the most damage-threatened coating is the AR coating, which sees the greatest energy. For this system, this would be the AR coating on the output of the tripler.

In order to minimize the 1054-nm damage threat, the output of the final amplifier will go directly into an expanding spatial filter. The most-threatened, 1054-nm coating is on the input lens to this spatial filter. Because of the large decrease in damage fluences in going from 1054 nm to 351 nm, the final spatial filter will have a minimum magnification of 1.4.

Fused silica will be used exclusively for optics in the frequency-converted section. Because of the Pt-inclusion damage problem, any locations in the 1054-nm chain where the peak fluence exceeds 0.75 J/cm^2 in the main pulse or 3.75 J/cm^2 in the foot will also be fused silica.

The base-line type of Ar coatings at both 1054 and 351 nm is the Sol-Gel technology. The damage fluences for these coatings[8] are given in Table 38.I.

Table 38.I Sol-Gel AR damage fluences

1054 nm on fused silica		351 nm on KDP	
0.62 ns	10 J/cm^2	0.5 ns	3.8 J/cm^2
5.5 ns	15 J/cm^2	5.0 ns	6.8 J/cm^2

Note: Difference in pulse widths between 1054 and 351 nm is due to frequency conversion.

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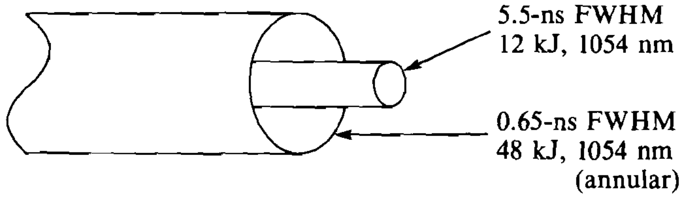
Using all of the above data and a postulated 80% fill factor, the minimum calculated clear aperture for the final amplifier is 17 cm for the main beam alone. The minimum calculated clear aperture for the foot beam is 6.2 cm. For a combined beamline where both pulses share the same 351-nm optics with a 70% fill factor, the minimum calculated clear aperture is 20 cm.

Coaxial Propagation: Co-propagation

Very early in the conceptual design of the upgrade it was realized that the 60 beams required for uniform target illumination presented a major beam-transport and beam-timing effort. Separate foot- and main-pulse beamlines doubled the difficulty. Propagating a shaped pulse through the laser system incurred an unacceptable conversion-efficiency penalty. The solution to this dilemma is to coaxially propagate the two beams. Figure 38.14 illustrates the concept. The foot pulse propagates as the inner beam and the main pulse propagates as the outer, annular beam. There is an antimixing zone between the two beams, accounting for 10% of the clear aperture area, to prevent interference effects between the two beams. The ratio of beam areas is 4.5:1 and the intensity ratio is 5.5:1 (main:foot). The two pulses are mixed on target by the DPP's located before each focus lens.

- Reduces transport optic cost and complexity by a factor of 2.



- An area ratio of 4.5:1 reduces the peak intensity ratio to 5.5:1.
- DPP's "mix" the two pulses on target.

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Fig. 38.14
Coaxial propagation: co-propagation.

Physical separation of the two beams allows optimization of the tripler thickness for both beams as shown in Fig. 38.15. The slower variation of 3ω damage fluences with temporal pulse width forces the two beams to operate at nearly the same fluence. Thus, there are only relatively minor differences in amplifier extraction between the two beams.

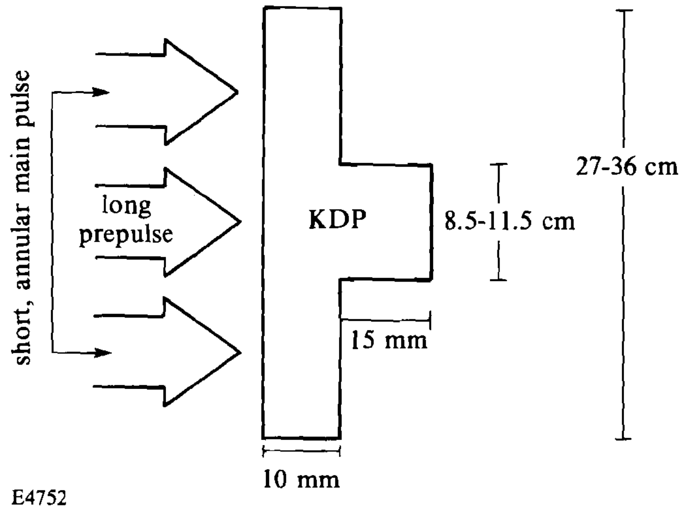

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Fig. 38.15
"Top hat" tripler shape allows efficient conversion of a co-propagated beam.

60-Beam Generation

The remaining problem is how to generate the 60 beams initially from the existing 24-beam system. Each of the 60 beams generated must have the same performance as the current 1054-nm OMEGA beamlines. Current OMEGA beamlines have produced over 200 J in a 0.8-ns pulse. It is desirable to perform the splitting at as small an aperture as possible to reduce costs and facilitate path-length equalization. The leading candidate staging is shown in Fig. 38.16. This staging, through the first 90-mm rod, is identical to the current OMEGA staging with the exception of the eight-way split being a six-way split.

Since the length of the chain has been increased and the small-signal gain has been correspondingly increased, provision has been made after the first 90-mm rod for the inclusion of active isolation to prevent chain self-oscillation. The need for isolation will be experimentally verified during the prototype phase.

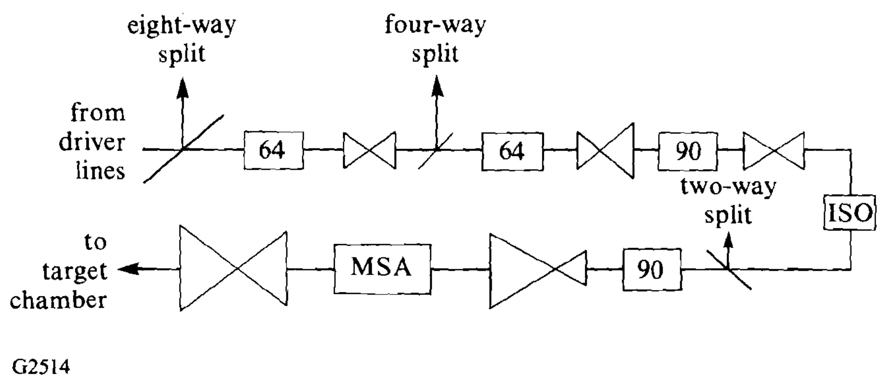

Fig. 38.16
Proposed restaging of OMEGA to generate 60 beams which have the same performance as the existing beamlines.

The staging shown in Fig. 38.16 has several advantages that are not immediately apparent. The saturated gain of the final 90 is 4.3, which is more than adequate to overcome the two-way split and the loss associated with the isolator. This means that the first 90 and splitting region can operate at relaxed fluence levels. Further advantage can be taken of the available drive in this configuration by including a slight ($\sim 5\%$) magnification in the relay between the 90's. This allows the majority of the rod system to operate at a reduced fill factor ($\sim 75\%$) in order to reduce radial gain variations and avoid birefringent areas in the rods.

Conclusion

A number of new ideas and emerging technologies have been coupled with proven laser designs to achieve a cost-effective upgrade to the OMEGA laser system. The novel multisegmented amplifier concept has been coupled with double-passing for high efficiency, high extraction, and concomitant lower cost. Co-propagation, combined with distributed phase plates, provides a compact method of generating the high-dynamic-range, 3ω pulse required on target. Extensive use is made of 16,000-shot-proven OMEGA design hardware to drive the MSA. This combination of new technology and verified designs will allow generation of 60 beams, each with 500 J in the required temporal shape at 351 nm.

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