Compact, Multijoule-Output, Nd:Glass, Large-Aperture Ring Amplifier

A high-gain, large-aperture ring amplifier (LARA) has been developed with a 37-mm clear aperture that delivers output energies of >15 J in a 1-ns pulse at a wavelength of 1.053 μm. The compact ring amplifier fits entirely on a 4' × 10' table and is the main component of the OMEGA Upgrade driver line. The key elements of the ring cavity are a flash-lamp-pumped, 40-mm-diam Nd:glass amplifier rod, a telephoto lens vacuum spatial filter, and a Pockels cell that optically switches the pulse to be amplified in and out of the ring cavity.

System Optical Configuration

The standard optical configuration for the LARA amplifier is shown in Fig. 58.32. A pulse originating from a regenerative amplifier passes through an apodizer before entering LARA. The apodizer modifies the beam profile in order to produce a prescribed near-field intensity distribution after amplification. A typical apodizer and its corresponding annular beam are shown in Fig. 58.33. The apodizer pattern (Fig. 58.33) is one of carefully shaped teeth protruding into the transmission region. The radially varying teeth width determines the radially varying transmission function. Although this concept is not new,[1] the fabrication technique used is new. The apodizer is manufactured by depositing a thin, opaque layer of chrome on one side of a plane-parallel BK7 substrate. The plane-parallel substrate minimizes pointing changes when the apodizer is inserted into the beam. Using standard lithographic techniques, the apodizer is etched into the chrome layer. The teeth in the apodizer are at high spatial frequency and are removed by the spatial filter in LARA, leaving behind the low-frequency, radial intensity modulation. Different apodizers can be used to produce different beam profiles after amplification in LARA. Annular, flat-topped, and a variety of other beam profiles have been produced in this fashion. After passing through the apodizer, the pulse is switched into LARA for amplification by reflection off the input polarizer.

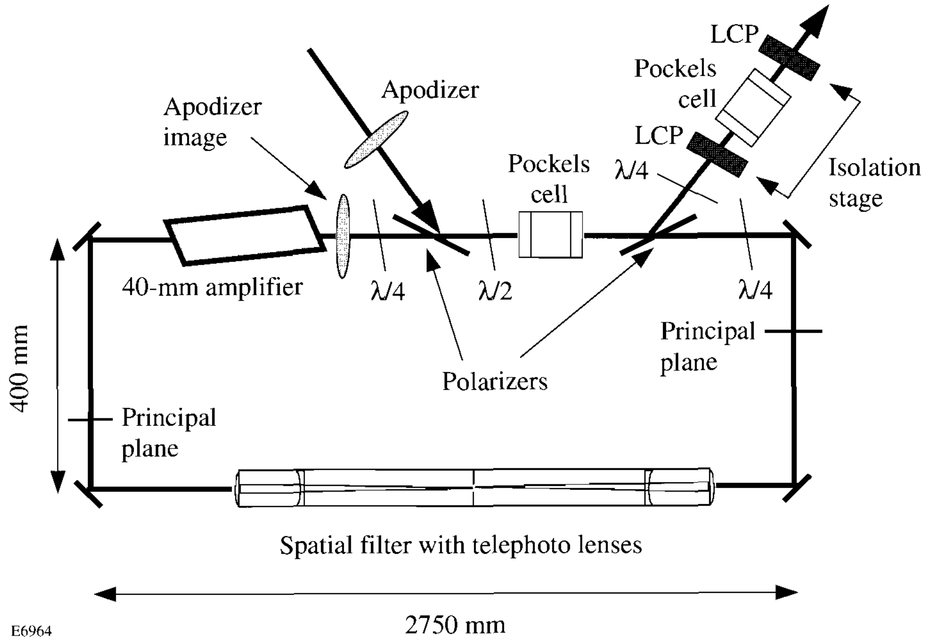

Figure 58.32
Standard LARA design with apodizer image at the output beam inside the cavity.

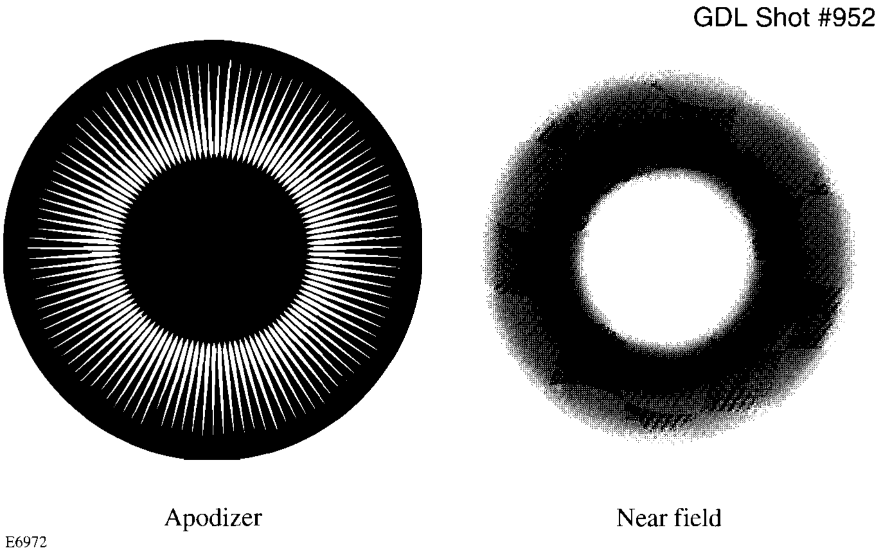

Figure 58.33
Cerated apodizer used to produce annular beam from LARA (left) with corresponding near-field output from LARA (right).

The polarization of a pulse inside LARA is controlled by the combination of two polarizers: a half-wave plate and a Pockels cell as shown in Fig. 58.32. With the Pockels cell off, s-polarized light enters LARA by reflection off the input polarizer. The half-wave plate changes the light to p-polarization, which is transmitted by the output polarizer. After one round trip, the light is again changed back to s-polarization by the half-wave plate and is reflected out of LARA by the output polarizer. Under an ideal situation where the polarizers have infinite contrast between transmitted p-polarized and reflected s-polarized light, a pulse can travel at most one round trip before being reflected out of LARA by one of the polarizers. This design feature limits the amount of amplified spontaneous emission (ASE) that can build up inside LARA.

If more than one amplification pass is desired, the Pockels cell can be pulsed to its half-wave voltage during the first round trip of an injected pulse. When the pulse passes through the polarizer section again, it experiences a full-wave rotation from the half-wave plate and pulsed Pockels cell and is transmitted by the output polarizer. After the pulse passes the Pockels cell for a final round trip, the Pockels cell is turned off, and the pulse is subsequently reflected out of LARA off the output polarizer. In this fashion, multiple round trips in LARA can be made by turning the Pockels cell on for multiples of the round-trip cavity time (22 ns). For example, four round trips occur when the Pockels cell is turned on for 66 ns.

Polarization control is also used for purposes other than containing the pulse in the LARA cavity. The addition of two quarter-wave plates, as shown in Fig. 58.32, changes p-polarized light to circular polarization while passing through the amplifier rod and spatial filter. The effects of radial birefringence are mitigated by passing circularly polarized light through the amplifier rod. Also, backreflected beams from near-normal surfaces in the cavity such as the spatial filter lenses are reflected out of LARA from the polarizers because of a half-wave rotation from double passing the quarter-wave plates. This prevents damage due to ghost reflections by directing the ghost energy out of LARA before it is amplified.

A vacuum spatial filter with telephoto lenses is placed inside LARA to provide 1:1 imaging in the cavity, provide spatial beam cleanup after each amplification pass, increase the threshold for "self-lasing" of the cavity, and cancel odd-order wavefront aberrations for an even number of round trips. A typical ring cavity design with 1:1 imaging would use a two-lens relay, with one lens at each principal plane in Fig. 58.32 and focal lengths equal to one-fourth of the round trip cavity distance. At the high energies of LARA, a vacuum relay is required to eliminate breakdown at the focus of the lenses. For a 1:1 imaged cavity the principal planes must lie in opposing legs of the ring and cause difficulties in the design of a vacuum relay. Therefore a relay with telephoto lenses is placed in one leg of the ring. The effective focal length of the telephoto lenses is equal to one-fourth the cavity round-trip distance, but the principal planes are displaced from the lens positions allowing the relay to lie in one leg of the ring.

Spatial amplitude noise from each amplification pass is filtered by placing a pinhole at the focus of the vacuum relay. The pinhole also reduces ASE in LARA by limiting the range of pointing angles that can propagate inside LARA. Since the spatial filter causes an image inversion when traversed, odd-order aberrations in LARA, such as coma, will be eliminated provided an even number of round trips are made.

After amplification, the pulse is switched out of LARA by reflection off the output polarizer and passes through a quarter-wave plate and an isolation stage. The isolation stage consists of two liquid crystal polarizers (LCP) of opposite handedness surrounding a Pockels cell. The isolation stage is used to improve the contrast between the amplified pulse out of LARA and any pre- or post-pulses. The isolation stage also protects LARA from light propagating back through the isolation stage.

One of the drawbacks of the present LARA design (Fig. 58.32) is the 1:1 imaging of the cavity that places the image of the input apodizer inside LARA. At times, space constraints do not allow for proper image relaying of the apodizer through the output of LARA. An alternative LARA design that overcomes this difficulty is shown in Fig. 58.34. Here, the image of the apodizer in the output beam falls outside the LARA cavity, which simplifies image relay into the rest of the amplifier chain.

System Characterization

Several features of the LARA amplifier are investigated: holdoff, gain versus bank energy, near field, interferometry, and prepulse contrast. Unless otherwise stated, the results presented are for a four-pass LARA in the configuration shown in Fig. 58.32. Since the amplifying medium in the LARA cavity is a flash-lamp-pumped, 40-mm-diam Nd:glass amplifier rod, a maximum repetition rate of one shot per 5 min is used for system characterization.

The holdoff voltage of the ring amplifier cavity is defined as the voltage to which the amplifier can be fired before self-lasing of the ring occurs. Self-lasing of the ring occurs when the round trip gain for ASE exceeds the round-trip losses with the Pockels cell in the "off" state. Below the self-lasing threshold, any ASE traveling around the ring can accumulate only over one round trip before being reflected from the cavity. The self-lasing threshold is primarily determined by the practical limitations set by the finite contrast of the polarizers and the Pockels cell, as well as nonideal wave plates, the size of the spatial filter pinhole, and the birefringence of optical components between the input and output polarizers. Since there are more optical components between the polarizers in the cavity configuration in Fig. 58.34, a lower self-lasing

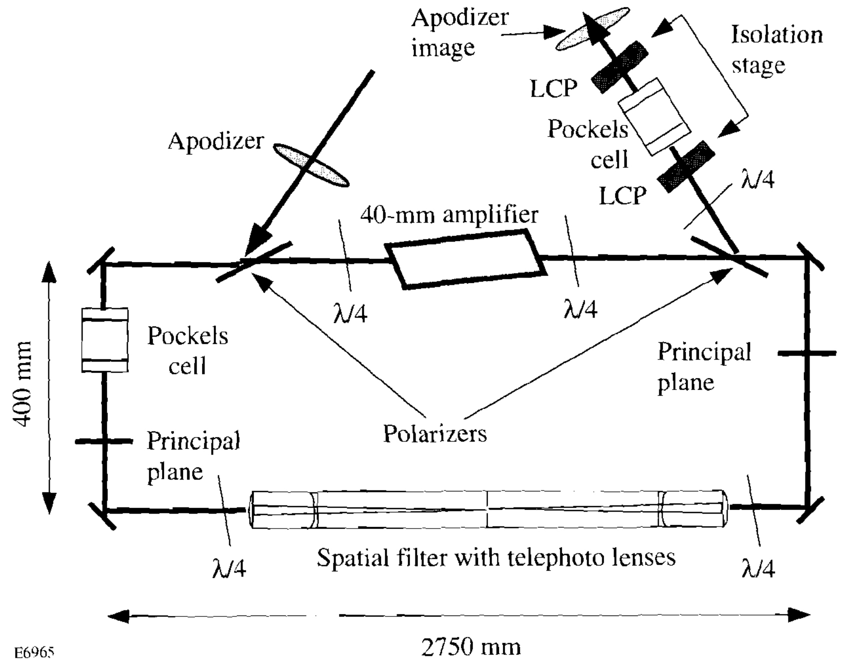

Figure 58.34
Alternative LARA design with apodizer image of the output beam outside the cavity.

threshold or holdoff voltage is both expected and observed. Holdoff voltages as high as 6.4 kV, with a corresponding single-pass, small-signal gain of $G_{ss} \approx 19$, have been measured for the cavity in Fig. 58.32, while holdoff voltages for Fig. 58.34 are around 6.0 kV ($G_{ss} \approx 16$). Since the gain bandwidth of Nd:glass[2] is ~200 Å, the optical elements of the LARA cavity must not provide only for high contrast at the 1.053-μm amplification wavelength, but also for wavelengths to either side. Thus, we observed a higher self-lasing threshold for zero-order wave plates than for multiple-order wave plates. It should also be kept in mind that incorrectly set wave plates in the cavity can result in catastrophic self-lasing with resulting damage to optical components.

The onset of self-lasing is easily diagnosed with the fluorescence traces from the amplifier rod. Figure 58.35 shows photodiode-recorded fluorescence traces of a LARA under normal operating and under self-lasing conditions without pulse injection. Self-lasing manifests itself in the familiar spikes superimposed on a usually smooth fluorescence trace. More dramatic self-lasing can be detected by placing burn paper outside of LARA facing the input and output polarizers.

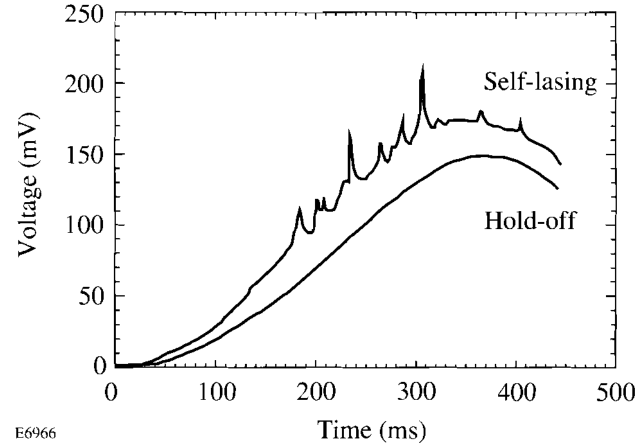

Figure 58.35
The fluorescence traces from a LARA amplifier exhibiting self-lasing (top trace) and under normal hold-off conditions (bottom trace).

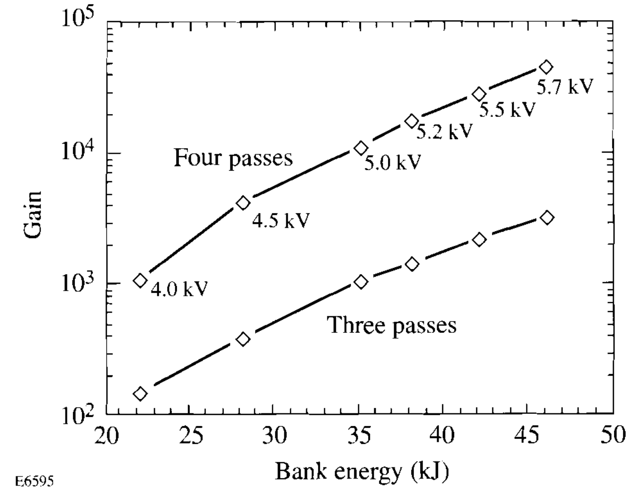

Figure 58.36
Total gain of LARA as a function of flash-lamp bank energy for three- and four-pass configurations.

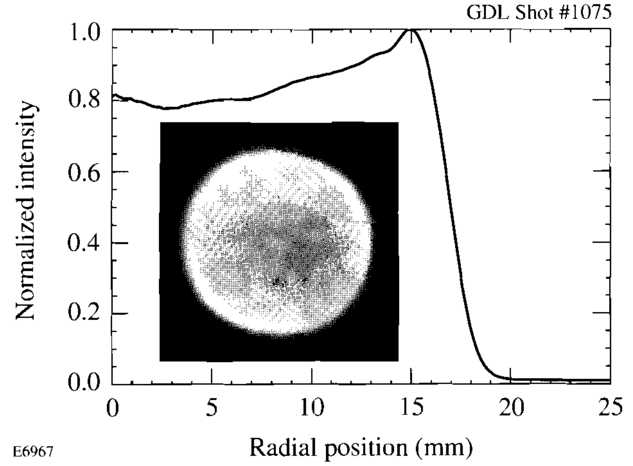

Figure 58.37
Near field of 13.7-J shot from LARA with azimuthally averaged lineout.

The total small-signal gain of the LARA system as a function of flash-lamp bank energy for three and four round trips is shown in Fig. 58.36. With four round trips, total gains of $\geq 10^5$ have been achieved at bank energies of 6 kV without noticeable degradation in beam quality. Figure 58.37 shows the output beam profile for a full-aperture, 13.7-J LARA shot with 140-μJ input energy. The azimuthally averaged lineout shows the 37-mm beam diameter with an intensity distribution peaked at the edges of the beam due to the radial gain in the 40-mm amplifier rod. The peaked edges were expected because the apodizer used with this test was not designed to produce a flattop beam at total small-signal gains of $\geq 10^5$. An appropriately designed apodizer can easily produce a flattop profile at this energy.

The wavefront quality of LARA at full aperture and high energy has been investigated with a self-referencing Mach-Zehnder interferometer.[3] Figure 58.38 shows a reduced interferogram of the LARA output at 17.8 J. The background phase error of the interferometer error is removed from the measurement using a separately recorded wavefront of the input beam without passing through LARA. The peak-to-valley wavefront distortion of an amplified full-aperture beam after four round trips is approximately 1 wave (see Fig. 58.37). Half of this wavefront distortion is directly attributable to the LARA Pockels cell. In the OMEGA Upgrade driver-line application, the aperture diameter is 20 mm and the corresponding peak-to-valley wavefront distortion is a very satisfactory ~0.25 waves.

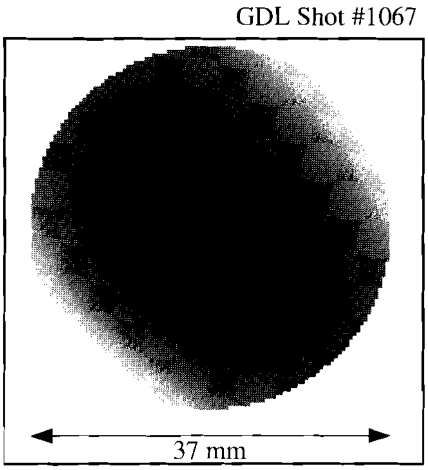

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Figure 58.38
Interferogram of 17.8-J shot from LARA (interferometer error subtracted); peak-to-valley wavefront error = 0.970±0.138 waves, rms error = 0.255±0.307 waves.

One interesting characteristic of LARA is its 'first-shot syndrome,' which manifests itself as a degradation of wavefront quality for the first shot of the day. Figure 58.39 shows the peak-to-valley wavefront error over a 37-mm aperture obtained for a series of shots on a typical day. The peak-to-valley wavefront quality of the first shot of the day with a "cold" amplifier rod is shown by the circle in Fig. 58.39. The series of data points below this circle shows a reduced peak-to-valley distortion for all subsequent shots taken at various intervals between 7 and 20 min. There is a ≥0.5-wave peak-to-valley reduction from the first shot of the day to all subsequent shots. The 'first-shot syndrome' is not well understood, but similar observations have been made previously on the 24-beam OMEGA system. As a practical precaution, the first shot of the day for LARA will not be allowed to propagate down the main amplifier chains of the OMEGA Upgrade.

For the OMEGA Upgrade, the required prepulse energy contrast on target is $>10^9$, which translates to a prepulse contrast for LARA of $>10^4$. Prepulses on the LARA output are due to leakage of a small percentage of the circulating pulse within LARA during each round trip. Without firing the LARA amplifier, the measured prepulse contrast is $\sim 4 \times 10^3$. Under amplified conditions the prepulse contrast is enhanced (multiplied) by the single-pass small-signal gain of the LARA amplifier (typically $G_{ss} \approx 10$) since the prepulse is due to the circulating main pulse during the next-to-last round trip inside LARA. Thus, the LARA prepulse contrast is $\geq 4 \times 10^4$, which is well within the OMEGA Upgrade requirements.

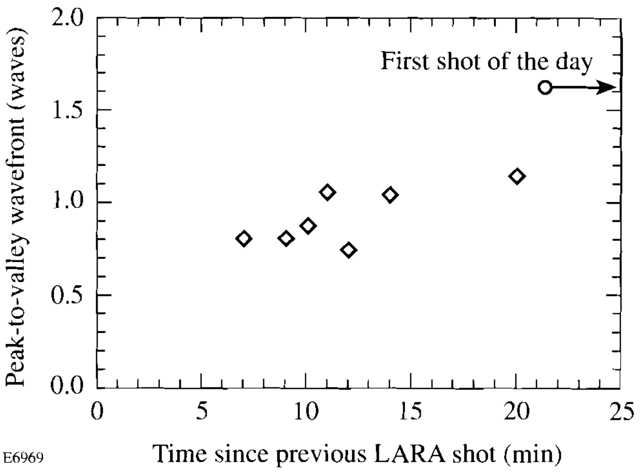

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Figure 58.39
The peak-to-valley wavefront quality of LARA output at full aperture for the first shot of the day (circle) and subsequent cycled shots (diamonds).

Conclusions

A high-gain, large-aperture ring amplifier (LARA) has been developed with a 37-mm clear aperture that delivers output energies of >15 J in a 1-ns pulse at a wavelength of 1.053 μm. The compact ring amplifier fits entirely on a 4' × 10' table and is the main component of the OMEGA Upgrade driver. The key elements of the ring cavity are a flash-lamp-pumped, 40-mm Nd:glass amplifier rod, a telephoto lens vacuum spatial filter, and a Pockels cell that injects the input pulse and ejects the output pulse from the ring cavity. LARA produces a high-energy output beam with excellent wave-front quality and near-field beam profile. LARA output beam profiles can be tailored by an input apodizer. At full aperture (37 mm), a four-pass LARA introduces ~1-wave peak-to-valley distortion on the wavefront quality of the beam. At the 20-mm aperture used by the OMEGA Upgrade, the peak-to-valley distortion is only ~0.25 waves. Excluding the first LARA shot of each day, a consistent wavefront quality is maintained for all shots. The prepulse contrast of LARA output is typically $>10^4$, which meets the OMEGA Upgrade specifications.

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