Highly Stable, Diode-Pumped, Cavity-Dumped Nd:YLF Regenerative Amplifier for the OMEGA Laser Fusion Facility

Introduction

The OMEGA facility is LLE's 60-beam, 30-kJ (UV) laser system for performing inertial confinement fusion (ICF) experiments. One of the main features of the OMEGA laser is a flexible optical pulse–shaping system[1] that produces 0.1- to 5-ns, complex-shaped, low-energy pulses that must be amplified to ~1-mJ level before being injected into power amplifiers. Regenerative amplifiers (regens) are well suited for this application, which requires high energy stability and output-beam quality, including low (<1%) beam ellipticity.

High output-pulse-energy stability was achieved on OMEGA with a negative-feedback system in a flashlamp-pumped regen.[2] This system establishes a stable prelase before the energy in the cavity starts to build up; however, this feedback system can cause dramatic pulse-shape distortion,[3] which is difficult to compensate for. A sophisticated negative-feedback system that does not distort the input-pulse shape was developed for the flashlamp-pumped OMEGA regen.[4,5] The only pulse-shape distortion in this regen results from gain saturation in the regen's active element.

This article presents the design and test results of a new highly stable, diode-pumped, cavity-dumped, compact Nd:YLF regenerative amplifier that does not use a negative-feedback system and thus has reduced system complexity.

Regenerative Amplifier Concept

The regenerative amplifier is the key component of the OMEGA laser driver line. The following tight requirements on regen stability and beam quality must be met:

- output-pulse energy > 0.2 mJ,
- high long-term energy stability (<1% rms fluctuation),
- high temporal pulse shape stability (<1% rms deviation),
- high beam quality (TEM_{00}; ellipticity <1%),
- wavelength tunability to match gain peak to seed-pulse wavelength, and
- OMEGA operational availability >90% with reliability and compactness.

Two major factors affect regen output-pulse-energy stability: gain fluctuations and injected-pulse-energy fluctuations.

Gain fluctuations change the energy and timing of the intracavity peak pulse; hence, they dramatically affect the regen's output-pulse energy when cavity dumping occurs at a given time. Diode pumping, due to its high stability, makes gain fluctuations negligible, contributing to output-pulse-energy stability. Stable gain also provides high temporal pulse-shape stability because the distortion caused by gain saturation is constant. The end-pump geometry of diode pumping significantly improves beam quality.

Injected-pulse-energy fluctuations primarily change the intracavity peak pulse timing, which causes output-pulse-energy variations when the regen is cavity dumped at a fixed time. In our case, the injected pulse energy changes because of (1) fluctuations in the pulse-shaping system and (2) different input-pulse shapes that present significantly different input-pulse energies. Earlier studies[6,7] have shown that output-pulse-energy fluctuations due to injected-pulse-energy fluctuations are minimized when the gain-over-loss ratio is high. We have developed a fast and simple regen simulation model that corresponds very well to our experimental results. The rate-equation regen model described in Ref. 6 has been simplified by treating the regen's active element as a thin gain layer. The input pulse is sliced in time. Gain and level populations in the active element are recalculated after each slice propagation using recurrence relations for fluence, gain coefficient, and gain-recovery coefficient. According to our calculations, the energy of the regen intracavity peak pulse depends weakly on the injected pulse energy for a broad range of injected energies, which is in agreement with results obtained in Ref. 7. Also, our calculations show that the peak of the intracavity energy dynamics is relatively flat and the peak pulse energy for different injected energies stays constant for several round-trips. These considerations make the concept of building a highly stable regen without a negative-feedback system viable.

Regenerative Amplifier Design

A cavity-dumped Nd:YLF regen with a 220-cm-long linear cavity has been developed to accommodate shaped pulses of up to 7-ns duration. The regen layout is shown in Fig. 91.7.

The choice of Nd:YLF as an active medium is required to match the gain peak of the Nd:phosphate-glass OMEGA amplifiers. The regen cavity is semiconfocal, formed by high-reflective mirrors—one flat and the other with a 4-m radius of curvature. An 8 × 8 × 20-mm Nd:YLF active element was placed near the middle of the cavity to avoid pulse-overlap effects during long-pulse amplification. The regen gain center wavelength can be tuned to the injected-pulse wavelength by adjusting the temperature of an active element placed on the Peltier element.

Two 25-W, fiber-coupled diode arrays operating at 805 nm were used for regen pumping. The regen was pumped at a 5-Hz repetition rate, although a higher repetition rate should be possible. An 800-μs pump-pulse duration was found to be optimal. The 0.6-mm pump fiber core was re-imaged into a 0.9-mm spot in the center of the active element. The cavity mode diameter inside the active element was calculated to be ~1 mm, so the pumped volume diameter was smaller than the mode diameter, allowing it to serve as an intracavity gain aperture. An additional intracavity aperture was installed for tighter beam-quality control.

Regen reliability is provided by a simple cavity design: a no-feedback-system, cavity-dumped linear resonator. A small, 15-in. × 38-in. regen footprint is provided by folding the cavity. A high gain/loss ratio in the cavity-dumping regime provides output-pulse-energy stability, while a thermostabilized solid-aluminum block design contributes to the overall regen parameter stability (Fig. 91.8).

Experimental Results

To test the regen performance, square optical pulses of various durations and energies produced by our pulse-shaping system[1] were used. First of all, we wanted to demonstrate that our regen simulation model adequately describes regen dynamics. We calculated and measured intracavity regen dynamics [Fig. 91.9(a)] and square-pulse distortion of the regen peak pulse [Fig. 91.9(b)] when a 4-ns FWHM, ~170-pJ square pulse was injected. It is evident that our regen model agrees well with experimental results. (In practice, energies of ~10 to 100 pJ are used.)

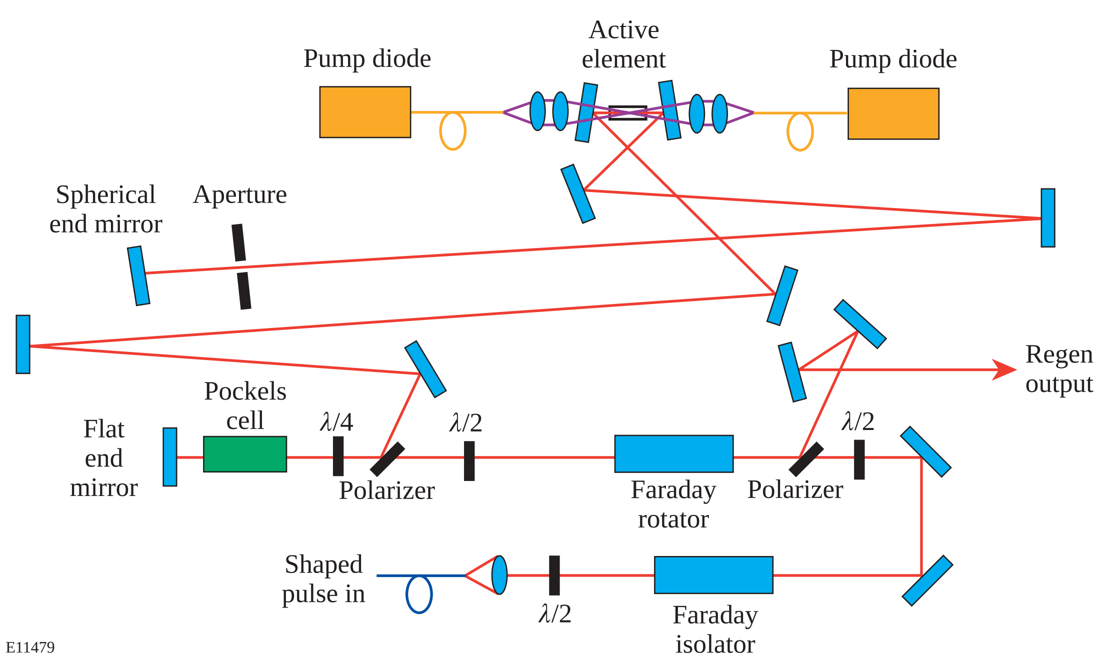

Figure 91.7
Layout of the diode-pumped, cavity-dumped Nd:YLF regen, which is able to amplify shaped pulses of up to 7-ns duration.

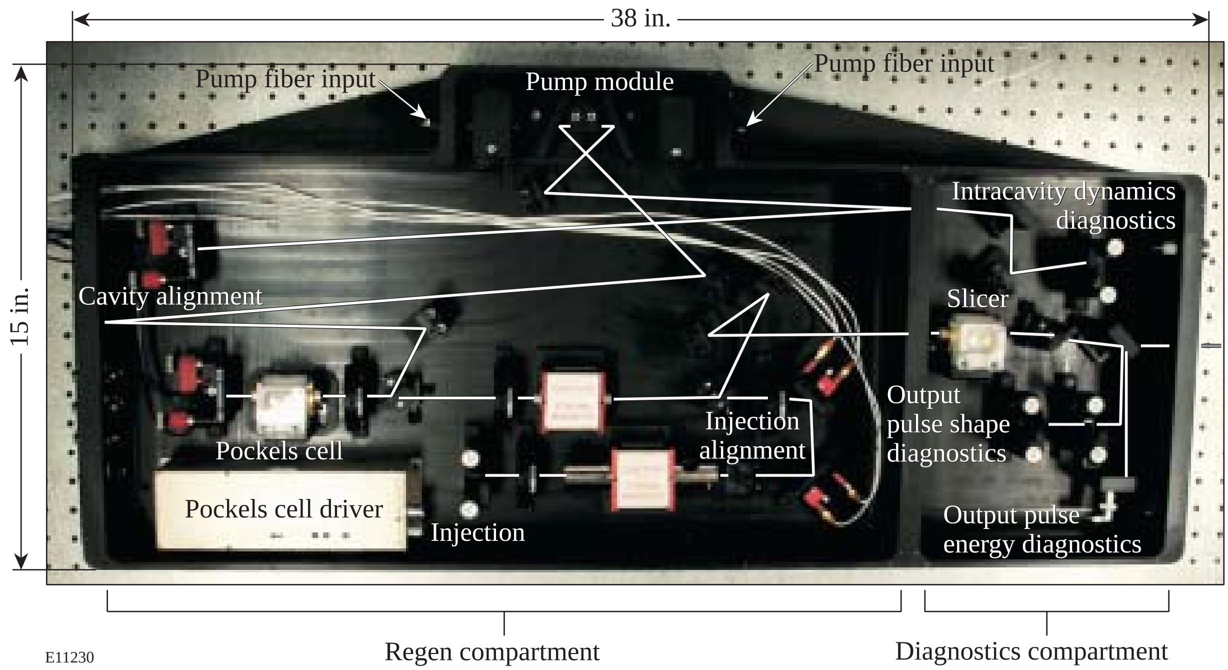

Figure 91.8
OMEGA diode-pumped regen design. Regen enclosure is made of a solid-aluminum block and includes regen and diagnostics compartments. The regen footprint is 15 in. × 38 in., including an optical diagnostics compartment.

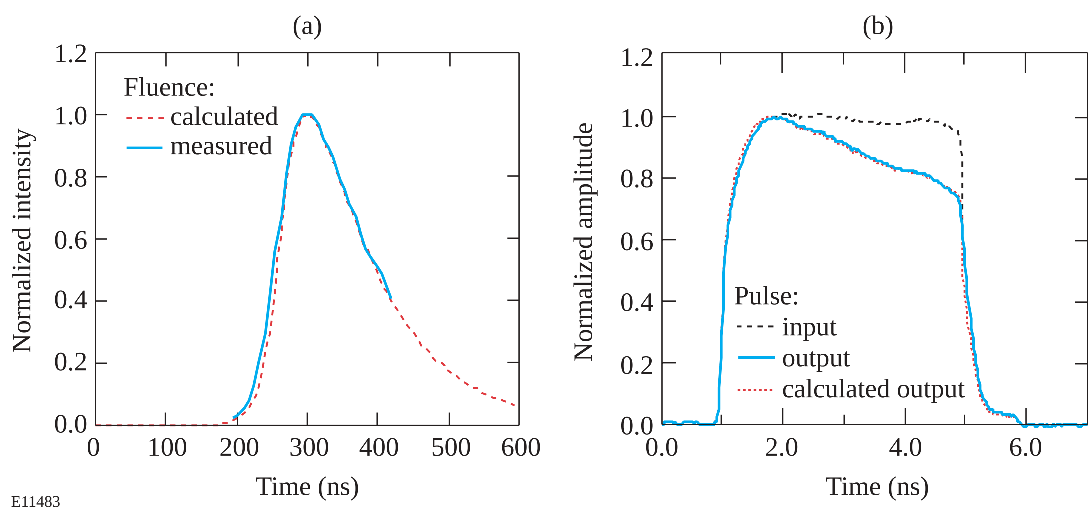

Figure 91.9
(a) Regen intracavity dynamics and (b) peak square-pulse distortion calculated and measured for a 4-ns injected square pulse.

To demonstrate regen insensitivity to an injected-pulse energy, we changed the injected square pulse width (energy) and measured the cavity-dumped output-pulse energy [Fig. 91.10(a)]. The output energy stays within a 1% range when injected energy changes by 600%. A decrease in the gain/loss ratio makes the regen more sensitive to injected energy variations [Fig. 91.10(b)].

We were able to inject pulses with energy as low as several picojoules, which yielded an ~10^9 regen overall gain. Regen energy stability was excellent: <0.9% rms fluctuations over a 24-h period [Fig. 91.11(a)]. It is worth noting that output-pulse-energy stability is higher at lower output energies [Fig. 91.11(b)].

We also measured the long-term stability of the output temporal pulse shape (Fig. 91.12). Temporal-pulse-shape variations did not exceed 1% rms over 5 h of operation. Temporal-pulse-shape stability is an extremely important driver-line parameter for OMEGA operations.

The regen beam profile was measured with an IR scientific-grade CCD camera with more than 1000:1 dynamic range and corresponded to a TEM_{00} mode. The beam ellipticity over the beam above the 0.001 level was computed using a second-moment calculation method was 1.5% with no intracavity aperture and <1% with the intracavity aperture that supported the TEM_{00} mode.

Conclusion

A highly stable, diode-pumped Nd:YLF regen for use in the OMEGA front-end laser system has been developed. This regen produces shaped optical pulses of up to 7-ns duration with low, <0.9% rms energy fluctuations for further amplification on OMEGA. Excellent temporal-pulse-shape stability and beam quality are the main advantages in comparison to previous designs.

ACKNOWLEDGMENT

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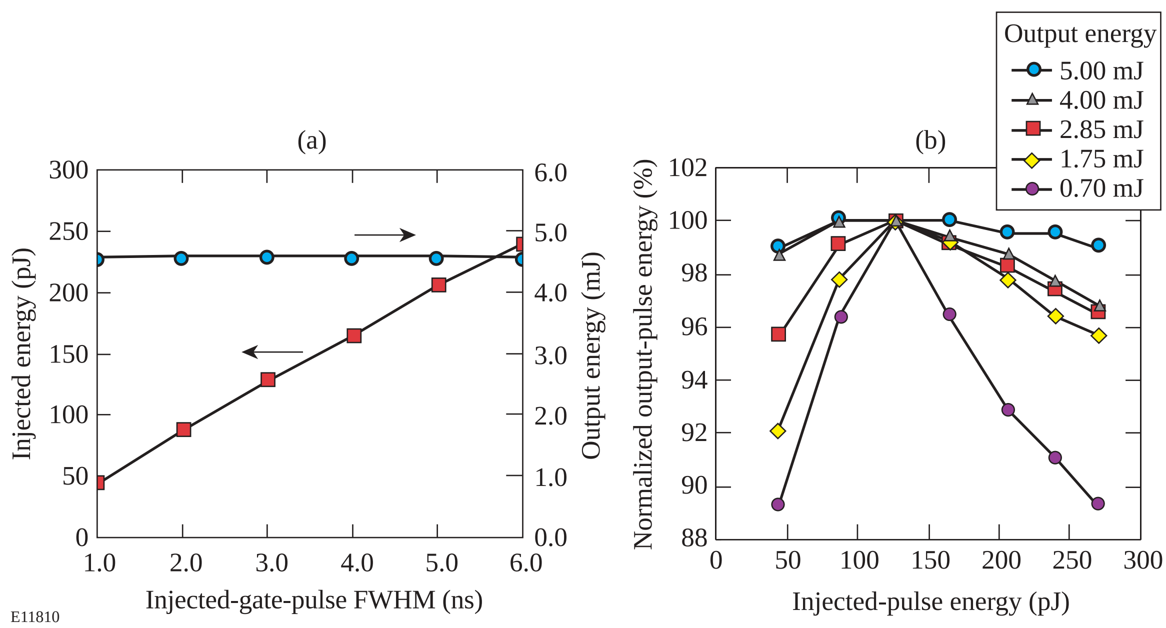

Figure 91.10
Regen output-pulse energy does not change with variations of injected-pulse energy, when (a) gain/loss ratio is high, and (b) becomes more sensitive to injected-pulse energy with decreasing gain/loss ratio. Note that the vertical scale of (b) is expanded to show the variation with input energy.

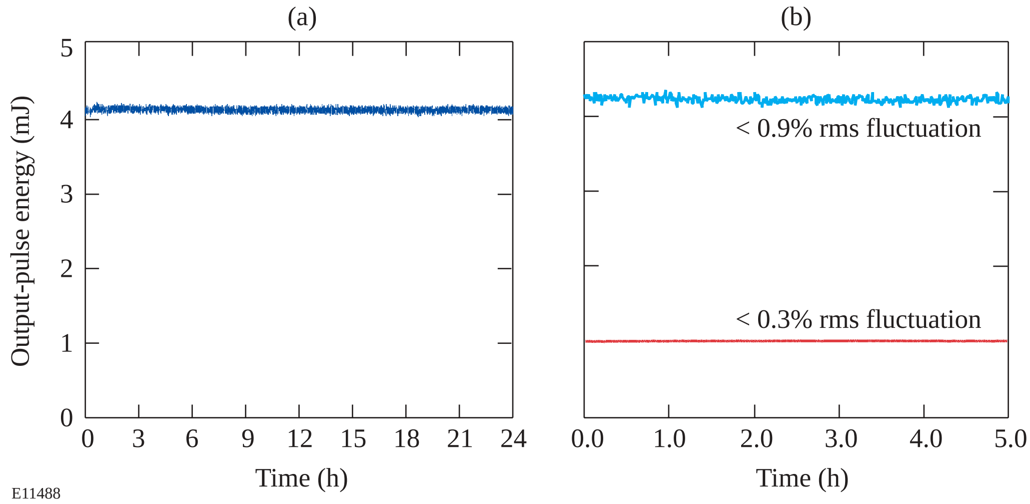

Figure 91.11
(a) Regen output-pulse-energy stability is <0.9% rms over 24 h; (b) regen stability is higher at lower output energies.

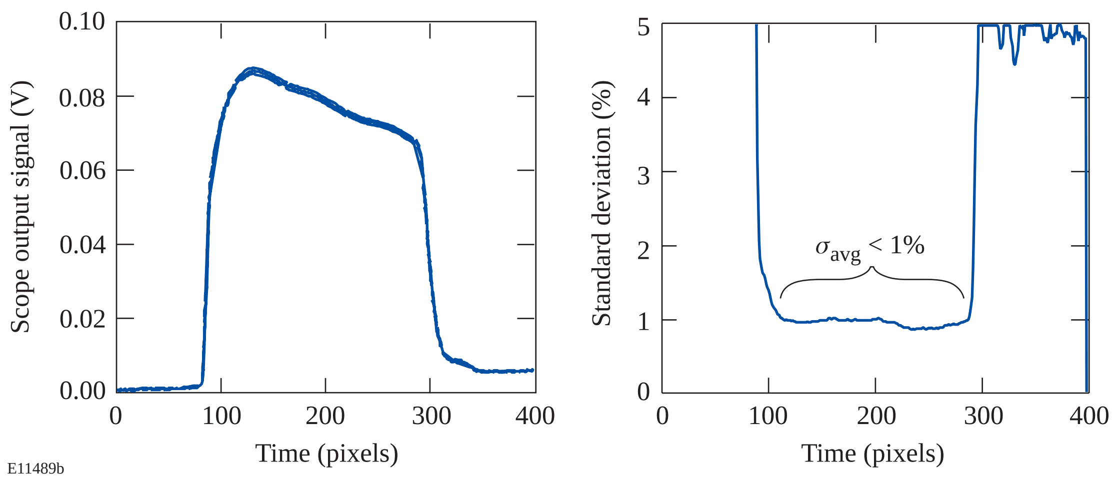

Figure 91.12
Regen output-temporal-pulse-shape stability is excellent: pulse shape standard deviation is <1% over 5 h.

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