Highly Stable, Diode-Pumped Master Oscillator for the OMEGA Laser Facility

The OMEGA facility is a 60-beam, 30-kJ (UV) laser system for performing inertial confinement fusion (ICF) experiments. One of the main features of the OMEGA laser is an optical pulse–shaping system capable of producing flexible temporal pulse shapes[1] (Fig. 76.1). The recently developed diode-pumped Nd:YLF master oscillator[2] is capable of satisfying the basic OMEGA requirements, such as single-frequency, long-pulse, *Q*-switched operation with high amplitude stability. Some OMEGA operational issues (modulator minimization procedures, bandwidth characterization, increased repetition rate, and temporal diagnostic calibration), however, have motivated the development of a new diode-pumped, multipurpose laser. The new laser is capable of serving as the OMEGA master oscillator (stable, single-frequency, *Q*-switched operation), as well as a source of stable, single-frequency cw radiation (for modulator characterization and minimization) and stable, sinusoidally modulated radiation (for temporal diagnostics calibration).

OMEGA Pulse-Shaping System

The heart of the OMEGA optical pulse–shaping system is an integrated-optic (IO) modulator. To obtain high-contrast, high-precision, shaped optical pulses, the modulator must be biased to provide zero transmission in the absence of an electrical waveform (modulator minimization procedure). To accomplish this on OMEGA, cw laser radiation from a different laser source than the master oscillator (the cw mode-locked laser) is manually directed to the modulator. This operator intervention is time consuming and places unnecessary stress on fiber-optic connectors and components. This operator intervention is eliminated with a master oscillator that can be easily switched to cw operation.

By increasing the laser repetition rate in *Q*-switched operation, precision pulse-shape and bandwidth measurements can be made with a high-bandwidth sampling oscilloscope. In addition, with careful laser-cavity-length control the laser can

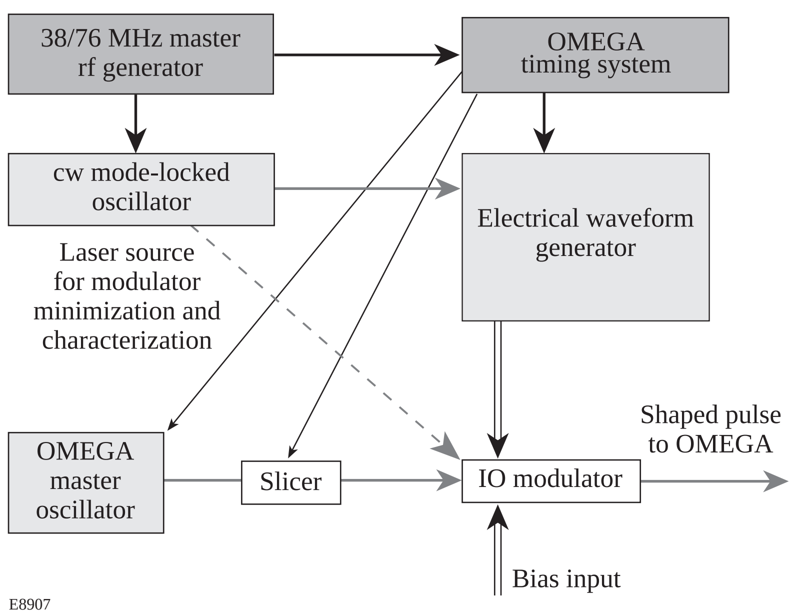

Figure 76.1
Block diagram of the OMEGA pulse-shaping system.

lase simultaneously on two adjacent cavity modes and provide a precise, temporally modulated signal for temporal diagnostics calibration (streak cameras, photodetectors, etc.).

Laser Characteristics

The basic design of the laser (Fig. 76.2) is similar to the one described earlier.[2] As a pump source we have chosen a single-stripe, 1.2-W, cw SDL-2326-P1 laser diode (a modification from the previous design) with a thermoelectric cooler that eliminates the need for water cooling. The diode wavelength is temperature tuned to 797 nm to provide maximum pump absorption in the active element. The polarization of the pump radiation is parallel to the *c*-axis of the active element, which increases pump absorption to approximately 80%.

Beam-conditioning optics for the diodes consist of an AR-coated aspherical lens (NA~0.68) and an AR-coated cylindrical lens. The pump radiation is focused into the active element through the dichroic end mirror. Transmission of the conditioning optics, focusing lens, and dichroic mirror is ~90% at 797 nm. The active element is a 4-mm-diam by 5-mm, 1.1% Nd:YLF wedged and AR-coated rod oriented with the Brewster prism to provide 1053-nm lasing. The acousto-optic modulator (AOM) used as *Q*-switch (GOOCH & HOUSEGO, QS080-2G-RU2) is wedged and AR coated for 1053 nm. In the cw operation regime (no rf power applied to the AOM) the laser generates a total of 260 mW of cw power (in both counter-propagating beams) with an optical-to-optical efficiency >21% at 1053 nm (Fig. 76.3).

Unidirectional single-frequency operation is achieved by applying a low (<200-mW) rf power to the AOM.[3] By removing the rf power from the AOM we obtain *Q*-switched, 50- to 200-ns (FWHM) pulses [Fig. 76.4(a)] at a repetition rate of up to 10 kHz. The energy content of the sliced, flat-top portion of the pulse [Fig. 76.4(b)] is 0.2 to 1.5 μJ, depending on the pulse width. Without removing the rf power to the AOM (*Q*-switch trigger off), the laser generates up to 100 mW of single-frequency cw power (optical-to-optical efficiency is ~13%).

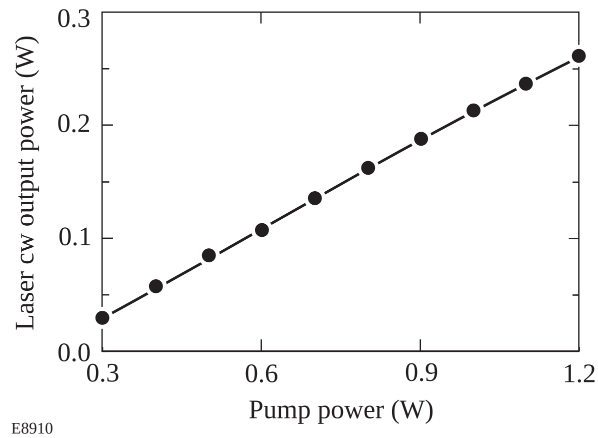

Figure 76.3
Laser cw output power versus diode pump power for bidirectional operation.

The spatial laser beam profile is close to TEM_{00} and is launched into a single-mode optical fiber delivery system for all our applications. We routinely achieve a single-mode fiber launching efficiency of the order of 85%, which indicates a high-quality beam profile.

Laser Parameter Control and Stabilization

To achieve single-frequency, highly stable (in terms of amplitude, timing jitter, wavelength) laser operation we employ several feedback loops:

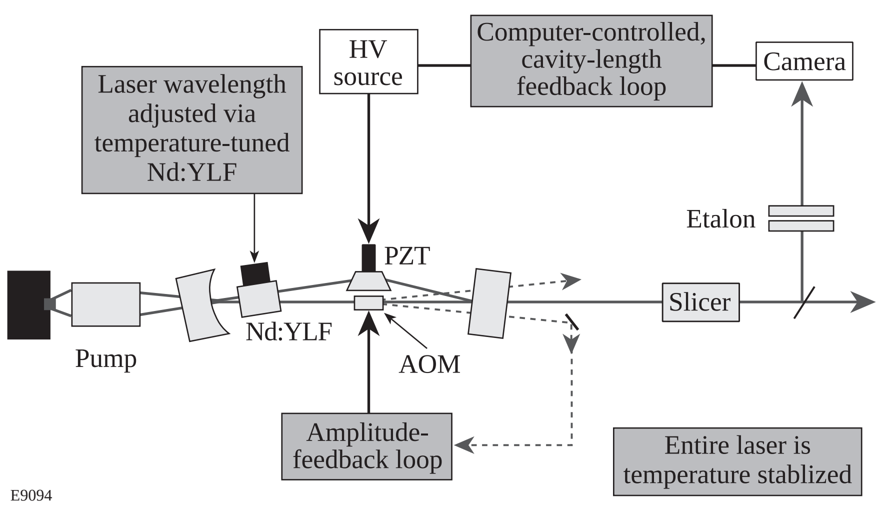

Figure 76.2
Block diagram of the multipurpose Nd:YLF laser.

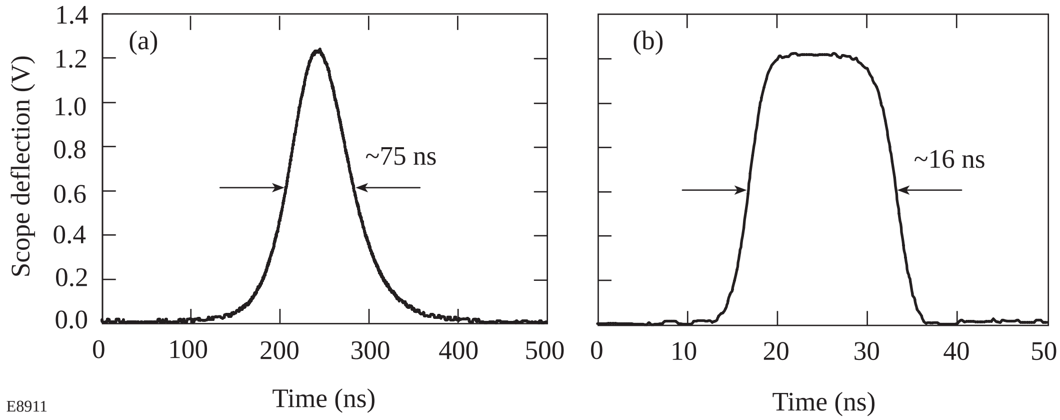

Figure 76.4
(a) The Q-switched pulse envelope and (b) sliced central flat-top portion of the pulse to be sent to the modulator.

- amplitude-feedback loop
- wavelength control and stabilization
- frequency-feedback loop
- overall laser temperature stabilization
- two-mode operation

1. Amplitude-Feedback Loop

To damp relaxation oscillations and stabilize the prelase phase, the rf power applied to the AOM is controlled with a circuit that provides negative amplitude feedback. One of the beams diffracted by the AOM is coupled into a 0.4-mm multimode fiber and sent to a diode that generates a feedback signal (Fig. 76.2). For a high (low) feedback signal the rf power to the AOM is increased (decreased), thus increasing (decreasing) the cavity losses and stabilizing the cw laser output power. With amplitude-feedback stabilization, a very smooth prelase phase with no relaxation oscillations is observed (Fig. 76.5), and the externally triggerable Q-switch leads to high amplitude stability and low temporal jitter of the output pulse. Amplitude fluctuations of the Q-switched pulse are 0.5% rms and the timing jitter is 3 to 5 ns rms depending on the Q-switched optical pulse duration.

2. Wavelength Control and Stabilization

Due to the large longitudinal mode spacing and the absence of wavelength-tuning elements (such as etalons, gratings, etc.) the laser is operating at the peak of the gain curve; thus, the only way to adjust and stabilize the lasing wavelength is to adjust the peak position of the Nd:YLF gain curve by changing and stabilizing the temperature of the active element. The operating temperature of the active element is 34°C to 36°C with no temperature control. Adjustment of the laser wavelength for OMEGA requires additional heating up to 39°C to 45°C. We have developed a miniaturized heater–sensor feedback loop that is mounted on the active element heat sink and can maintain its temperature to within 0.1°C. Figure 76.6 shows the wavelength tuning and stabilization by adjusting and maintaining the temperature of the active element. We have found the thermal wavelength coefficient $\Delta\lambda/\Delta T$ to be +0.08 Å/°C.

3. Frequency-Feedback Loop and Overall Temperature Stabilization

To ensure single-frequency operation we have developed a computerized wavelength-feedback loop. The laser spectrum is measured with an air-spaced etalon and analyzed by a computer equipped with a CCD camera and framegrabber. If the fringe peak moves, the computer produces a driving voltage to change the high voltage on the piezoelectric translator (PZT)

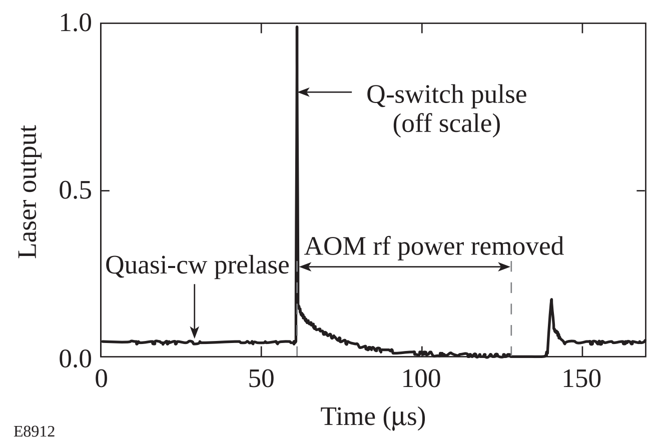

Figure 76.5
Amplitude feedback provides constant prelase for higher amplitude stability of the Q-switched pulse with lower timing jitter.

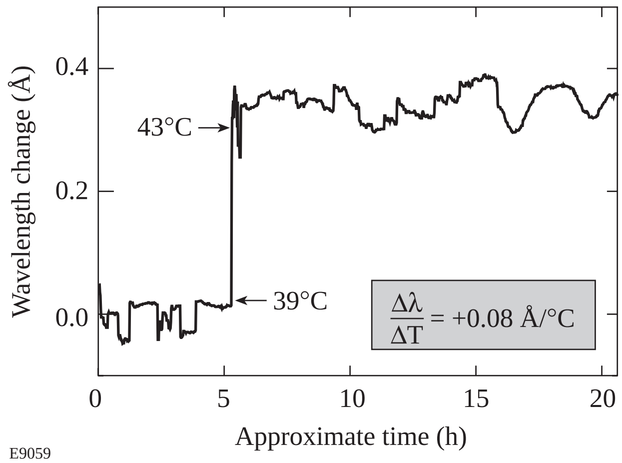

Figure 76.6
The laser output wavelength is adjusted and stabilized by controlling the temperature of the active element.

to correct the laser cavity length and bring the fringe peak to its initial position. The following procedure locates the correct fringe position (reset): The computer scans the PZT driver voltage until the two-mode operation is detected; it then reverses the scan to find the next two-mode operation voltage; and finally, it sets the voltage between these two-mode operation voltages. This reset procedure is repeated every 0.5 h and ensures single-frequency operation [Fig. 76.7(a)]. The thermal drift due to room-temperature changes, however, causes an undesirable wavelength drift. When the laser housing and active element are temperature stabilized [Fig. 76.7(b)], the laser runs single frequency with a residual wavelength drift of 0.01 Å rms over 15 h of operation (Fig. 76.8).

We have taken the envelope of the sliced flat-top pulse using a 20-ps-resolution streak camera. This envelope is extremely smooth (Fig. 76.9), indicating a high single-frequency contrast.

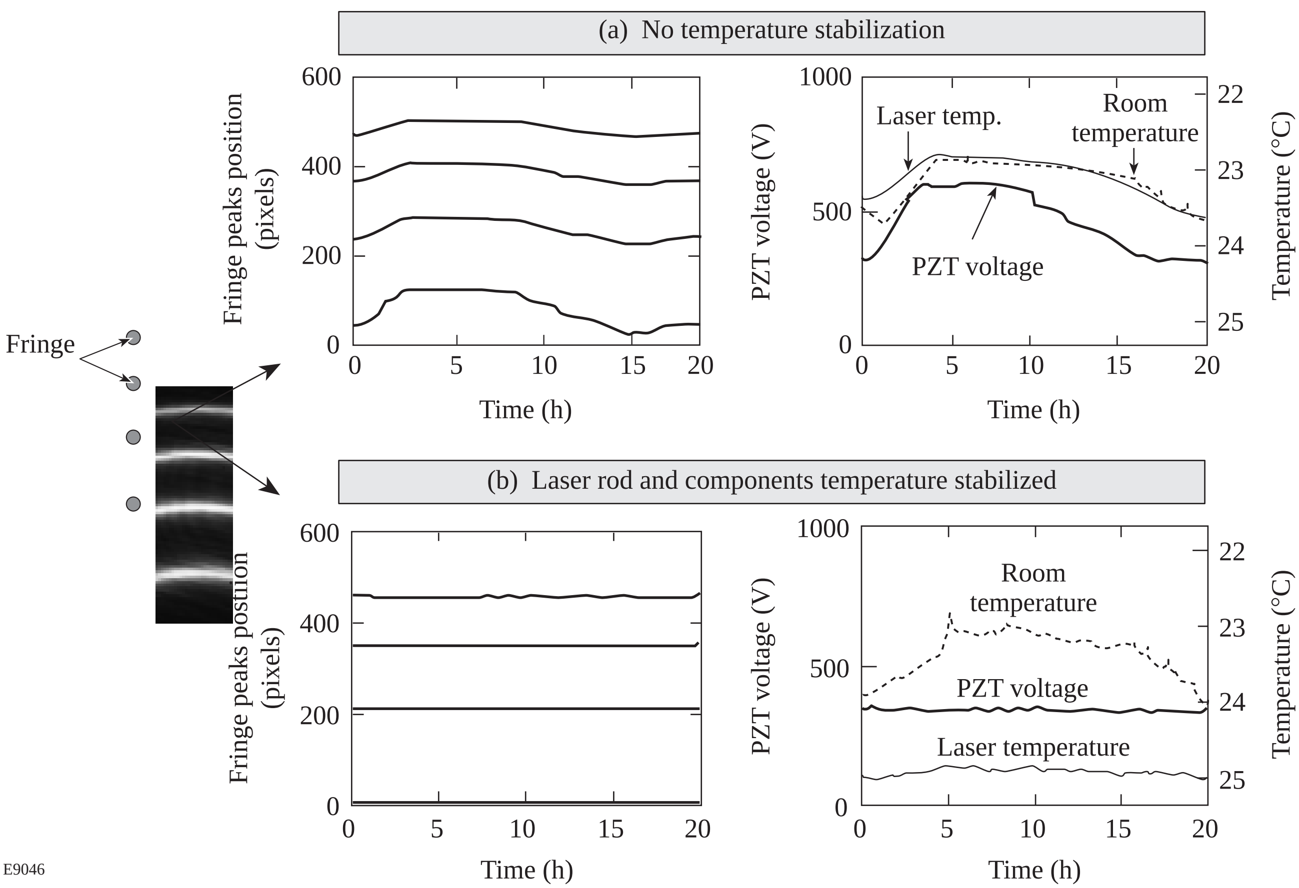

Figure 76.7
The laser operates with a single frequency; however, with no temperature stabilization the frequency drifts over time and follows the room temperature (a). Temperature stabilization of the active element and laser components significantly improves wavelength stability (b).

4. Two-Mode Operation

By applying the appropriate computer-controlled feedback to the PZT-mounted prism in the laser cavity, the laser can be forced to operate over many hours on two adjacent longitudinal modes with approximately equal amplitudes [Fig. 76.10(a)]. In this case the pulse's temporal structure is a deeply modulated sinusoidal signal with a 267-ps period [Fig. 76.10(b)]. This signal can be particularly useful for OMEGA temporal diagnostics calibration such as streak camera sweep speeds, etc.

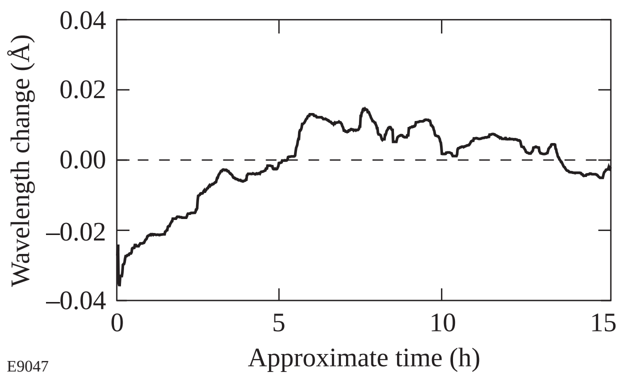

Figure 76.8
The laser wavelength stability is 0.01 Å over 15 h.

Conclusion

We have developed a diode-pumped, multipurpose Nd:YLF laser for the OMEGA laser facility that is suitable for our pulse-shaping applications, including modulator minimization and characterization, as well as temporal diagnostics calibration. The laser combines three functions without realignment:

- *Q*-switched, single-frequency master oscillator for the OMEGA laser,
- cw single-frequency operation for pulse-shaping applications, and
- the source of a stable sinusoidal optical signal for diagnostics applications.

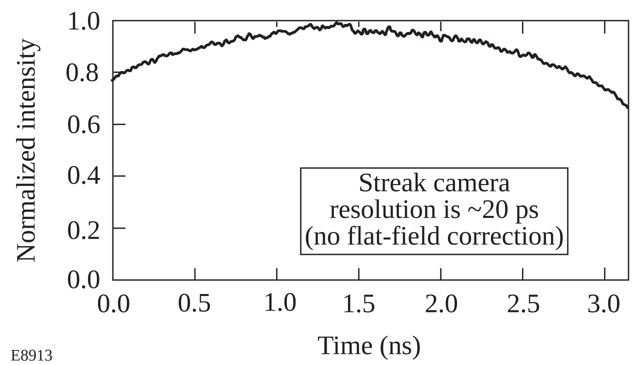

Figure 76.9
Streak camera measurement of the pulse envelope (no flat-field correction) showing high single-frequency contrast.

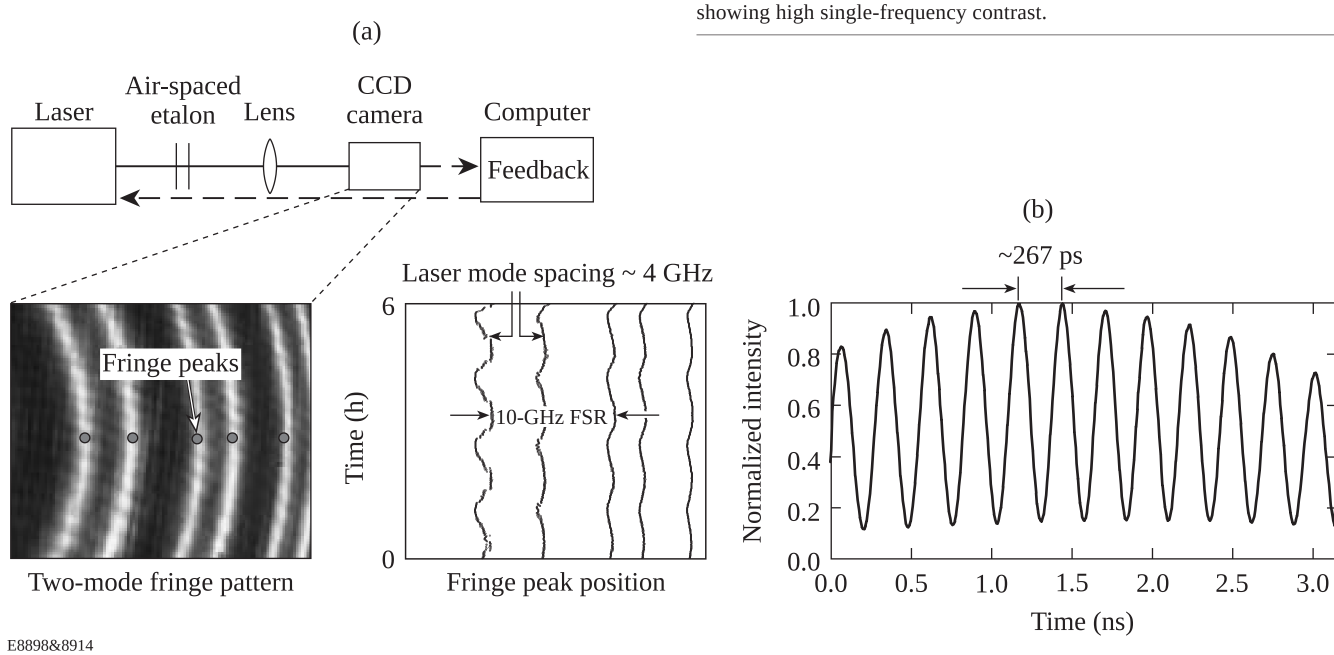

Figure 76.10
(a) Long-term, two-mode operation and (b) streak camera measurement of the optical sinusoidal signal (no flat-field correction).

The laser output is either up to 100 mW of cw single-frequency radiation or *Q*-switched pulses with a smooth or sinusoidally modulated envelope at a repetition rate of ≤10 kHz. Changeover requires no laser realignment.

ACKNOWLEDGMENT

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