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A RELIABLE LOW–MAINTENANCE FLASHLAMP–PUMPED TI:SAPPHIRE LASER OPERATING AT 120 PPS*

K. H. WITTE
Stanford Linear Accelerator Center,
Stanford University, Stanford, CA 94309

Abstract

Flashlamp-pumped Ti:sapphire lasers have been reported to produce high-energy pulses with broad tunability. However, with the flashlamps operated close to their explosion energy, and thermal loading effects in the laser rod, these lasers were restricted to low repetition rates (typically around 10 PPS). Higher repetition rates at constant laser pulse energy reduce the flashlamp lifetime drastically. The author reports on a reliable flashlamp-pumped Ti:sapphire laser that has been operating at 120 PPS for over 10^9 shots with the only cavity or pump chamber maintenance being flashlamp changes less than every 2×10^8 pulses—the lowest maintenance reported. A specular dual-lamp pump chamber was used to pump a 4 mm × 6 inches, 0.1% doped Ti:sapphire rod. This resulted in a very low lasing threshold, which ensured a stable output at low pump levels. The criterion for pump power was to obtain a highly stable output at the edge of the selected tuning range, from 790 to 860 nm. The combination of flashlamp walls, flashlamp flow tubes, and rod flow tube as ultraviolet light filters prevented laser rod solarization.

Introduction

The first reports on direct flashlamp pumping of Ti:sapphire were made by L. Esterowitz et al.[1] in 1984 and by L. Esterowitz[2] in 1985. They obtained 8 mJ and over 250 mJ of laser output energy, respectively. In the years following, higher output energies (exceeding 1 J/pulse) were reported.[3,4] Repetition rates reached 40 PPS.[3] Improved laser crystal quality contributed to a good portion of this success.

The flashlamp lifetimes however could not compete with those of other solid state lasers, for two main reasons; first, the short upper state lifetime[5] of 3.2 μs in Ti:sapphire requires flashlamp pulse durations of only a few microseconds. Second, the lasing threshold was 20 J flashlamp pump energy and higher. Combined, this demanded a significant fraction of the flashlamp explosion energy. The crystal must also be pumped as far as possible over the lasing threshold to produce a stable output with little spiking and little shot-to-shot energy jitter. Hence, for high flashlamp lifetime, the coupling from flashlamp to rod must be at top efficiency to keep the input far under the flashlamp explosion energy.

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Ideally, maintenance for this type of laser should consist only of flashlamp changes. In the past, however, other critical maintenance items such as UV filters, laser rods, and pump chamber reflectors have required frequent replacement.

The system described below is one that operates at higher repetition rates with improved flashlamp lifetimes and minimal pump chamber maintenance. It features a modestly tunable beam with low shot-to-shot energy jitter. The drawback of this laser compared to most previously reported flashlamp-pumped Ti:sapphire lasers (which all concentrated on high-energy pulses) is the lower output energy per pulse.

Design

Pump Chamber

A dual elliptical design with silver reflectors was chosen to pump a 0.1 % doped Ti:sapphire rod. Two 6 mm (ID) flashlamps are imaged on a 4 mm-diameter laser rod in the common focus of the double elliptical reflector. The rod length is 6 inches. The smaller rod diameter and low doping level were selected to reduce the lasing threshold. The conversion efficiency can be improved by choosing smaller lamp diameters, because these can be imaged more completely on the rod. However, this is not expected to improve the flashlamp lifetime. The loss in conversion efficiency by using larger diameter lamps is therefore not regarded as important. To provide efficient and nonhazardous cooling, the rod, the pump chamber, and the flashlamps are sequentially water cooled. Both the flashlamp walls and the flashlamp flowtubes act as a far-UV filter. The rod flow tube acts as a near-UV filter and fluorescence converter.

Modulator

The 1.67 μF capacitor is charged by a 10 kV, 8 kJ/s power supply. It can be discharged through one thyratron to ground and the two flashlamps in series. This produces a 7.5 μs-long (FWHM) electrical pulse. A simmer power supply in parallel to the flashlamps maintains a 3.3 A current through the flashlamps. This extends their lifetimes and stabilizes the high-voltage discharge. It also lowers the rise time of the high-voltage pulse.

Laser Cavity

The laser cavity is optimized for operation between 780 and 870 nm. The narrow band antireflection coatings are centered at 830 nm. The plane outcoupling mirror reflects 90% at 830 nm. A single quartz plate acts as birefringent tuner, providing 0.7 nm bandwidth (FWHM) in the laser cavity tuning range.

Results

Most data were taken with the laser operating at 120 PPS and tuned to 860 nm. The power was regulated to maintain an output shot-to-shot energy jitter of < 3% rms. This corresponds to an almost constant output power for the following reasons: apparently only the flashlamps are aging, and constant output power requires the high voltage to be increased, with the flashlamps darkening in time. Higher voltage shortens the electrical discharge slightly and also shifts the output spectrum of the flashlamps further into the UV. However, both effects have little influence on the output energy or the jitter.

For maintaining the above jitter level, typical output energies are 40 to 50 mJ/pulse at 860 nm (0.7 nm FWHM bandwidth) and 120 PPS, compared to about 100 mJ/pulse free running at 810 nm (7 nm FWHM bandwidth) with the same input energy of 25 to 35 J. With these specifications, over 2×10^8 shots of flashlamp lifetime were achieved in continuous operation. Outside of the flashlamp changes about every three weeks the pump chamber did not require any maintenance for over 10^9 shots (at continuous 120 PPS operation). After the billion shot milestone, the pump chamber did not exhibit any degradation upon a visual inspection. Laser rod solarization due to insufficient UV filtering had been observed in the past. A simple indicator for this was gradual output power drop, followed by a partial recovery after the rod was left unpumped at room temperature. This behavior was not observed for the setup reported here.

The output is almost equal for a stable or an unstable laser resonator. The plane/plane design was chosen here. The beam divergence is typically 1 mrad, mostly due to thermal lensing in the laser rod.

Three plots of output power vs. time are shown below. The first graph shows the pulse shape of a typical single shot, taken at 120 PPS. The output energy was 40 mJ at 860 nm with a pulse width of about 8.5 µs (FWHM; neglecting the spike intensity). Envelopes of 250 shots are shown in the second and third graph for a low pump level and a high pump level, respectively. The data were again taken at 120 PPS with the laser tuned to 860 nm. The output at the low pump level shows significant spiking and shot-to-shot jitter (both in time and in pulse energy) for an output energy of 20 mJ/pulse. This pulse was observed close to the lasing threshold of 8 J/pulse total flashlamp pump energy. The output at the higher pump level (60 J electrical input energy resulted in 160 mJ laser output energy) is very stable with a shot-to-shot energy jitter of about 2% rms. The first plot was taken under conditions typical for the above quoted flashlamp lifetime.

Pulse repetition rates of 200 PPS have been demonstrated as well as average output powers in excess of 30 W.

References

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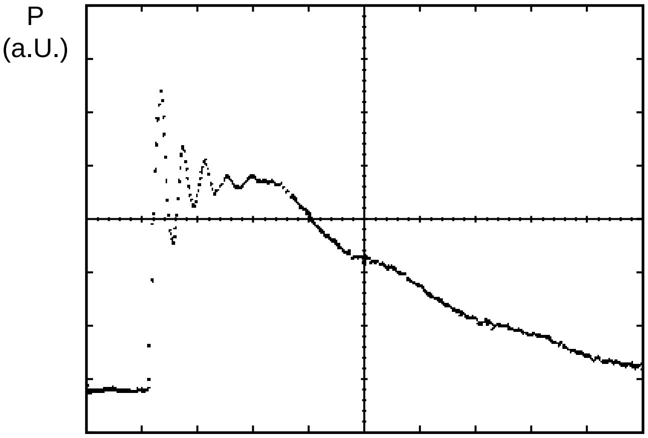
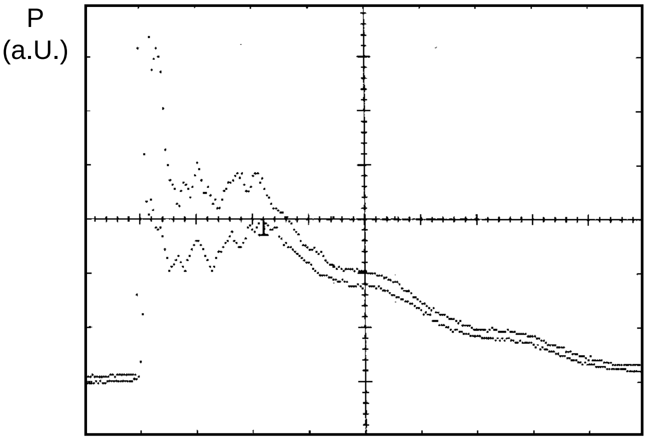
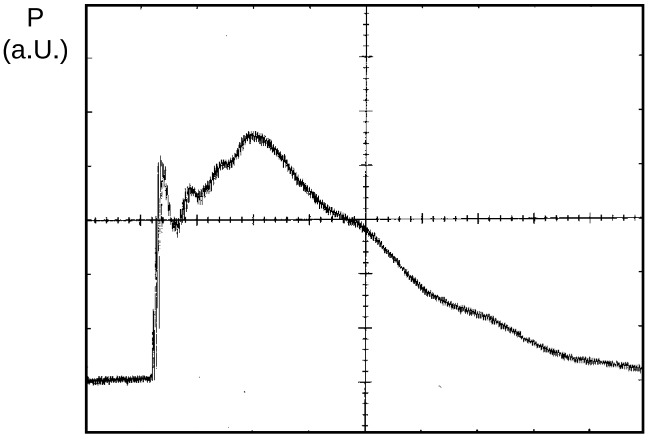


Graph 1; Typical pulse shape:
single pulse at 860 nm, 120 PPS
and 40 mJ/pulse output.



Graph 2; Pulse shape at low pump level:
envelope of 250 pulses at 860 nm,
120 PPS and 20 mJ/pulse output.



Graph 3; Pulse shape at higher pump level:
envelope of 250 pulses at 860 nm,
120 PPS and 160 mJ/pulse output.

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