CONF-??????-- Sum ?

BNL — 46036

MAY 1 3 1991

SUMMARY OF THE LASER WORKING GROUP*

I. J. Bigio, N. A. Kurnit

Los Alamos National Laboratory, Los Alamos, NM

W. R. Donaldson

*Laboratory for Laser Energetics,
University of Rochester, Rochester, NY*

K. Geissler

CERN, Geneva, Switzerland

T. Srinivasan-Rao

Brookhaven National Laboratory, Upton, NY 11973

October 1988

Laser Working Group

I. J. Bigio and N. A. Kumit, *Los Alamos National Laboratory*

W. R. Donaldson, *Laboratory for Laser Energetics, Univ. of Rochester*

K. Geissler, *CERN*

T. Srinivasan-Rao, *Brookhaven National Laboratory*

Summary

The laser working group considered several options to deliver synchronized laser pulses of the required energy to the photocathode and laser triggered switches. These requirements actually decreased during the course of the workshop, and the values finally settled upon (<10 μJ in 100 fs at ~250 nm for the photocathode and ~20 mJ in 2 ps near either 250 nm or 1 μm for the switches) were considered to be well within the state of the art. Some development work may be required, however, to provide a system that has the desirable characteristics of stability, ease of use and low maintenance.

The baseline concept, which is similar to a number of existing systems,[1-3] utilizes doubled Nd:YAG-pumped dye oscillator/amplifiers to produce an upconverted picosecond pulse that can be amplifed to tens of mJ in a KrF excimer laser. A fraction of the dye oscillator output is also compressed by means of a fiber-grating compressor[4] and further amplified in a dye amplifier before being upconverted to produce the synchronized pulse for the photocathode.

As shown in Fig. 1, the proposed system would consist of a cw mode-locked Nd:YAG laser that is frequency-doubled and used to synchronously pump a dye oscillator to produce a train of ~2 ps pulses at 648 nm. A portion of the mode-locked Nd:YAG laser output is also used to injection control a Q-switched and cavity-dumped regenerative Nd:YAG amplifier to produce ~60 mJ at 1.06 μm in a pulse of ~100 ps duration.[5] A single pulse from the dye oscillator is amplified in sequential dye amplifiers pumped by the 532 nm frequency-doubled output of this Nd:YAG regenerative amplifier. This dye laser pulse, of approximately 1 mJ energy, is doubled and mixed with a portion of the unconverted 100-ps 1.06-μm pulse to produce ~50 μJ in 2 ps at
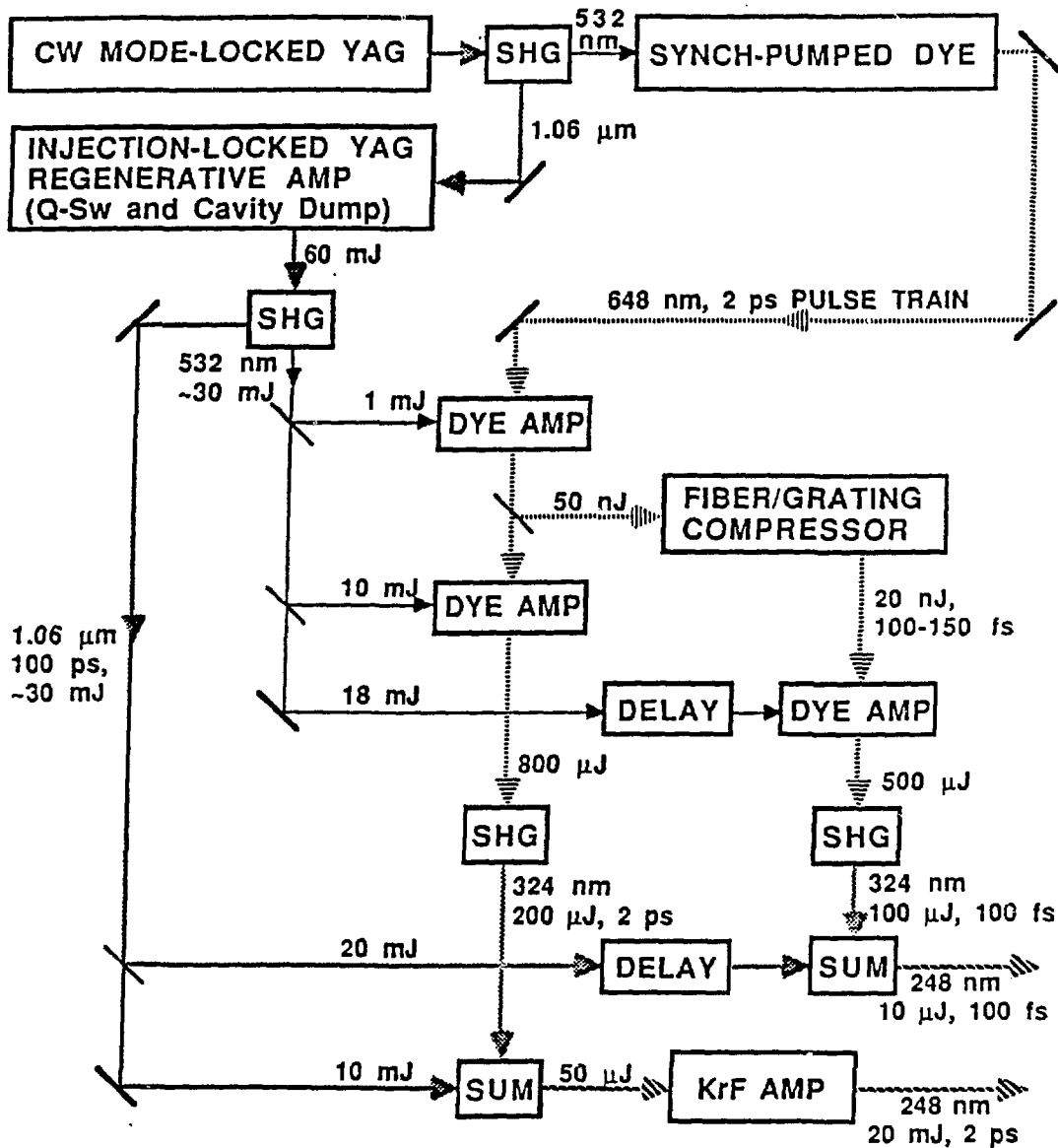
MASTER

Fig. 1. Block diagram of laser system for generating 10 μJ in 100 fs by sum frequency mixing of a doubled dye with the Nd:YAG pump and similar synchronized source for KrF amplification to 20 mJ in 2 ps. Indicated energies are estimates of amounts needed for producing desired sum frequency outputs.

248 nm; this pulse is then spatially filtered and amplified through one or two passes of a KrF gain medium to yield ~20 mJ (or more, depending on the KrF aperture) of output energy. The synchronized 100 fs pulse is produced by splitting off a small fraction of the output of the first dye amplifier, chirping it in a fiber, and compressing it with a grating pair. This pulse is then amplified in another dye amplifier (pumped by part of the same 532 nm pulse), doubled, and mixed with the remainder of the unconverted 1.06 μm pulse to produce on the order of 10 μJ in 100 fs. The conversion efficiency of this step is low because phase matching across the full pulse bandwidth requires very thin crystals, and innovative methods may be needed even to reach this degree of conversion. If necessary, a small KrF amplifier (or possibly a subaperture of the main amplifier) can be used to deliver the required 10 μJ or, in fact, substantially more. The bandwidth of KrF is sufficient to support pulses considerably less than 100 fs in duration.

The infrared option for solid-state switches can be fulfilled by replacing the Nd:YAG regenerative amplifier with a Nd:glass regenerative amplifier that is injection controlled by a fiber-grating-compressed pulse from the mode-locked oscillator. This also removes the need for a KrF amplifier, but imposes severe limitations on the ultimate repetition-rate achievable.

Although the system described above has the advantage of largely duplicating existing technology, it should be noted that it does have certain shortcomings. Stability and maintenance of the dye laser systems will require considerable ongoing technical support. The mixing process, particularly for the shorter pulse, will require rather thin crystals and may be less efficient than estimated. This could entail the need for a larger pump laser than indicated. A significant limitation to the efficiency of the sum-frequency process is the long duration (and hence high fluence) of the Nd:YAG pulse as compared to the short pulse, and substantial improvement may be possible by compressing the 1.06 μm pump pulse. Fortunately, much less energy will suffice for the 100 fs mixed output if it is amplified in KrF, and less than 50 μJ can be utilized for the 2 ps input to the KrF amplifier. The input to the amplifier does affect the overall gain required, however, and this relates to another problem typical of excimer amplifiers: their high gain leads to the presence of significant amplified spontaneous emission (ASE) that precedes the short pulse one wishes to amplify. In a single amplification stage, most of the ASE can be filtered out because of its high divergence. In a second amplification stage (whether through the same or a separate amplifier), the small amount of ASE that passes through the spatial filter will see unsaturated gain, whereas the short pulse will be amplified into saturation. The contrast ratio between the prepulse and the main pulse is therefore degraded, and achieving

ASE energy of less than 5% of the main pulse appears difficult[1,2] unless additional electrooptic or nonlinear optical techniques are utilized. This amount of energy in a long prepulse will almost certainly be unacceptable for the switch, and additional work on improving the contrast ratio appears necessary for this application. The 100 fs pulse will need sufficiently low gain that a single pass in a small, gently-pumped gain medium should suffice, and ASE should not be a problem. If the main amplifier is used, the pulse can be injected on the leading edge of the pump pulse so that little ASE precedes it, but there may be significant post-pulse ASE.

Another option, which avoids some of these difficulties but presents some uncertainties of its own, follows from some of the results discussed by W. R. Donaldson at this workshop. This alternative would replace the dye amplifiers, and possibly the KrF amplifier as well, with alexandrite solid-state amplifiers. One possible configuration starts with a dye laser, pumped as before by the doubled output of a cw mode-locked Nd:YAG laser, and operated as a colliding-pulse laser[7] to produce pulses of ~100 fs duration near 750 nm. These pulses are temporally expanded to ~1 ns by a dispersive grating pair, and a single pulse is regeneratively amplified to ~4 mJ in an alexandrite amplifier. A fraction of this pulse is compressed back to its original pulse length, and then tripled to give ~10 µJ in 100 fs near 250 nm. The remainder of the pulse is spectrally filtered to reduce its bandwidth, amplified to ~100 mJ in an additional alexandrite amplifier, compressed to ~2 ps by another grating pair and tripled to yield the required 10 mJ. If the desired energy outputs and conversion efficiencies can be reached, this would provide a relatively reliable, low maintenance system. However, this high an output has not as yet been demonstrated in a short alexandrite pulse.[8] It would be possible to boost the energy, if necessary, by using a KrF amplifier to amplify the tripled output. Since relatively high drive energies would be available, a single pass would be sufficient, and ASE should not be a major problem. For solid-state switches, the high-power alexandrite amplifier would be replaced by a regenerative Nd:glass amplifier injection-controlled by a compressed pulse from the cw mode-locked laser.

An even more attractive alternative (in the case of the uv option, unless the alexandrite laser can be used for solid-state switching) would be to also replace the mode-locked Nd:YAG laser and sync-pumped dye laser with a mode-locked alexandrite laser. Alexandrite has sufficient bandwidth to support the short pulses required but has apparently only been mode-locked down to 8 ps,[9] and this was achieved in a somewhat unstable fashion by passive mode-locking using

an intracavity dye saturable absorber. Short pulses appear to be difficult to obtain without the use of a saturable absorber because of the low gain and high saturation fluence of alexandrite, and active mode locking alone has produced ~100 ps pulses, whereas active/passive mode locking has yielded ~60 ps.[10] Nevertheless, the desired pulse widths may be achievable by, for example, mode locking and fiber/grating techniques, combined with injection control of a regenerative amplifier. Such a system would provide a completely solid-state, low-maintenance approach for generating the short pulses.

All of the alternatives discussed above require on the order of $300 K in capital equipment, and probably at least double that amount in manpower. The first system entails the least development, but is more maintenance intensive. A choice may depend on availability of some of the equipment as well as more detailed assessments of the practicality of the other approaches.

References:

1. A. P. Schwarzenbach, T. S. Luk, I. A. McIntyre, U. Johann, A. McPherson, K. Boyer, and C. K. Rhodes, "Subpicosecond KrF* excimer-laser sourcs," Opt. Lett. 11, 499 (1986).

2. J. P. Roberts, A. J. Taylor, P. H. Y. Lee, and R. B. Gibson, "High-irradiance 248-nm laser system," Opt. Lett. 13, 734 (1988); J. P. Roberts, A. J. Taylor, C. S. Lester, and T. R. Gosnell, "Synchronously pumped subpicosecond dye oscillator-amplifier system," Conf. on Lasers and Electrooptics '88, Anaheim, April 25-29, 1988, paper FF5.

3. C. H. Nam, W. Tighe, S. Suckewer, J. F. Seely, U. Feldman, and L. A. Woltz, "Observation of asymmetric Stark profiles from plasmas created by a picosecond KrF laser," Phys. Rev. Lett. 59, 2427 (1987).

4. W. J. Tomlinson, R. H. Stolen and C. V. Shank, "Compression of optical pulses chirped by self-phase modulation in fibers," J. Opt. Soc. Am. B 1, 139 (1984), and references therein.

5. Energies of this order and greater have been demonstrated using a self-filtering unstable resonator: M. D. Dawson, W. A. Schroeder, D. P. Norwood, A. L. Smirl, J. Weston, R.N. Ettelbrick, and R. Aubert, "Characterization of a high-gain picosecond flash-lamp-pumped Nd:YAG regenerative amplifier," Opt. Lett. 13, 990 (1988). However, these authors report some degradation in beam quality above ~50 mJ.

6. R. L. Fork, B. I. Greene, and C. V. Shank, "Generation of optical pulses shorter than 0.1 ps by colliding pulse mode locking," Appl. Phys. Lett. 39, 671 (1981).

7. P. Bado, M. Pessot, J. Squier, A. Mourou, and D. J. Harter, "Regenerative amplification in alexandrite of pulses from specialized oscillators," IEEE J. Quantum Electron. QE-24, 1167 (1988).

8. V. N. Lisitsyn et al., "Generation of 0.7-0.8 μ picosecond pulses in an alexandrite laser with passive mode locking," Sov. J. Quantum Electron. 12, 368 (1982).

9. L. Horowitz, P. Papanestor, and D. F. Heller , "Mode-locked performance of tunable alexandrite lasers," Proc. Int'l. Conf. on Lasers '83, San Francisco, Dec. 12-16 (1983), ed. by R.C. Powell, STS Press; J, C. Walling, D. F. Heller, H. Samelson, D. J. Harter, J. A. Pete, and R. C. Morris, "Tunable alexandrite lasers: development and performance," IEEE J. Quantum Electron. QE-21, 1568 (1985).

DISCLAIMER