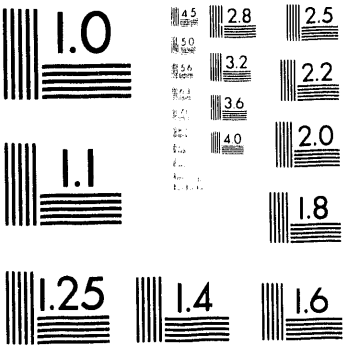
1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

1 of 1

Conf-9308186--1

UCRL-JC-114059
PREPRINT

Phase Conjugation and Pulse Compression of High Energy Lasers: From Nanoseconds to Microseconds

C. B. Dane
L. A. Hackel

OCT 14 1993
OSTI

This paper was prepared for submittal to the
Second International School and Topical Meeting
on Applications of Nonlinear Optics
Prague, Czech Republic
August 16-20, 1993

June 1, 1993

Lawrence Livermore National Laboratory

This is a preprint of a paper intended for publication in a journal or proceedings. Since changes may be made before publication, this preprint is made available with the understanding that it will not be cited or reproduced without the permission of the author.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor the University of California nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial products, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or the University of California, and shall not be used for advertising or product endorsement purposes.

Phase conjugation and pulse compression of high energy lasers: from nanoseconds to microseconds*

C. B. Dane and L. A. Hackel

Lawrence Livermore National Laboratory
Livermore, CA 94550

I. Introduction

SBS phase conjugation is playing a crucial role in the scaling of solid state laser systems to high average power. Amplifier systems with near diffraction limited beam quality have been demonstrated with average power outputs of 100W in Nd:glass[1] and Nd:YAG.[2] Wavefront correction provided by an SBS phase conjugate mirror not only significantly lowers the output divergence of the laser, it also increases the maximum average power obtainable by preventing damage to optical components caused by distortion of the beam profile due to uncorrected thermally induced aberrations. The output pulsewidth format required for applications of high average power pulsed solid state lasers is extremely varied, ranging from below a nanosecond to many microseconds. However, most demonstrated applications of SBS phase conjugation to high average power laser systems have involved the amplification of typical Q-switched oscillator pulses of 7-30 ns in duration.

Based on the requirements imposed by specific applications for high average power solid state laser systems, we have investigated and demonstrated the operation of SBS phase conjugated amplifier systems with output pulsewidths ranging from 1 ns to 1 μs. The specific considerations for the various pulsewidth regimes as well as details of the experimental investigations will be presented.

II. Q-switched pulse amplification

As stated before, a significant amount of work has been done in this 7-30 ns pulsewidth regime. Even so, in our efforts to develop a high beam quality 25 J/pulse,

---

*This work was performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

MASTER

5 Hz Nd:glass amplifier system, a new aspect of the temporal dynamics of SBS phase conjugation was discovered. The relatively low single pass gain of the Nd:glass flashlamp pumped slab requires a number of gain passes to achieve efficient energy extraction with injection pulses of less than 100 mJ. We devised a modified regenerative amplifier architecture which eliminates a Pockels cell inside the optical ring and uses passive polarization switching to provide 8 gain passes. Efficient extraction of 25 J pulses, however, requires an input energy to the SBS cell, after 4 gain passes, of 2.5-3 J. Measurements documented in the literature indicated that the wavefront reversal fidelity would be expected to be reduced at input energies only 5-10X the typical SBS thresholds of a few millijoules.[3] It was discovered, however, that by using input laser pulses with gradually rising leading edges rather than shaped pulses in which the leading edges had been intentionally sharply truncated, good fidelity could be observed for over 100X the SBS threshold.[4] The use of a two cell SBS configuration in which a second cell is placed in the collimated beam ahead of the focused SBS cell further shields the energy reaching the oscillator.[5] With this configuration, the amplifier was operated at an average power of 115 W with 29 J pulses 14 ns in duration and with a PRF of 4 Hz. The measured output divergence was 1.25X the diffraction limit and the fidelity of the output wavefront as compared to the input was 0.95.

A second key aspect of the successful SBS phase conjugation in this system was the careful relay imaging of the multiple gain passes back onto themselves in the amplifier slab and importantly, the relay imaging of the amplifier aperture to the input lens of the SBS oscillator. It was found that free optical propagation to the SBS cells results in the distortion of the near field irradiance profile of the beam. Accurate recovery of a wavefront reversed signal back at the source of the aberrations in the amplifier then requires both the accurate reproduction of the incident wavefront as well as the incident irradiance distribution at the conjugator. Strong gain variation resulting from the irradiance distortion in the SBS amplifier makes the accurate reproduction of the spatial profile impossible and very poor fidelity results. When the amplifier aperture is image relayed to the conjugator cells, however, a smooth irradiance profile is presented to the SBS amplifier. The fidelity is then dependent primarily on the accuracy of wavefront reversal in the SBS oscillator since any residual error in the irradiance profile is corrected in the gain saturation of the final amplifier passes.

III. Pulse compression

Bulk optical damage in the gain medium due to nonlinear self focusing limits the minimum pulsewidth that can be efficiently directly amplified in a solid state laser system. There is, however, strong motivation for certain laser applications to deliver the output in only 1-2 ns such as in the case of pumping x-ray laser plasma sources. We have demonstrated a new optical configuration for SBS pulse compression that is readily scalable to high energy laser pulses.[6] Using passive polarization optical switching, this design provides independent pumping energies to an SBS oscillator and amplifier without the use of attenuators. By decreasing the optical delay to the oscillator cell, the relative timing of the Stokes injection pulse can be adjusted so as to prevent the loss of the leading edge of the pump pulse before the oscillator reaches threshold. This allows the oscillator to be operated at energies well below thresholds for other competing nonlinear processes while maintaining high overall system energy efficiency. Successful compression of a 2.5 J input pulse from a width of 15.8 ns to 1.7 ns has been demonstrated with 80% energy efficiency, resulting in a 5X increase in peak power.

A numerical model has been developed which solves the coupled differential equations governing the dynamics of the pump, Stokes, and acoustic waves. Using this model, the performance of the pulse compressor system is well described over a wide range of operating parameters. The model has now been used to design an optimized two cell compressor for the full 25 J pulse energies deliverable by the Nd:glass regenerative amplifier system and should deliver peak power increases of >15X with >80% energy efficiency.

IV. Long pulse amplification

For laser applications such as the illumination of distant targets for speckle interferometric imaging, pulsewidths at least 500 ns (to a maximum of 3 μs) in duration are required. This allows the temporal beat between frequency shifted portions of an illuminator beam to be recorded on each pixel of a large receiving detector array with available analog to digital conversion rates. The average output power and high beam quality requirements for the illuminator also dictate the incorporation of a phase conjugate mirror. Our regenerative amplifier design uses passive polarization switching to couple into and out of the amplifier ring and the Pockels cell which isolates the high energy output from the input optical path can be replaced with a Faraday rotator. In this manner, an 8 pass amplifier is achieved with no input pulse

width constraints. If the SBS phase conjugator performance can be maintained for a microsecond pulse, efficient amplification is possible.

There are several significant issues involved with the SBS phase conjugation of a long pulse. Clearly, the first is that with the same stored and extracted energy in the amplifier, the SBS needs to accommodate the resulting reduction in peak power. Since in this amplifier design 2-3 J reach the phase conjugator, this does not present a limitation. The second issue is the possibility that for input pulsewidths that greatly exceed the acoustic decay time of the SBS medium there will be instabilities in the temporal pulseshape and an increase in spectral bandwidth caused by phase instabilities in the Stokes return. These effects have been well documented by experimental measurements, but only for input energies very near the SBS threshold.[7] The results of our measurements and numerical simulations indicate that the magnitude and more importantly, the occurrence frequency of these "phase jumps" is reduced to insignificant levels when the SBS is operated at only moderate levels above threshold.

The final consideration in the SBS phase conjugation of microsecond laser pulses is the possibility of competition from other nonlinear scattering processes. These can manifest themselves in two ways: processes with comparable nonlinear gains to reverse SBS but much longer dephasing times or stimulated scattering that results from energy deposition in the medium by linear or nonlinear absorption. Initial attempts to use CCl_4 to conjugate 500 ns input pulses resulted in low reflectivity and frequent optical breakdown at the focus of the SBS oscillator. More careful investigation revealed that a competing process reached threshold ~200 ns into the pulse width. By switching the SBS medium to high pressure N_2, this competition was suppressed and high reflectivity, high fidelity return was measured. Using a 40 mm sub-section of the 120 mm amplifier aperture, we demonstrated the extraction of 8 J, 500 ns pulses with high beam quality.

V. Conclusion

We have demonstrated a single laser amplifier architecture incorporating SBS phase conjugation with output pulsewidths that can span the range between 1 ns and 1 μs. SBS phase conjugation provides not only high beam quality with low divergence, it makes high average power output from these systems possible. Many applications require very high beam quality output from a solid state laser system such as, for example, efficient nonlinear frequency conversion. It is our belief, however, that

optimal high average power operation will always benefit from the use of nonlinear wavefront correction techniques, regardless of the divergence requirements for the particular application.

References

1. C. B. Dane, L. E. Zapata, and L. A. Hackel, "Long pulse regenerative amplifier architecture with near diffraction-limited output divergence," Conference on Lasers and Electro-Optics, CWI1, Baltimore, MD, May 2-7, 1993.
2. R. J. St. Pierre, H. Injeyan, R. C. Hilyard, M. E. Weber, J. G. Berg, R. Senn, M. G. Wickham, C. S. Hoefer, G. Harpole, and J. P. Machan, "High brightness diode-pumped solid-state laser development," Conference on Lasers and Electro-Optics, CWI3, Baltimore, MD, May 2-7, 1993.
3. J. J. Ottusch and D. A. Rockwell, "SBS Phase Conjugation Fidelity Fluctuations," *Opt. Lett.* **16**, 369-371 (1991).
4. C. B. Dane, W. A. Neuman, and L. A. Hackel, "Pulse-shape dependence of stimulated-Brillouin-scattering phase-conjugation fidelity for high input energies," *Opt. Lett.* **17**, 1271-1273 (1992).
5. G. J. Crofts and M. J. Damzen, "Experimental and theoretical investigation of two-cell stimulated-Brillouin-scattering systems," *J. Opt. Soc. Am. B* **8**, 2282-2288 (1991).
6. C. B. Dane, L. A. Hackel, and W. A. Neuman, "High Energy Pulse Compression," submitted to *IEEE J. Quantum Electron.*
7. M. S. Mangir, J. J. Ottusch, D. C. Jones, and D. A. Rockwell, "Time-Resolved Measurements of Stimulated-Brillouin-Scattering Phase Jumps," *Phys. Rev. Lett.* **68**, 1702-1705 (1992).

DATE
FILMED
12/28/93

END