AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910

301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

1 of 1

UCRL-JC-116760
PREPRINT

High Average Power Parametric Frequency Conversion—New Concepts and New Pump Sources

S. P. Velsko
M. S. Webb

This paper was prepared for submittal to the
Laser Diode Technology & Applications VI
SPIE OE/LASE '94
Los Angeles, CA
January 22-29, 1994

March 1994

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.

MASTER

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 product, 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.

High average power parametric frequency conversion— new concepts and new pump sources

Stephan P. Velsko and Mark S. Webb

Lawrence Livermore National Laboratory
P. O. Box 808, Livermore, CA 94550

1. INTRODUCTION

A number of applications, including long range remote sensing¹ and antisensor technology,² require high average power tunable radiation in several distinct spectral regions. Of the many issues which determine the deployability of optical parametric oscillators (OPOs) and related systems, efficiency and simplicity are among the most important. It is only recently that the advent of compact diode laser pumped solid state lasers has produced pump sources for parametric oscillators which can make compact, efficient, high average power tunable sources possible. In this paper we outline several different issues in parametric oscillator and pump laser development which are currently under study at Lawrence Livermore National Laboratory.

2. OPO CONVERSION EFFICIENCY AND RESONATOR DESIGN

It is generally appreciated that, in the absence of thermal effects, the efficiency of conversion in a parametric oscillator depends on three factors. The first of these is *pump brightness*, which is directly proportional to the peak power and inversely proportional to a beam quality parameter, such as M^2 . The sensitivity of OPO efficiency to pump brightness depends on the angular sensitivity or walkoff angle of the particular phasematching process involved. Noncritically phasematched processes, with vanishing angular sensitivity and walkoff, are the least sensitive to degradations in pump brightness.

The second factor can be denoted the *dynamic range* effect, and arises most commonly when beams with Gaussian spatial or temporal profiles are used as OPO pump sources. If the intensity is adjusted to place the peak of each pulse at the optimum gain, the energy in the *wings* of such pulses will not be converted efficiently. Conversely, if the intensity is adjusted to make the wings closer to the optimum gain, at the peak of the pulse the OPO crystal is overdriven, leading to back conversion or worse, to optical damage. Thus, overall conversion efficiency is improved, in principle, if the pump pulse is *square* both in space and time, since only then can the entire beam be converted at the optimum gain value.

The third factor affecting conversion efficiency is the OPO *build-up time*, or alternatively, the number of round trips the steady-state resonated wave(s) can make during the duration of the pump pulse. Since the conversion of the pump is small until the resonated wave builds up to approximately the same power as the pump wave, the larger the fraction of the pump pulse which sees the resonated wave at its steady state value, the larger the fraction of pump that will be efficiently converted.

Efficient extraction of energy from solid state lasers in high quality beams usually requires the use of image relayed MOPA configurations or power oscillators with well designed unstable resonators.³ The spatial profiles of MOPA generated beams are ideally supergaussian, as are the output beams of certain unstable resonators. To study the optimization of resonators for OPOs pumped by beams with relatively flat spatial profiles, we have constructed an image relayed Nd:YAG MOPA system with an output of 1 J/pulse in 200 ns pulses at 1.06 μm . By having a large energy and long pulse duration, we obtain reasonable brightness and a large number of round-trip times for typical OPO cavity lengths. We have used this pump to drive a lithium niobate OPO (5 cm long, 47° cut type I, resonating 1.5 μm , idler at 3.7 μm).

Our initial experiments have focused on output coupler optimization and back-conversion effects. Figure 1 shows the pump depletion efficiency as a function of input energy for a 2.9 mm diameter pump beam. Our preliminary hypothesis is that back conversion effects, enhanced by the large circulating resonated wave power present with such high output coupler reflectivities, are the cause of the sharp turnover in conversion efficiency at the higher input energies. It should be noted, however, that the resonator mirrors also have appreciable reflectivities (10-20%) at the 3.6 μm idler wavelength so that partial double resonance character may be affecting the threshold levels and turnover points in this experiment.

Figure 1. Pump depletion efficiency as a function of input energy.

Figure 2a shows the spatial profile of the pump pulse at the final image plane, which is relayed to the center of our test OPO cavities. We have studied two different cavity types. Figure 2b shows the spatial profile of the resonated wavelength at approximately the same plane as the pump image, obtained with a flat-flat cavity (Fresnel number $\approx 1,000$). Under these conditions, the resonated wave spatial profile is reminiscent of the lowest order cavity eigenmode of a high Fresnel number flat-flat cavity.⁴ In contrast, Figure 2c shows the spatial profile of the resonated wave for a hemispherical cavity in which the flat high reflector is replaced by a 10 meter curvature spherical mirror. For this cavity, we calculate a lowest order mode diameter of 1.2 mm, close to the observed size of the actual resonated wave.

The hemispherical cavity exhibited a much lower threshold and a much more stable output energy than the flat-flat cavity. Nonetheless, it is clear from Figure 2 that the spatial overlap of resonated wave and pump is considerably smaller for the hemispherical cavity than for the flat-flat cavity. Thus, neither simple cavity design is ideal for efficient extraction of energy from the flat pump beam. We are now turning our attention to a class of imaging *unstable* resonators, such as that shown in Figure 3. In this cavity, effective output coupling for the resonated wave is provided by the magnification of its image (relayed from the pump image plane) on each round trip. Image inversion is expected to exert a smoothing effect on the

output beam spatial profile even in the presence of considerable pump non-uniformity. Finally, the ring architecture is advantageous for average power applications because it reduces the thermal load on the OPO crystal from absorption of the resonated wave.

Figure 2. Beam profiles of pump laser and resonated wave with flat and hemispherical cavities.

Figure 3. Unstable, self imaged ring cavity

2. MULTISPECTRAL PARAMETRIC GENERATION AND NON-RESONANT OPOs

Another area of current interest is in the generation of simultaneous multi-line output for mid-infrared DIAL applications. In particular, we have begun to study the properties of the "non-resonant OPO" (NROPO), first described by Guyer and Lowenthal.^{5,6} Figure 4 shows schematically the basic NROPO architecture.

Figure 4. Schematic of the non-resonant OPO. R is the mirror reflectance, and p , s , and i denote pump, signal, and idler, respectively.

Figure 5 shows the results of a steady-state plane wave calculation of pump depletion efficiency for an idealized NROPO compared to a singly resonant OPO (SRO). Within the plane wave theory, the NROPO has a threshold drive which is equivalent to an SRO with a 50% output coupler.

Figure 5. Plane wave calculations of NROPO and SROPO. Zeta is the drive parameter $\zeta = CLI^{1/2}$, with C = nonlinear coupling parameter, L = crystal length, and I = pump irradiance.

The most compelling property of this device is that it provides high regenerative parametric amplification without cavity resonances. Thus, seed pulses with arbitrary spectral content can be amplified within the gain bandwidth of the device. Our initial experiments will utilize a dual frequency seeder based on frequency stabilized tunable diode lasers.

3. NEW HIGH AVERAGE POWER PUMP SOURCES

Certain long range remote sensing missions will require average power mid-infrared sources in the 10-100 watt regime. These power estimates arise from the constraint of high energy per pulse for adequate LIDAR returns coupled with the requirement of high repetition rate for speckle averaging. Such high average powers from an OPO would require a one to two orders of magnitude improvement over existing commercial technology. Leaving aside the question of average power OPO design, it is clear that pump lasers with up to several hundred watts of average power (in high quality beams!) would be required. The simple extension of MOPA technology is far from compelling for these applications, having an intrinsically unfavorable tradeoff between efficiency and system complexity.

In contrast, we have pursued a single gain element, power oscillator approach to the multi-hundred watt pump source.⁷ Figure 6 shows layout of the basic power oscillator, consisting of a diode laser array-pumped Nd:YAG slab, polarizer, Q-switch, and mirrors. A key element is the Q-switch, which was designed to minimize stress depolarization under high average power conditions. Figure 7 shows the current performance of the Q-switched oscillator, which was operated at a repetition rate of 2.5 kHz. The 250 watt output is more than a factor of 5 higher than was available previously from single gain element power oscillators. The multi-transverse mode output beam was of sufficient brightness that we were able

to generate over 100 watts of $0.53\text{ }\mu\text{m}$ light ($\approx 50\%$ conversion efficiency) using a single KTP crystal. In the future, we intend to demonstrate unstable resonator architectures with much higher beam quality.

Figure 6. Q-switched, diode-pumped power oscillator architecture.

Figure 7. Output of Q-switched power oscillator at 2.5 kHz, as a function of diode drive current.

4. CONCLUDING REMARKS

High average power pump sources such as the 250 watt system described above will certainly challenge our ability to design efficient, spectrally controlled parametric converters which can take full advantage of these high average powers. In addition to the issues outlined above, we are also addressing device architecture and materials problems which directly impact the design of average power OPOs. Among these are high aspect ratio geometries for minimizing thermal gradients and thermally insensitive phasematching orientations in biaxial OPO crystals. In the future we can anticipate substantial progress in this area.

5. ACKNOWLEDGMENT

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.

6. REFERENCES

1. R. M. Measures, *Laser Remote Sensing*, Krieger Publishing Co., Malabar, FL, 1992.
2. B. Anderberg and M. Wolbarsht, *Laser Weapons*, Plenum Press, New York, 1992.
3. A. E. Siegman, *Lasers*, University Science Books, Mill Valley, CA, 1986.
4. H. Kogelnik and T. Li, "Laser beams and resonators," *Applied Optics* 5, 1550-1567, 1966.
5. D. Guyer and D. Lowenthal, "Novel cavity design for a high efficiency, high energy near infrared β -BaB₂O₄ parametric generator," *Proc. SPIE* 1220, 41-44, 1990.
6. D. Guyer, "High output coupling cavity design for optical parametric oscillators," U.S. patent 5,079,445 (1992).
7. S. Velsko, C. Ebberts, B. Comaskey, G. F. Albrecht, and S. Mitchell, "100 watt average power at 0.53 μ m by external frequency conversion of an electro-optically Q-switched diode pumped power oscillator," Lawrence Livermore National Laboratory, UCRL-JC-115126, Dec. 1993 (submitted to *Applied Physics Letters*).

DATE

FILMED

8/3 /94

END