REPORT DOCUMENTATION PAGE

AFRL-SR-BL-TR-98-

0861

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED 15 Mar 97 to 14 Mar 98 (Final)

4. TITLE AND SUBTITLE (DURIP 97) Wavelenght Agile Spectroscopic Sources Based on Quasiphasematched Structures	5. FUNDING NUMBERS 61103D 3484/US
6. AUTHOR(S) Dr Dominic	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Dayton 300 College Park Dayton OH 45469-0001	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) AFOSR/NE 801 North Randolph Street Rm 732 Arlington, VA 22203-1977	10. SPONSORING/MONITORING AGENCY REPORT NUMBER F49620-97-1-0170
11. SUPPLEMENTARY NOTES	
12a. DISTRIBUTION AVAILABILITY STATEMENT APPROVAL FOR PUBLIC RELEASED; DISTRIBUTION UNLIMITED	12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

An Infinity Pulsed ND: YAG Laser System with 2nd and 3rd Harmonic Generators was purchased from Coherent, Inc. It was purchased on September 26, 1997 for $91,000.00.

19990115 029

14. SUBJECT TERMS			15. NUMBER OF PAGES
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL

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UNIVERSITY of DAYTON RESEARCH INSTITUTE

21 December 1998

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Air Force Office of Scientific Research
110 Duncan Avenue, Room B115
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SUBJECT: Grant No. F49620-97-1-0170

Dear Dr. Schlossberg:

Enclosed is one copy of the Final Report for the subject grant.

Should any additional information be required, please contact the undersigned at (937) 229-2919.

Sincerely,

Barbara Yamini
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Administrative Assistant,
Contracts and Grants

cc: Ms. Karen Buck, AFOSR/PKA

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Final Report
AFOSR DURIP Grant
Vince Dominic
University of Dayton
"Periodically-poled lithium niobate for spectroscopic applications"

Here's what we bought:

An Infinity Pulsed N_D:YAG Laser System with 2nd and 3rd Harmonic Generators was purchased from Coherent, Inc. It was purchased on September 26, 1997 for $91,000.00.

Here's what we did with it:

The Coherent Infinity laser was utilized in two different experimental investigations. One investigation was led by Andy Zakel and investigated pumping periodically-poled lithium niobate (PPLN) optical parametric oscillators (OPO's) and amplifiers (OPA's) with the Infinity laser while simultaneously seeding the OPO with the narrowband output of a tunable laser diode. The second investigation was led by Prof. Peter Powers and investigated a widely tunable, narrow band spectroscopic source based on optical parametric generation (OPG) followed by optical parametric amplification. The details of the two separated investigations are given below.

Injections seeded systems

This section summarizes the efforts to develop a high-energy, narrow-band, tunable laser source for spectroscopy. Several laser sources based on difference frequency generation in periodically poled lithium niobate (PPLN) have been investigated. Use of low power, narrow-linewidth laser sources have been used to injection seed both optical parametric amplifiers (OPA) and monolithic optical parametric oscillators (OPO). Also included is a summary of future investigations and improvements to existing systems.

Pump and Injection Seed Sources

The pump laser used for all experiments is a Coherent Infinity Nd:YAG laser which produces 500 mJ of single mode, 1064 nm light in 3 ns pulses. The two injection seed sources used were a New Focus 6262 External Cavity Tunable laser diode and the signal output of a bow-tie cavity singly resonant oscillator (SRO). Both sources have narrow-band output and M^2 values lower than 1.1. The maximum cw output powers of the SRO and laser diode are 100 mW and 4 mW respectively.

SRO Injection Seeded Monolithic OPO

The SRO was used to injection seed a 10 mm long multigrating monolithic OPO with SiO_2 coatings on the crystal end to increase the maximum fluence through the 1 mm X 1 mm grating aperture. Both the SRO and the monolithic OPO were operated in a 29 μm grating at 140 C and 135 C respectively.

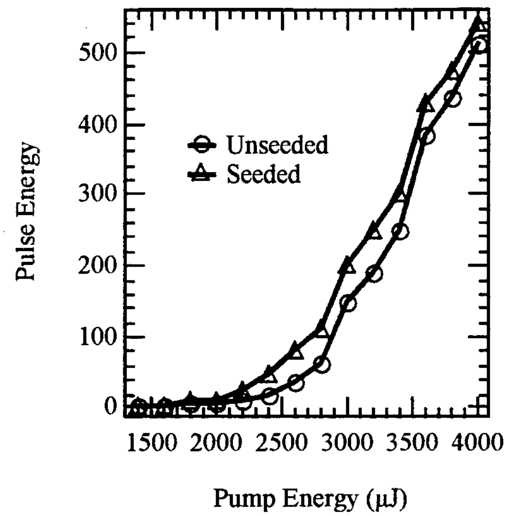


Figure 1. Signal output vs pump energy.

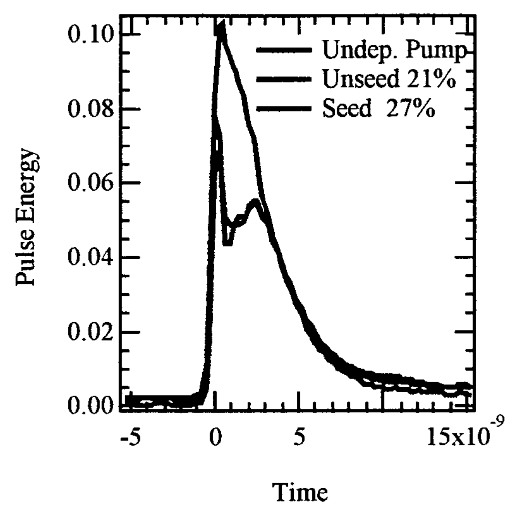


Figure 2. Pump depletion measurements.

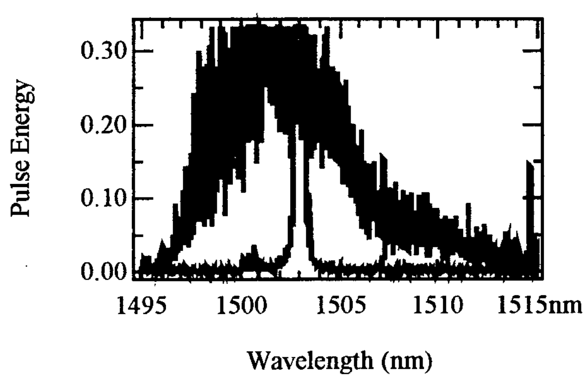


Figure 3. Seeded and unseeded signal bandwidth measurements taken using monochromator with ~0.1 nm resolution.

The pump was relay imaged using 1000 mm and 125 mm lenses and produced an spot size of 315 μm within the PPLN crystal. The seed was introduced to the optical system via a normal incidence input coupler (HR 1.4 μm - 2.0 μm, HT@1.064 μm). It was likewise relay imaged using the same lens configuration and produced a spot size of 325 μm in the crystal. Threshold for unseeded operation of the monolithic OPO was 2.4 mJ and ~2.2 mJ for seeded operation. The maximum extracted energy from the seeded OPO was 554 μJ when pumped with 4.2 mJ. The maximum pump depletion measured was 27% (4 mJ pump) when the OPO was seeded. Injection seed powers ranged from 40 mW when the SRO was operating poorly to 80 mW when it was running well. The bandwidth measurements were taken with 3 mJ of pump and 70 mW of seed.

Laser Diode Seeded OPA: Large Beam Diameter in Crystal

A 50 mm long multigrating OPA crystal was injection seeded with the New Focus laser diode. The grating apertures were 1 mm X 1 mm and the ends of the crystal were AR coated for the pump and the signal by Quality Thin Films. Again, the same relay image lenses were used and the diode beam was introduced via the input coupler. The 29.5 μm grating was used and the crystal temperature was 155 C. Without the seed, the threshold for operation (optical parametric generation) was 600 μJ. When seeded, threshold dropped to ~350 μJ. Average cw seed power was 1.4 mW and the maximum pump used was 2.3 mJ which produced 450 μJ of narrow-band output and a corresponding pump depletion of 67%. Signal energy was measure as a function of injected seed power and pump pulse energy. Beam quality measurements were also made both near threshold and at two times threshold.

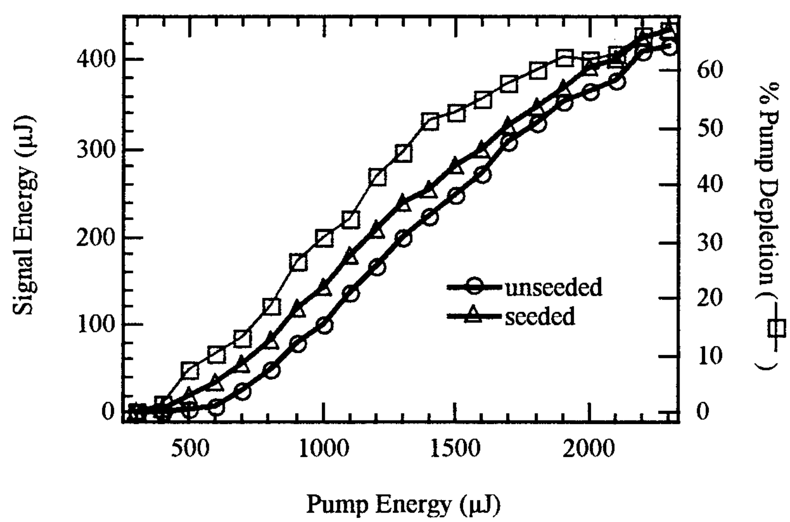


Figure 4. Signal energy and pump depletion as a function of pump energy.

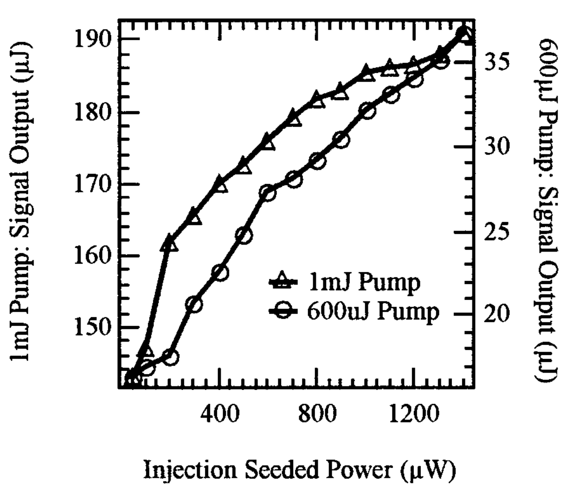


Figure 5. Signal energy vs seed power.

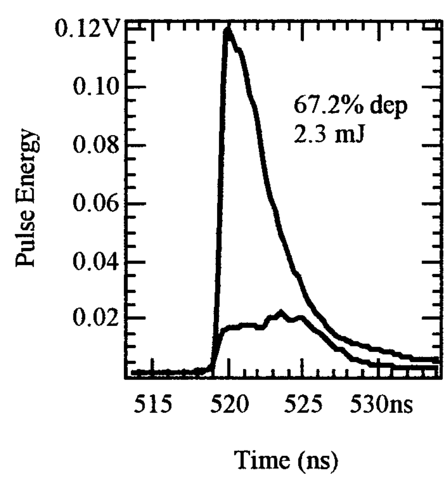


Figure 6. Pump depletion.

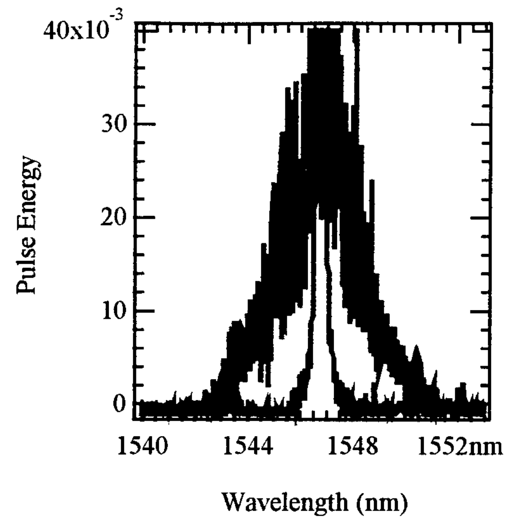
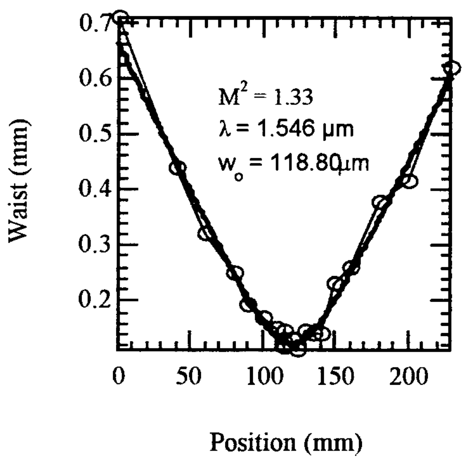


Figure 7. Seeded and unseeded OPA bandwidth.



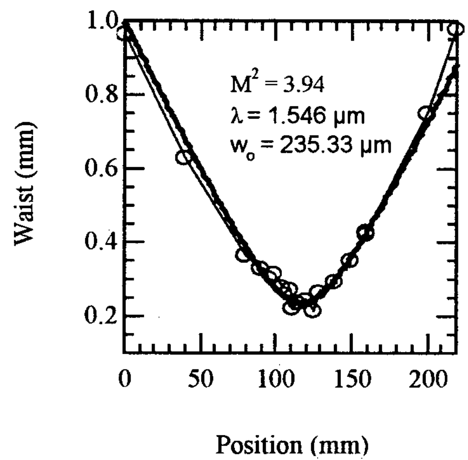


Figure 8. Beam quality near threshold.

Figure 9. Beam quality at 2X threshold.

For presented data, the injection seed wavelength was typically 1546 nm. Note the large increase in the measured M^2 at two times threshold. At three times threshold, the M^2 could not be effectively measured due to spatial quality of the beam. Simulations of this configuration have suggested that the M^2 would be over 10 for three time above threshold.

Laser Diode Seeded Small Beam Monolithic OPO and OPA

In an effort to improve beam quality, tightly focused pump and seed beams were used in the same OPO and OPA crystals. By focusing the beam in the crystal we are able to fill the full angular bandwidth of the PPLN thus controlling the bandwidth and divergence properties of the output signal. Here we have focused the pump beam down to 54 μm and the seed to 65 μm X 115 μm (elliptical beam) in the crystal. The laser diode was operated at ~1 mW (in the crystal) from 1546 nm to 1547 nm. Threshold for the unseeded OPO operation was ~80 μJ and ~40 μJ for the unseeded OPA.

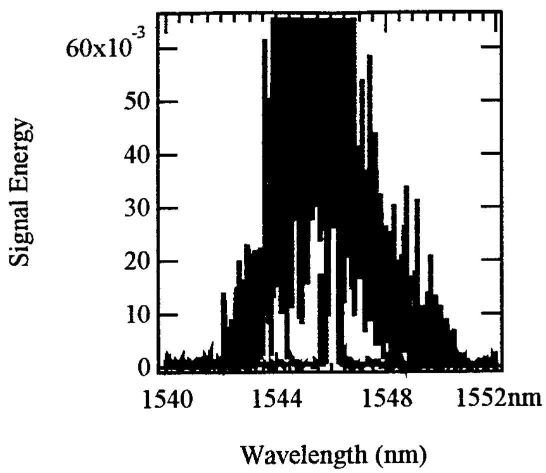


Figure 10. Seeded and unseeded OPO bandwidth.

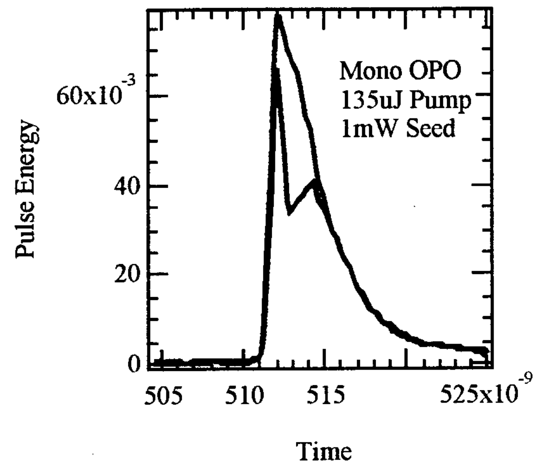


Figure 11. Pump depletion 20%.

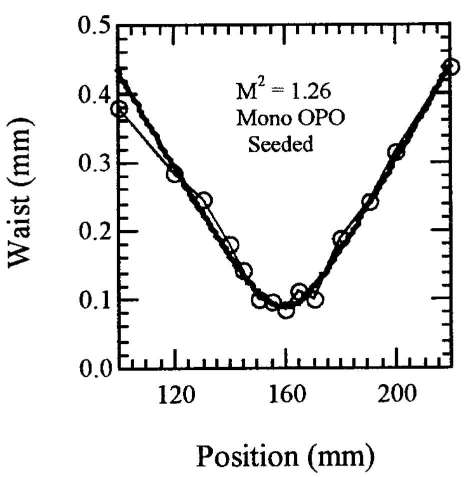


Figure 12. Seeded OPO M^2.

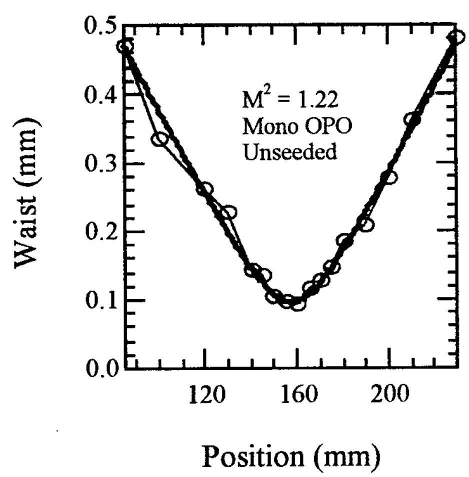


Figure 13. Unseeded OPO M^2.

The beam quality of the signal output from the seeded and unseeded small beam OPO was excellent. However, the maximum energy extracted from the device was only 25 μJ when pumped at 140 μJ. This corresponded to a pump depletion of ~20%. Excellent clamping of the signal to the seed wavelength was observed. It is important to note that while the bandwidth and M^2 data were promising the crystal was not pumped above two times threshold.

The OPA crystal was used in the exact same configuration but since it had a lower threshold we were able to obtain data for the bandwidth, pump depletion and beam quality well above threshold.

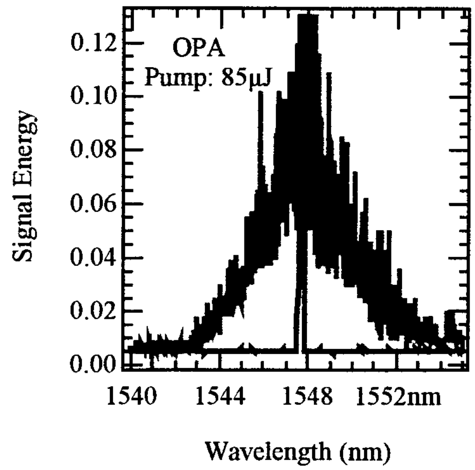


Figure 14. OPA Bandwidth measurements

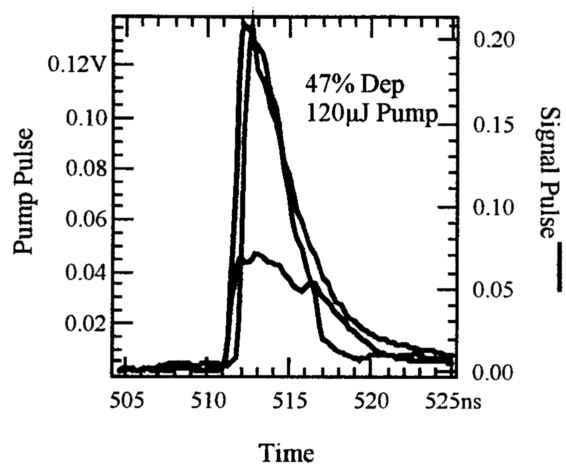


Figure 15. Pump depletion and signal pulse.

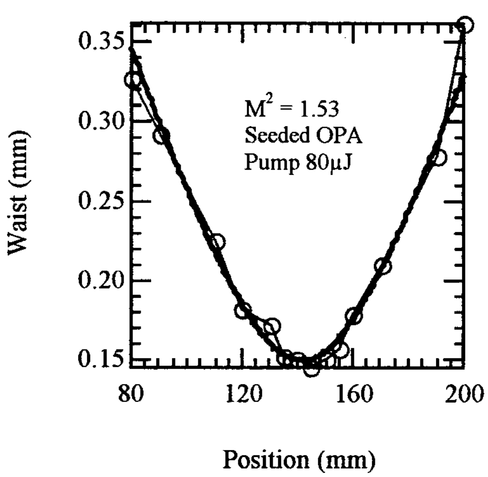


Figure 16. Seeded OPA at 2X threshold.

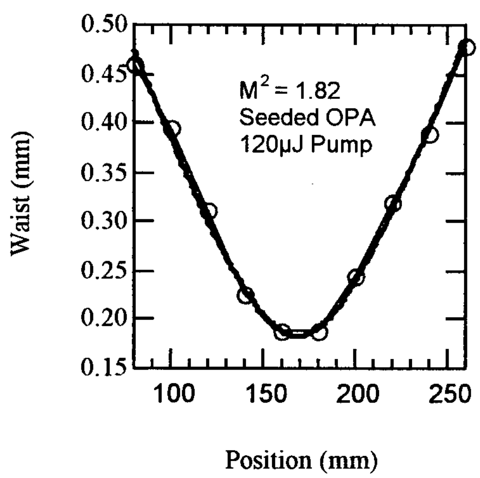


Figure 17. Seeded OPA at 3X threshold.

The maximum signal extracted from the seeded OPA was 35 μJ at 125 μJ of pump. This corresponded to ~50% pump depletion and produced a signal pulse ~2 ns wide. The M^2 values were still below 2 which indicates a high beam quality even when pumped three times above threshold.

Two Stage System

Single crystal OPO/OPA systems can be used to produce narrow-band, high quality signal beams with approximately 30 μJ per pulse. A single crystal has been shown to produce, in this case, well over 500 μJ of energy, but this high energy is not contained within a beam of high quality. Thus, a two stage system must be used to produce a signal beam with near diffraction limit M^2 and high energy.

The first stage in such a system would be seeded with a narrow-band source such as a laser diode and produce approximately 35 μJ of energy. This signal beam can then be used to injection seed a second crystal such as a low gain OPA. By operating the second stage OPA below or near threshold, the amplified signal would retain the same beam quality and bandwidth properties of the signal produced in the first stage. Such a system should produce over 1 mJ of narrow-band, tunable, good M^2 light.

Optical parametric generator/Optical paremetric amplifier

In the nanosecond regime, optical parametric generation is not efficient with traditional birefringently phasematched materials. With periodically poled lithium niobate (PPLN), however, the conversion efficiency of an OPG can be high even with nsec pulses. Zayhowski□ demonstrated 25% conversion to the signal and idler in a single-pass PPLN OPG with 0.9 nsec pulses. This high conversion leads to the possibility of simple tuning over large wavelength ranges with nsec pulse durations. Tuning is accomplished by changing the crystal periodicity (using a multi-grating PPLN□, or a fan-out design□,□) or by changing the crystal temperature. Although the conversion efficiency is high, the bandwidth of these pulses is large, greater than 10 cm-1. To generate a narrow linewidth, diode laser seeding of the OPG is possible, and such a scheme has been demonstrated□. Diode laser seeding works well, but the tuning range of the system is limited by the tuning range of the diode laser. In addition two lasers are required which adds cost and complexity to the overall system.

A demonstration is described of a two-crystal configuration that will allow for narrow linewidths, broad tunability, and high conversion efficiency using a single nsec pump source. A two stage OPG/OPA configuration is used where the output of the OPG (either signal or idler) serves as a seed for an OPA (or OPG). Prior to injection into the OPA, the output of the OPG is filtered with a Fabry-Perot etalon giving a narrow bandwidth seed. Narrow linewidth and broad tunability are thus achieved with a simple apparatus.

The optical layout is shown in figure □ seq figure * MERGEFORMAT □1□. A Coherent Infinity Nd:YAG laser operating at a repetition rate of 30 Hz served as a pump source for both the OPG stage and the OPA stage. The pulse duration (FWHM) of the 1.064 nm pump was 3 nsec. The pump beam was split with a half-wave plate and polarizing beamsplitter, allowing a variable partitioning of the pump energy between the OPG and OPA stages. The total energy sent to both stages was typically 1.5 mJ. For the results shown here, the OPG was an 11 mm x 1mm PPLN crystal and the OPA was a 6 mm x 1 mm PPLN crystal. Both crystals were mounted in temperature-controlled heaters and were operated at temperatures ranging from 120 to 160oC.

One of the pump beams was focused into the first OPG crystal generating signal and idler beams. The bandwidth of the signal and idler were large, typically greater than 10 cm-1, as seen in Figure 2 (unseeded output). The output energy was typically 100 uJ for an input energy of 800 uJ. The signal generated in this first stage was spectrally filtered with a Fabry-Perot etalon. The filtered signal (seed) was then focused into the second PPLN crystal where it was amplified by the second pump beam.

Figure 2 shows the spectra of the signal generated by the second stage. Both seeded and unseeded operation are shown in the figure. The seeded operation is characterized by several large 'spikes'. The spacing of these spikes is the free spectral range of the etalon used for this experiment. In subsequent experiments (done at Sandia) a larger free spectral range etalon was used such that only one of these spikes is present. When the seed stage is blocked, the output of the second stage is a broad bandwidth characteristic of a single stage OPG.

Further characterization and testing were performed at Sandia.

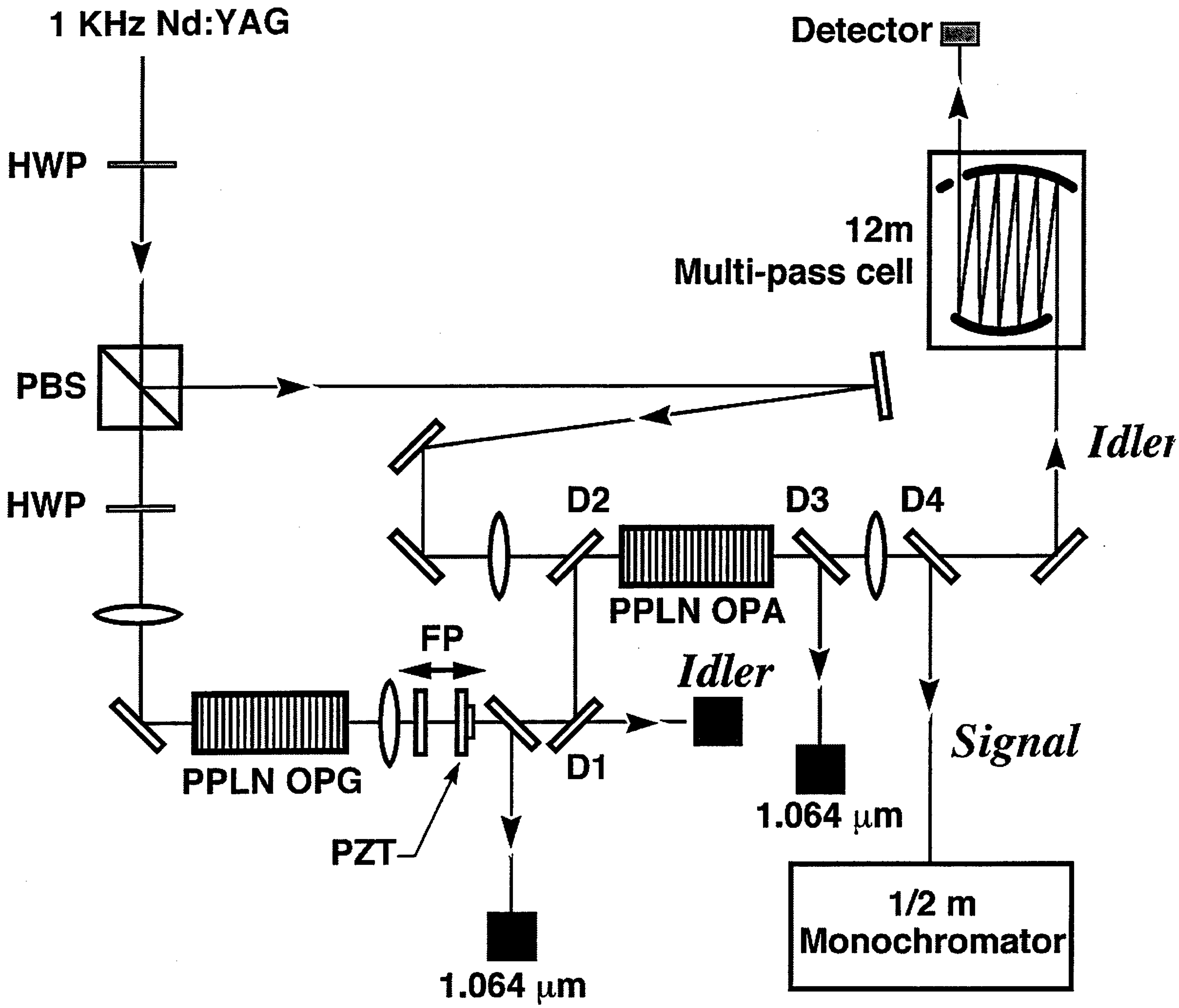
J. J. Zayhowski, Opt. Lett. 22, 169 (1997).

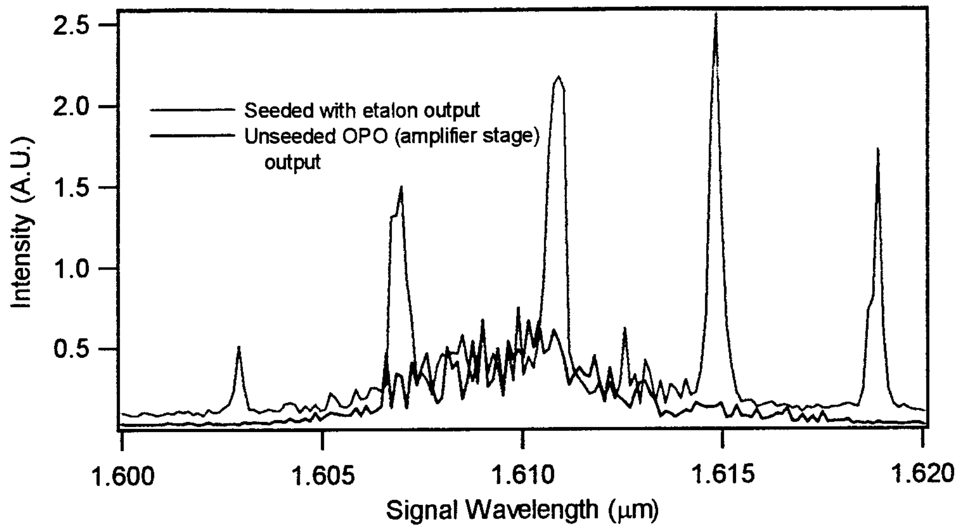
L. E. Myers, R. C. Eckardt, M. M. Fejer, R. L. Beyer, and W. R. Bosenberg, Opt. Lett. 21, 591 (1996).

Y. Ishigame, T. Suhara, and H. Nishihara, Opt. Lett. 16, 375 (1991).

P. E. Powers, T. J. Kulp, and S. E. Bisson, Opt. Lett. 23, 159 (1998).

A. Zakel, M. Missey, V. Dominic, P. P. Yaney, P. E. Powers, T. D. Raymond, Accepted for presentation at OSA Annual Meeting, 1998.


1 KHz Nd:YAG
Detector
HWP
12m
Multi-pass cell
PBS
Idler
HWP
D2
D3
D4
PPLN OPA
FP
Idler
PPLN OPG
D1
Signal
1.064 μm
PZT
1/2 m
Monochromator
1.064 μm



Seeded with etalon output
Unseeded OPO (amplifier stage) output
Intensity (A.U.)
2.5
2.0
1.5
1.0
0.5
1.600
1.605
1.610
1.615
1.620
Signal Wavelength (μm)