(140)

Nonlinear Optics'98

Materials, Fundamentals and Applications Topical Meeting

10 – 14 August 1998

Princeville Hotel
Princeville, Kauai, Hawaii

IEEE Catalog #: 98CH36244
Library of Congress # 98-85597

WB2
11:00am - 11:15am

Robust high-power and wavelength-tunable femtosecond fiber system based on engineerable PPLN devices

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Introduction

Synchronously-pumped optical parametric oscillators (OPO) were traditionally regarded as being the only approach for providing wavelength tunable high-average-power and high-repetition-rate pulses from compact femtosecond laser systems. Relatively low peak powers are required by OPO for efficient frequency conversion. In contrast, an alternative approach based on optical parametric generation (OPG) was traditionally considered to be disadvantageous in this respect as being limited to low average power, low repetition rate and requiring complex table-top size femtosecond lasers for delivering high-energy pump pulses.

However, the concept of parametric generation possesses a significant potential advantage due to the simplicity and robustness of OPG compared to femtosecond OPO. Stability of synchronously pumped femtosecond OPO depends critically on matching the lengths of the femtosecond oscillator and parametric oscillator cavities, which constitutes a substantial hindrance for developing robust commercial devices based on this scheme.

Here we report a robust high-power, high-repetition rate and wavelength-tunable femtosecond laser system based on optical parametric generation and a compact fiber chirped-pulse-amplification circuit, both implemented using engineered PPLN devices.

Parametric generation using a compact fiber CPA system

The main advantage of using PPLN for OPG is that it requires substantially less pump energy than other available nonlinear materials. For femtosecond pulses an OPG-threshold of ~50 nJ has been experimentally demonstrated [1]. Efficient (20 %) energy conversion has been obtained with 100 nJ pump pulses from a table-top, diffraction-grating based fiber CPA system [1].

Chirped pulse amplification is essential for femtosecond pulse amplification in fiber amplifiers due to the limited peak power allowed by the limited cross-sectional area of a guided-wave mode. Previous implementations of compact fiber CPA using chirped fiber gratings [2] could not reach parametric generation thresholds due to the peak-power limitations in a fiber grating itself.

Here we use a compact CPA circuit based on a chirped-period, quasi-phase-matched (QPM) grating compressor in electric-field poled lithium niobate [3]. Unlike waveguide devices, bulk QPM compressors do not have limitations on the mode size and, therefore, on the recompressable pulse energies. Additionally, such a QPM compressor combines second-harmonic generation and pulse compression in one crystal, efficiently producing the 780 nm pump pulses required for 1 – 3 μm tunable OPG.

0-7803-4950-4/98/$10.00 1998 IEEE

Experimental set-up

The compact fiber CPA system is shown in Fig. 1. It consists of a mode-locked femtosecond Er-fiber oscillator, Er-fiber preamplifier, high-power cladding-pumped Er/Yb fiber amplifier and a CPPLN pulse compressor. The simplicity and compactness of this frequency-doubled fiber CPA system is apparent. Essentially, it has the same number of components as direct pulse amplification in a fiber would require.

A 5 MHz oscillator produces 180 fs, 100 pJ seed pulses at 1560 nm, which are stretched in 12 meters of a positive-dispersion fiber (β_2 = + 0.108 ps^2/m) to about 18 ps. Pulse compression is accomplished at the output of the power amplifier by passing the amplified stretched pulse through a 6 cm long CPPLN crystal. The recompressed second-harmonic pulses at 780 nm are 380 fs long (assuming a Gaussian pulse shape). This pulse broadening occurs due to spectral gain narrowing in the fiber amplifier.

The important feature of the current system is that a specially designed large-core fiber was used in the power amplification stage. The maximum energy extractable from a fiber amplifier without nonlinear distortions is proportional to the stretched-pulse duration, which currently is limited by the maximum available CPPLN crystal length of ~6 cm. By using a 24 μm mode-size fiber, we were able to scale-up the maximum extractable energy for 18 ps stretched pulses in order to obtain efficient parametric generation.

Also shown in Fig. 1 is an optical parametric generator based on a 3 mm-long PPLN crystal. We used a set of filters to suppress 1550 nm throughput into the OPG crystal, and thus to avoid unwanted parametric amplification at this wavelength. OPG has been achieved using a multiple-grating device with QPM periods from 19.5 to 21.5 μm for wavelength tuning at a fixed temperature.

Experimental results

Fig. 2 shows compressed-pulse, second-harmonic output power as a function of stretched-pulse input power at the fundamental wavelength for CPPLN compressor. Up to 0.5 W of 780 nm output has been obtained for 1.2 W of fundamental amplified input internally in the PPLN crystal. This was achieved at 10 W of cladding-coupled 976 nm pump power from a broad-stripe diode array and 30 mW of injected preamplified signal into an Er/Yb power amplifier. Pulse energy extraction of this CPA system has been tested in a separate measurement yielding distortion-free pulses of up to 0.4 μJ at 1560 nm.

100 nJ second-harmonic pump pulses at 780 nm were sufficient to achieve ~ 20 % OPG conversion efficiency yielding up to 94 mW of wavelength-tunable output from the current system. A typical wavelength tuning curve obtained with a multigrating PPLN is shown in Fig. 3.

Conclusions

Combined use of conventional unchirped and chirped PPLN structures facilitates the implementation of compact and robust fiber-CPA systems, producing high average power and high repetition rate, femtosecond output tunable from 1 – 3 μm. The achievable pulse energies and average powers can be scaled further by increasing the stretched pulse duration, amplifier-fiber core size and by using higher power diode-laser arrays.

References

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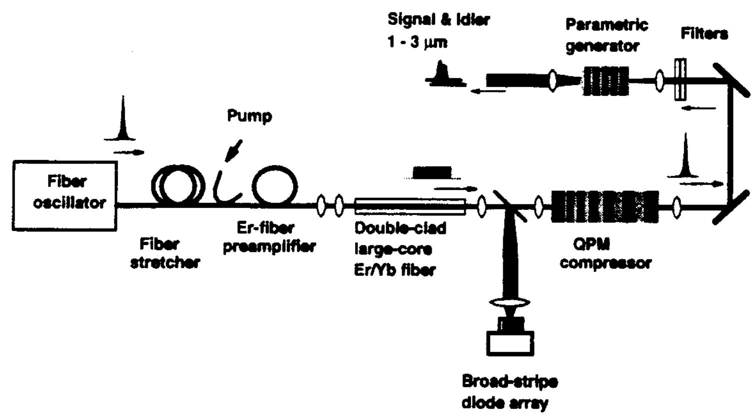

Fig. 1 Compact wavelength tunable fiber CPA system

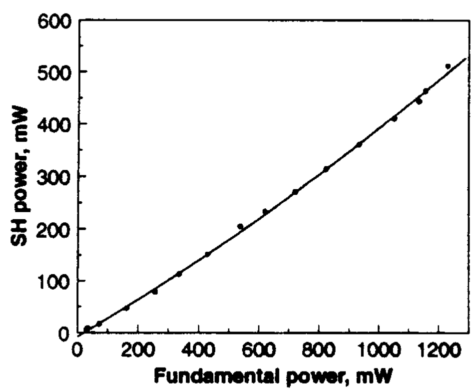

Fig. 2 CPPLN compressor power characteristics

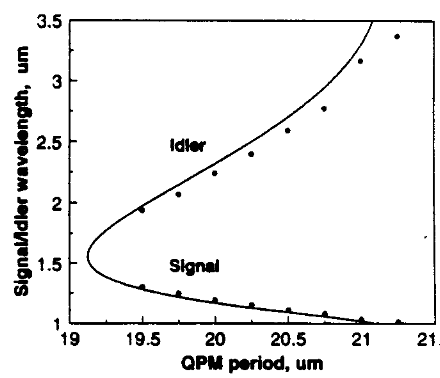

Fig. 3 Typical OPG tuning characteristics