Whitepaper

1GHz OPO generates few-cycle near-IR pulses using a **gigajet** Ti:Sapphire pump source

Abstract

Recently published work from Heriot-Watt University[1] reported the generation of 23fs pulses at a wavelength of 1.6µm from a degenerate doubly resonant optical parametric oscillator pumped by a 1GHz gigajet Ti:Sapphire oscillator from Laser Quantum as shown in figure 1.

Frequency combs[2], a spectrum consisting of a series of discrete, equally spaced elements, are now an essential tool for optical metrology, astronomical spectrograph calibration, high-resolution direct spectroscopy, optical atomic clocks and asynchronous optical sampling. Allowing a direct link from radio to optical frequencies, frequency combs are becoming increasingly important and one day may even help redefine the measurement of time.

With the comb spacing directly proportional to the repetition rate of the pump laser there are proven advantages to moving to the GHz regime. However, the generation of a direct comb from a Ti:Sapphire laser limits the available wavelength range to that of the laser itself. To increase the wavelength range, and therefore expand the possible applications of frequency combs, the use of Optical Parametric Oscillators[3] (OPO) has been introduced.

In its simplest form an OPO converts an input laser wave (called "pump") with frequency ω_p into two output waves of lower frequency (ω_s, ω_i) by means of second-order nonlinear optical interaction. The sum of the output waves' frequencies is equal to the input wave frequency: $\omega_s + \omega_i = \omega_p$. A special case is the degenerate OPO, when the output frequency is one-half the pump frequency, $\omega_s = \omega_i = \omega_p/2$. In this case the pump source was a **gigajet** (Figure 1).

The group at Heriot-Watt focused on generating not only high repetition rate pulses in the near-IR but also broadband pulses.

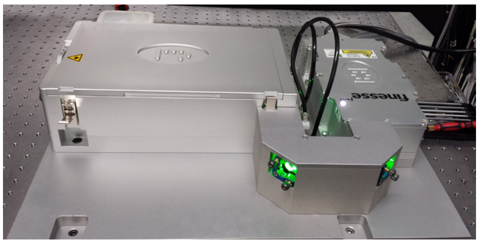

Figure 1: Laser Quantum **gigajet**

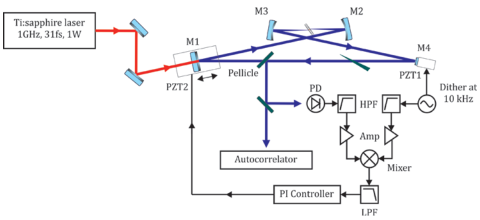

Figure 2: Experimental Layout. Optical and electronic layout of the degenerate 1 GHz PPKTP OPO. HPF, high-pass filter; LPF, low-pass filter; PD, photodiode; PZT, piezoelectric transducer

To achieve the required near-IR wavelength a doubly resonant degenerate OPO was used based on a Brewster-cut periodically-poled potassium titanyl phosphate (PPKTP), the first synchronously pumped OPO to utilise such a crystal. PPKTP offer numerous advantages over the traditionally used periodically poled lithium niobate (PPLN) including a lower material dispersion in the near-IR region and a substantially larger conversion bandwidth of 1000nm for a 0.6mm long PPKTP crystal.

The experimental layout is shown in figure 2.

The **gigajet** oscillator is pumped by a Laser Quantum **finesse pure CEP** laser. As the OPO cannot store energy, synchronous pumping is used to generate short pulse durations from the **gigajet** output of 31fs, with a central wavelength of 803nm and average power of 1W.

The OPO itself is a 4-mirror ring cavity with 0.5mm length PPKTP cut at a Brewsters angle of 1.6µm.

Mirror M1 is mounted on a translational stage allowing for adjustment of the cavity length. A $1/e^2$ waist size of 14.1µm was achieved by use of curved mirrors M2 and M3 with 20mm radius. In addition M2 was silver coated to allow direct focusing of the pump beam onto the PPKTP crystal. The inclusion of piezoelectric transducers PZT1, mounted to M4, and PZT2, mounted to the translational stage of M1, allowed for dither locking the cavity as well as the ability to scan several pump wavelengths.

(Full experimental details can be found in Optics Letters)[1]

The resulting output power of the OPO can be seen in figure 3 as the cavity length was scanned over a range of several pump wavelengths. Both peaks A and B were found to be degenerate with B having the broadest bandwidth.

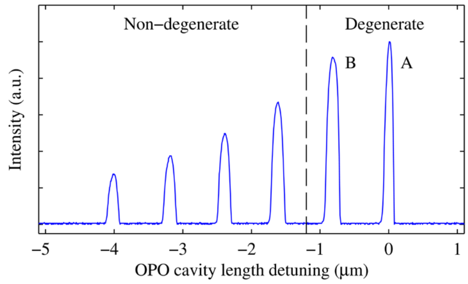

Figure 3: Output power of the OPO as the cavity length was scanned. The spacing between oscillation peaks corresponds to one pump wavelength. While both peaks A and B were found to be degenerate, the broadest bandwidth was obtainable from peak B.

With the exceptional power stability of the **gigajet** it was found that 270mW of signal power could be achieved with 950mW incident pump power, whilst powers as low as 27mW also resulted in an OPO output.

By computer modelling the output, it was determined that inclusion of a 1mm fused silica wedge would result in a broader bandwidth output as the silica acts to compensate for the material dispersion of the PPKTP crystal.

This resulted in a bandwidth of 169nm as shown in figure 4.

By combining the unique characteristics of the **gigajet**-1GHz repetition rate at 803nm with 30fs pulses with a degenerate OPO, it has been shown that pulses as short as 23fs or 4.3-cycles can be generated at 1.6µm with a FWHM bandwidth of 169nm.

This new system opens the way for ultra-broadband, mode resolvable, near-IR frequency combs at high repetition rates as well as the possibility of supercontinuum generation.

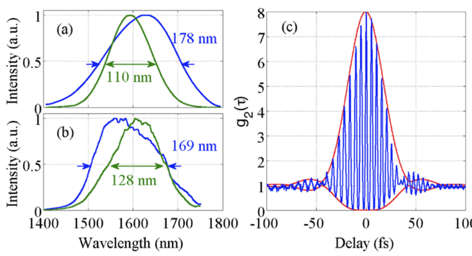

Figure 4: (a) Modeled spectra of the OPO operated without (green) and with (blue) a 1 mm fused-silica intracavity wedge. (b) Experimental spectra obtained without (green) and with (blue) an intracavity fused-silica wedge. (c) Two-photon autocorrelation of the OPO pulses generated using the intracavity fused-silica wedge. The red line shows the autocorrelation envelope derived by Fourier transforming the blue spectrum in (b), illustrating that the pulses are transform-limited directly from the OPO cavity. Full width half-maximum bandwidths are shown in (a) and (b).

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References:

[1] McCracken RA, Reid DT. 2015. Few-Cycle near-infrared pulses from a degenerate 1GHz optical parametric oscillator. Optics Letters. Vol. 40 No. 17.

[2] Hänsch, Hall and Glauber, 2005 Nobel Prize in Physics http://www.nobelprize.org/nobel_prizes/physics/laureates/2005/

[3] Hall GJ, et al. 1993. Synchronously pumped optical parametric oscillators using all-solid-state pump lasers. JOSA-B. Vol.10, pp.2168-79