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Synchronously pumped, mid-infrared CdSe optical parametric oscillator

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Synchronously pumped optical parametric oscillators (SPOPOs) are efficient sources of tunable ultrashort pulses, with low threshold average power requirements, since gain is defined by peak power. An attractive material for such devices is cadmium selenide (CdSe) due to its high nonlinearity (d_{31} = 18 pm/V), wide transparency range (0.75-25 μm) and high optical quality. Previous efforts involving CdSe in OPOs have been restricted to angle-tuning, and using Q-switched pump sources. We present here the first continuous-wave, mode-locked SPOPO based on non-critically phase-matched (NCPM) CdSe, with agile tuning of the idler over the range 9.1-9.7 μm, the longest wavelength achieved using a SPOPO to date. Pump-wavelength-tuning over a wide range (necessary for the NCPM arrangement) was provided by the signal output of a periodically poled lithium niobate (PPLN) SPOPO, operating close to degeneracy using a single PPLN grating period. The use of a diffraction grating to tune the signal of the PPLN SPOPO [1] was a key factor in obtaining clean, single-frequency pump conditions, with tuning achieved by simple grating rotation.

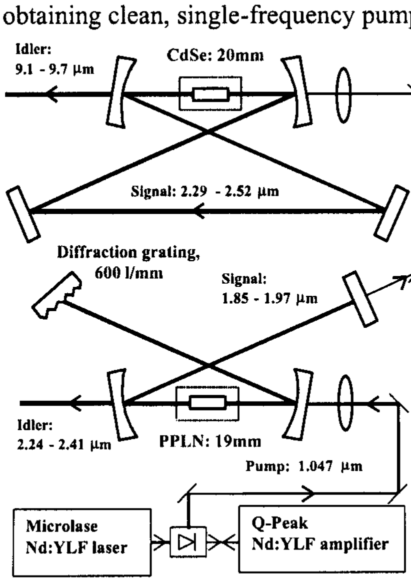

Fig. 1. Tandem-SPOPO configuration.

Figure 1 shows the tandem-SPOPO configuration, with the primary pump source, a Nd:YLF oscillator/amplifier system, providing a continuous train of 4-ps pulses at 120 MHz. A ring configuration was used for the CdSe SPOPO in order to minimise signal losses, with the idler extracted via the curved mirror after the crystal. Up to 800 mW of average power was available to pump the CdSe crystal over the range 1.85-1.97 μm. Figure 2 shows theoretical tuning curves for NCPM CdSe, over a range of pump wavelengths limited by two-photon absorption at the short end, and the signal limit from the PPLN SPOPO at the long end. A 20-mm length of crystal was used, with AR-coatings ensuring low loss for pump and signal wavelengths. Group-velocity walk-off was small over this length for all three waves. The NCPM arrangement allowed tight focussing of the pump and signal beams. Despite signal intracavity intensities reaching ~ 2×10^{12} W/m^2 no sign of optical damage was observed. Nor were detrimental thermal effects, such as those seen in a SPOPO using $AgGaSe_2$ [2], observed here, due to the six times higher thermal conductivity of CdSe and its lower absorption losses.

Typical pump depletions were 30-40%, with minimum measured threshold average pump powers of 150 mW. Using an analysis incorporating focussing and temporal behaviour, predicted thresholds agree to within a factor of 2. Round-trip cavity loss was determined, via a Findlay-Clay analysis of threshold vs. mirror reflectivity, to be ~3%, consistent with a crystal absorption of ~1%. Experimental tuning, achieved by rotation of the diffraction grating, is shown inset in figure 2, limited by mirror reflectivity roll-off for the signal at long idler wavelengths, and increasing atmospheric water-vapour absorption for short idler wavelengths. A maximum idler average power of 11 mW was recorded after transmission through various elements, corresponding to idler average powers of up to 70 mW generated internal to the crystal. Initial measurements of the directionality of the idler beam suggest a surprisingly good beam quality. Idler spectra were recorded using a monochromator and pyroelectric detector, with typical FWHM bandwidths of ~25 nm over the idler tuning range, consistent with bandwidth-limited, 5-ps pulses.

A CdSe SPOPO has been demonstrated for the first time. It has produced longer wavelengths than previous SPOPOs, with scope for wider tuning (8-12 μm) and significant further power-scaling.

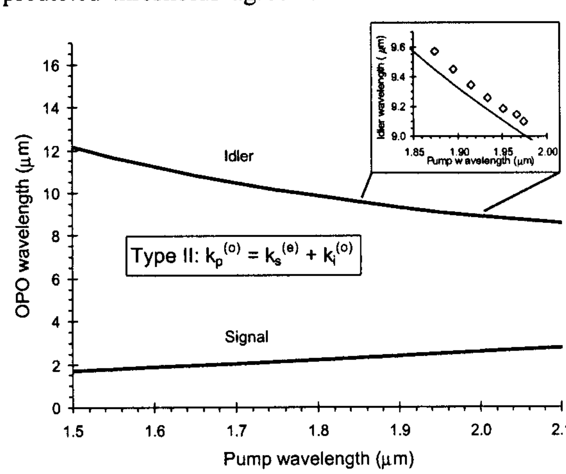

Fig. 2. Theoretical non-critical phase-matching, and experimental tuning (inset).

[1] D.C. Hanna, M.V. O'Connor, M.A. Watson, and D.P. Shepherd, J. Phys. D: Appl. Phys. **34**, 2440 (2001).
[2] S. Marzenell, R. Beigang, and R. Wallenstein, App. Phys. B **69**, 423 (1999).