

**infrared**

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## **PhD Thesis Defense CALLUM O'DONNELL 'Novel Femtosecond Optical Parametric Oscillators in the Infrared'**

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Optical Parametric Oscillators

ICFO-The Institute of Photonic Sciences

High-repetition-rate femtosecond laser sources are essential laboratory tools for spectroscopy, microscopy, amongst other applications. With the relative length of one femtosecond to one second being similar to the length of 1 second compared to the age of

the universe, such lasers enable scientists to probe physical processes at unimaginably short timescales. Furthermore, the high peak powers can excite strong nonlinear response in delicate material samples without delivering potentially damaging levels of energy. The infrared (IR) spectral region across 1-12  $\mu\text{m}$

rich in molecular absorption features, but in general poorly served by conventional coherent light sources. Optical parametric oscillators (OPOs) represent the most viable solution to this long-term issue, due to their table-top nature, and unparalleled tunability and spectral brightness in the near- and mid-IR. Recent breakthroughs in nonlinear crystal technology have opened the door to

the generation of laser light in the previously difficult to access region above 4  $\mu\text{m}$ , using high power lasers near 1  $\mu\text{m}$ . Exploiting these new nonlinear materials to improve the spectral coverage and output power of OPOs has the potential to provide important societal benefits, particularly in the fields of frequency metrology, security, and medical imaging. In addition, theoretical modelling and exploration of devices with novel cavity designs can lead to technological advances which improve

OPO affordability and increase their appeal to a wider scientific audience.

In this thesis, we have demonstrated three OPOs across 1-8.4  $\mu\text{m}$  in the infrared, which are pumped using well-established Ti:sapphire laser technology. The first is a compact and cost-effective device tunable across 1051-1700 nm in the near-IR, producing sub-10 fs pulses at 80 MHz. The incorporation of an optical fibre into the cavity leads to excellent passive power and wavelength stability, and enables soliton formation to be observed, together with other interesting nonlinear effects. We have also demonstrated an efficient, low-threshold mid-IR OPO exploiting group-velocity match effects in MgO:PPLN, which enables the use of a long (42 mm) nonlinear crystal. In doing so, we report quantum conversion efficiencies as high as 48% from the near-IR (810 nm) pump to the mid-IR (3.4-4.3  $\mu\text{m}$ ), and use the source to perform basic spectroscopy.

The third device uses Ti:sapphire light at 810 nm to directly pump the new nonlinear crystal CdSiP<sub>2</sub>, generating up to 20 mW average power across 6.6-8.4  $\mu\text{m}$  in the deep mid-IR. As the first demonstration of a single-stage Ti:sapphire-pumped deep mid-IR OPO with practical output powers, it has potential for medical imaging applications in the important amide II and III

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