Fibre MOPA pumped MIR parametric wavelength conversion

R. T. Murray,1,* T. H. Runcorn,1, S. Guha,2 and J. R. Taylor1

1Femtosecond Optics Group, Department of Physics, Imperial College London, Prince Consort Road, London SW7 2BW, UK
2Air Force Research Laboratory, Materials and Manufacturing Directorate, Wright Patterson Air Force Base, Ohio 45433, USA

Corresponding author: *robert.murray10@imperial.ac.uk

Abstract: We review recent work on generating MHz repetition rate, nanosecond pulsed, multi-Watt level average powers in the 3.3–3.5 µm region, using Yb:fibre and Er:fibre MOPAs to pump MgO:PPLN OPAs.

OCIS codes: (190.4970) Parametric oscillators and amplifiers; (140.3070) Infrared and far-infrared lasers; (140.3510) Lasers, fiber

1. Motivation and overview
The mid-infrared (MIR) spectral region contains many important vibrational and ro-vibrational molecular absorption lines, important in applications ranging from atmospheric spectroscopy to materials processing. In particular, the 3–5 µm range of the MIR corresponds to the first atmospheric transmission window, relevant for remote sensing and defensive countermeasure applications. Optical parametric oscillators (OPOs) are a proven route to generating high power, widely tunable radiation in this region, from the continuous wave to ultrafast regimes. In particular Yb:fibre based master oscillator power amplifier (MOPA) pumped PPLN OPOs have been highly successful in recent years, for their ability to convert high power near-infrared radiation around 1.06 µm to the MIR and the temporal flexibility they offer [1]. Recently, we have been investigating optical parametric amplification (OPA), or difference-frequency generation (DFG), based single-pass alternatives to conventional resonant OPOs, to avoid the need for a cavity and the corresponding design constraints that this can impose; such as, fixed repetition rates, unstable cavities and/or poor output beam qualities at high average power levels.

In this paper, we review recent results on high average power nanosecond pulse generation in the 3.3–3.5 µm region. By mixing pulsed Yb:fibre and Er:fibre MOPAs in PPLN, it is possible to generate multi-Watt level output powers (≥6.0 W from 3.3–3.5 µm) with pump depletion levels approaching 80% [2–5]. We make use of numerical simulations employing focussed Gaussian beam theory [6,7], which can be used to both guide and verify experimental work [4,5].

2. Multi-Watt level MIR generation from 3.3–3.5 µm using synchronized fibre lasers
Figure 1 (a) shows the architecture used, with synchronized Yb:fibre and Er:fibre MOPA systems pumping a MgO:PPLN crystal. Fully fibre integrated MOPA systems provide robust and compact pump sources, with excellent beam quality and power scaling potential. Electrical synchronization can be easily achieved with a common clock with electrical delay lines ensuring excellent pump/signal pulse overlap in the crystal without the need for any optical path length adjustment. Example MIR wavelength tuning, achieved through PPLN crystal temperature and Er:fibre MOPA central wavelength adjustment, is shown in Fig. 1 (b).

We initially demonstrated ≥3.4 W from 3.3–3.5 µm with pump conversion efficiencies reaching 78% [3]. The Yb:fibre MOPA pump source consisted of a 150 ps fixed duration, 40.0 MHz repetition rate, actively mode-locked laser diode, amplified in a chain of Yb:fiber amplifiers to 17 W of average power (2.5 kW peak). However, strong back-conversion of the signal/idler power back to the pump due to excessive peak-power in the pump pulses was observed, leading to a drop in conversion at the highest pump average powers. Replacing the fixed duration, gain-switched diode, with a duration tunable intensity modulated diode, allowed shifting of the point of maximum conversion to the highest average power levels. This resulted in ≥6.2 W of MIR power at conversion efficiencies exceeding 75% [5], as shown in Figs. 1 (c) and (d). The produced MIR radiation also displayed excellent beam quality, with measured M2 values of ≤1.4 in both horizontal and vertical beam axes.
Fig. 1. (a) Nanosecond based master oscillator power amplifier (MOPA) OPA system architecture. Yb:fiber/Er:fiber MOPA systems are used to pump a single pass OPA stage. (b) Example wavelength tuning in the mid-IR [2]. (c) Amplified signal, generated idler and combined powers generated, with the corresponding pump conversion efficiencies shown in (d) [4].

These average powers, conversion efficiencies and high quality transverse mode profiles are competitive with those achieved in resonator based systems (OPOs), but achieved using a simpler, in terms of free space optics employed, single pass approach. For applications where the broader wavelength coverage that can be achieved in OPOs is not needed, the synchronized fibre MOPA pumped OPA approach could potentially be more favourable. The potential to combine the output of the Yb:fibre and Er:fibre MOPAs in a single delivery fibre to the nonlinear crystal is also attractive, again making the system more compact and robust against environmental perturbations in comparison to standard OPOs.

3. Ongoing source development

We will introduce ongoing work aimed at continued power scaling of the MIR light, employing ≥ 100 W level Yb:fibre MOPA systems to pump MgO:PPLN, with the aim of generating near diffraction limited MIR radiation at the ≥ 20 W level. We are also investigating the use of non-oxide nonlinear crystals, such as BGSe [8, 9], to allow the mixing of different rare-earth doped fiber MOPAs, for example Erbium, 1.55 µm, with Thulium, 1.91 µm, producing radiation in the 7-9 µm region. Generating high average power MIR light beyond the transparency window of PPLN, is of particular interest for accessing the second atmospheric transmission window between 8–12 µm. Finally, we will discuss the possibility of extending this further with the use of Raman-shifted fibre laser sources mixed with conventional rare earth doped fibre MOPAs, to generate arbitrary wavelength combinations in the MIR.

Acknowledgements

RTM and JRT gratefully acknowledge funding from the EOARD (FA9550-17-1-0194) and the EPSRC (EP/N009452/1). THR was funded by an EPSRC Impact Acceleration Award (EP/K503733/1).
References