Ultra-narrow-linewidth Mid-infrared Optical Parametric Oscillator

I. Ricciardi[1], S. Mosca[1], M. Parisi[1], P. Maddaloni[1], L. Santamaria[1], M. De Rosa[1], G. Giusfredi[2], and P. De Natale[2]

[1] *CNR-INO, Istituto Nazionale di Ottica, Via Campi Flegrei 34, 80078 Pozzuoli (NA), Italy*
[2] *CNR-INO, Istituto Nazionale di Ottica, and LENS, via Carrara 1, 50019 Sesto Fiorentino FI, Italy*

Presenting Author: iolanda.ricciardi@ino.it

Highly stable and spectral pure laser sources are crucial for a wide range of demanding applications, including high-resolution spectroscopy, frequency metrology, and precision tests of fundamental physics. We demonstrate Hz-level narrowing of a singly resonant optical parametric oscillator (OPO), emitting in the frequency range between 2.7 and 4.2 μm [1–2], where intense ro-vibrational transitions of many molecules with a natural linewidth as low as a few Hz are present.

In our experimental set-up a Nd:YAG laser, frequency narrowed at 1-Hz-linewidth (over 1 ms) against a stable ultra-low-expansion (ULE) Fabry–Pérot cavity, is amplified up to 10 W to pump the OPO. The OPO is based on a periodically poled MgO:$LiNbO_3$ crystal placed in a bow-tie cavity resonant for the signal. The crystal has seven different poling periods, allowing the continuous tuning of the idler frequency between 2.7 and 4.2 μm, with about 1 Watt of emitted power. We exploit a transfer oscillator scheme [3], according to which an optical frequency comb synthesizer acts as the transfer oscillator between a highly stable pump laser mode and the resonating OPO signal mode: as a consequence, the spectral features of the pump laser are transferred to the signal mode, independently of technical fluctuations of the comb frequencies. In turn, the fluctuations of idler mode frequency will be of the same order of the pump laser ones, as in a singly-resonant OPO the idler linewidth is the sum of the two uncorrelated pump and signal linewidths. The transfer oscillator is an amplified mode-locked Er:doped fibre laser, followed by a nonlinear photonic fibre, generating an octave-spanning frequency comb, between 1–2 μm, of equally spaced modes (repetition rate, $f_r \simeq 250$ MHz).

For the diagnostics of the residual frequency noise of the pump mode we used a reference Fabry–Pérot cavity, made by a couple of HR mirrors glued on an invar spacer, kept under vacuum for environmental isolation. The invar cavity is loosely locked (10-Hz-bandwidth) to the pump frequency by a Pound–Drever–Hall (PDH) scheme. Thus, for spectral frequencies greater than the locking bandwidth, the power spectral density (PSD) of the PDH signal gives the free-running relative frequency noise between the pump and the invar cavity. For times shorter than 1 ms the integrated PSD gives a pump linewidth around 1 Hz.

The signal residual frequency noise has been estimated in a similar way, using a second reference invar cavity. In this case, for times shorter than 1 ms we estimated a signal linewidth around 1 Hz, which summed to the 1 Hz pump linewidth, results in an idler linewidth at the Hz-level.

References

[1] I. Ricciardi, E. De Tommasi, P. Maddaloni, S. Mosca, A. Rocco, J.-J. Zondy, M. De Rosa, and P. De Natale, Opt. Express **20**, 9178–9186 (2012)
[2] I. Ricciardi, E. De Tommasi, P. Maddaloni, S. Mosca, A. Rocco, J.-J. Zondy, M. De Rosa, and P. De Natale, Mol. Phys. **110**, 2103–2109 (2012)
[3] H. R. Telle, B. Lipphardt, and J. Stenger, Appl. Phys. B **74**, 1–6 (2002)