Optical Parametric Oscillators: New Advances

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Optical parametric oscillators (OPOs) are now recognized as viable sources of widely tunable coherent radiation, covering spectral regions form ultraviolet (UV) to mid-infrared (mid-IR), in time-scales from the continuous-wave (CW) to ultrafast femtosecond domain. The development of birefringent nonlinear materials such as β-BaB_2O_4, LiB_3O_5, $KTiOPO_4$ and, most recently, BiB_3O_6 has had a major impact on pulsed OPO technology, while the advent of quasi-phase-matched (QPM) ferrolelectric crystals, particularly MgO:PPLN and MgO:sPPLT, has led to important breakthroughs in CW and low-intensity OPOs.

By deploying ultrafast femtosecond and picosecond pump sources based on the Kerr-lens-mode-locked (KLM) Ti: sapphire as well as mode-locked solid-state and fiber lasers, near- to mid-IR spectral regions from ~1 μm up to ~5 μm are now accessible with ultrafast OPOs. Average output powers in excess of 10 W are routinely available from picosecond and sub-picosecond OPOs pumped by solid-state and fiber lasers, while power levels as much as 1 W can be generated with femtosecond OPOs pumped by the KLM Ti:sapphire laser. Using additional multistep external and internal frequency upconversion techniques for the pump laser and the OPO, the spectral coverage of Ti:sapphire-pumped femtosecond OPOs has been further extended to unprecedented new limits, across the visible down to 250 nm in the UV, with a tunable range of 250-2500 nm available to a single OPO device based on BiB_3O_6 and β-BaB_2O_4 as nonlinear crystals. In the CW regime, the deployment of high-power solid-state and fiber lasers at/near 1064 nm in combination with MgO:PPLN and MgO:sPPLT has enabled the generation of high-power near- to mid-IR radiation from ~1.4 μm to ~5 μm at power levels approaching 20 W. The generation of CW radiation below ~1.4 μm has also been made possible by using green lasers based on internal frequency-doubled solid-state lasers, using novel external single-pass second harmonic generation of high-power fiber lasers at 1064 nm in MgO:sPPLT, and by deploying optically-pumped semiconductor lasers (OPSLs) to pump CW OPOs based on MgO:sPPLT as the gain medium, providing single-frequency watt-level output powers in high beam quality down to ~850 nm. The spectral coverage of CW OPOs has also been extended to the visible, down to ~400 nm in the blue, using internal upconversion of green-pumped CW OPOs based on MgO:sPPLT, with BiB_3O_6 as the frequency-doubling crystal. These advances have led to the coverage of spectral regions across ~250-5000 nm with ultrafast femtosecond and picosecond OPOs and ~400-5000 nm with CW OPOs.

At the same time, the development of OPO devices beyond 5 μm in the mid-IR has recently witnessed significant progress with the advent of new nonlinear crystals. Access to wavelengths >5 μm has been traditionally difficult with OPO devices in all temporal regimes, due to the onset of absorption in the oxide-based birefringent and QPM materials. Chalcogenide crystals such as CdSe and $AgGaSe_2$ provide the required transparency at longer wavelengths, but low bandgap energy precludes pumping near ~1 μm due to two-photon absorption. Other chalcogenide crystals with larger bandgap, such as $AgGaS_2$, may be pumped near ~1 μm, but poor thermo-mechancial properties and low damage threshold prevent practical device operation. As such, exploitation of many chalcogenide materials requires long-wavelength laser pump sources with limited availability near ~2 μm, or the deployment of cascaded pumping schemes with the associated complexities. However, the development of new nonlinear crystal $CdSiP_2$ has now led to major breakthroughs in wavelength generation with OPOs in the 6000-6500 nm spectral range, pumped directly at 1064 nm by Nd-based solid-sate lasers. This talk will provide an overview of the advances in OPO devices from CW to ultrafast femtosecond and picosecond regime, from the UV to mid-IR, and discuss strategies for future progress in this technology.

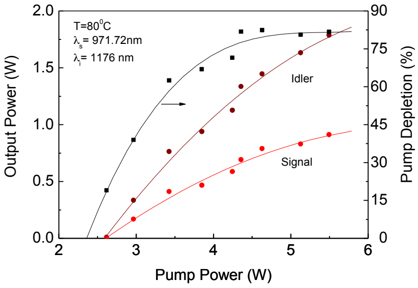

Fig. 1. Output power characteristics and pump depletion for a CW OPO pumped by an OPSL.

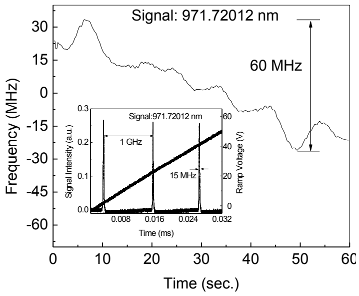

Fig. 2. Frequency stability and (inset) single-mode spectrum of a CW OPO pumped by an OPSL.

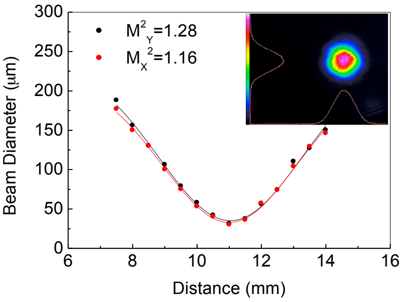

Fig. 3. Variation of signal beam diameter and corresponding signal beam profile of a CW OPO pumped by an OPSL.

References

[1] G. K. Samanta and M. Ebrahim-Zadeh, *Opt. Lett.* **35,** 1986-1988 (2010).
[2] O. Kokabee, A. Esteban-Martin, and M. Ebrahim-Zadeh, *Opt. Lett.* **35**, 3210-3212 (2010).