# *Progress in Optical Parametric Oscillators*

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Optical parametric oscillators (OPOs) represent versatile coherent light sources capable of providing widely tunable radiation at wavelengths not accessible to conventional lasers. While the first experimental demonstration of an OPO was reported in 1965, for many years there was a lack of progress in OPO technology due to the absence of viable nonlinear materials and laser pump sources. With the advent of a new generation of birefringent crystals such as $\beta$-$BaB_2O_4$ and $LiB_3O_5$ in the mid-1980s, and quasi-phase-matched (QPM) materials, particularly periodically-poled $LiNbO_3$ (PPLN), in the mid-1990s, there began a resurgence of interest in OPO devices as potential alternative to lasers for the generation of coherent light in new spectral regions. In the intervening period, OPO devices have been transformed from laboratory prototypes into practical coherent light sources, capable of accessing difficult wavelength regions and addressing novel applications beyond the reach of lasers. Advances in OPO technology have been particularly rapid in the pulsed regime due to the ready availability of high-energy (mJ-100s mJ) nanosecond pump lasers, where the use of Q-Switched Nd-based lasers near 1.06 $\mu$m and their harmonics near 0.53 and 0.35 $\mu$m has enabled the realization of practical pulsed nanosecond OPOs covering wavelength regions from ~400 nm up to beyond ~10 $\mu$m.

On the other hand, the development of ultrafast and continuous-wave (cw) OPOs has been confined mainly to the 1-5 $\mu$m spectral range, with the 5 $\mu$m cutoff determined by absorption in oxide-based nonlinear crystals and the 1 $\mu$m limit imposed by the absence of suitable mode-locked and cw pump lasers in the visible and UV, and a lack of suitable birefringent and QPM materials. However, through application of novel techniques based on frequency up-conversion together with parametric down-conversion, it is now also possible to access short wavelengths into the UV and across the visible using ultrafast and cw OPOs, making this technology a powerful tool for practical generation of coherent radiation across an expansive spectral range from the UV to mid-IR and in all time-scales from the cw to ultrafast femtosecond and picosecond regime. Here, we describe such techniques for the development of ultrafast and cw OPOs in the visible and UV, and present the extension of these approaches to the rapidly evolving fiber laser technology. Using internal frequency up-conversion schemes in ultrafast and cw OPOs, it is now possible to access wavelength regions from 230 nm in the UV, across the visible, and into the infrared, while the application of fiber laser technology in combination with new QPM nonlinear crystals (Fig. 1) can permit the development of compact, high-power cw OPOs pumped by visible fiber-based sources (Fig. 2). We will also review important recent developments in ultrafast and cw OPO near- and mid-IR, and highlight some applications in science and technology.

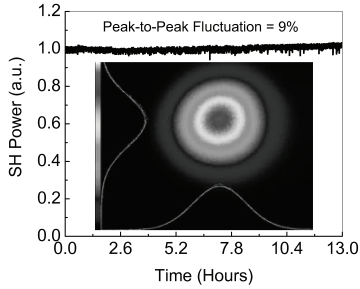


Fig. 1 Single-pass second-harmonic-generation of cw Yb fiber laser in MgO:sPPLT, providing stable single-frequency radiation at 532 nm at 32.7% conversion efficiency. The plot shows output power stability at 9.64 W over 13 h, and (inset) far-field $TEM_{00}$ energy distribution and intensity profiles of the generated green beam.

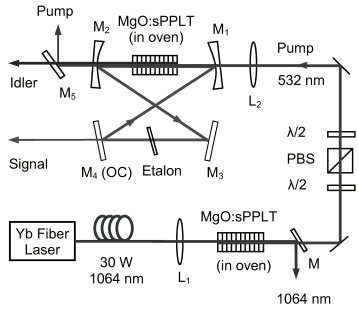


Fig. 2. High-power cw OPO based on MgO:sPPLT pumped at 532 nm by 9.64 W of cw green radiation obtained by simple single-pass second-harmonic-generation of cw Yb fiber laser in MgO:sPPLT.

**References**

[1] M. Ghotbi, A. Esteban-Martin, and M. Ebrahim-Zadeh, *Opt. Lett.* **33**, 345 (2008).
[2] G. K. Samanta, S. C. Kumar, and M. Ebrahim-Zadeh, *Opt. Lett.* **34,** No. 10 (2009).