New Frontiers in Tunable Laser Technology: Optical Parametric Oscillators Spanning the Ultraviolet to Mid-Infrared

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The development of practical solid-state laser sources in different regions of optical spectrum has been an important goal of research in laser science and technology, since Maiman demonstrated red laser action in ruby in 1960. Major efforts have been devoted to provide coherent radiation in difficult spectral regions using conventional laser techniques, yet, after nearly 50 years, extended wavelength bands across the ultraviolet (UV), visible and infrared (IR) still remain inaccessible to lasers. The potential of optical parametric oscillators (OPOs) for the generation of widely tunable laser light at new wavelengths was recognized soon after the invention of the laser, and the first experimental device was demonstrated in 1965. However, for nearly two decades thereafter, there was little progress in practical development of OPO devices due to the absence of viable nonlinear materials and laser pump sources. With the advent of a new generation of birefringent nonlinear crystals such as β-BaB_2O_4 and LiB_3O_5 in the mid-1980s, and quasi-phase-matched materials, particularly periodically-poled $LiNbO_3$ (PPLN), in the mid-1990s, there began a resurgence of interest in OPO technology for the generation of coherent radiation in new spectral regions. In the intervening period, OPO devices have been transformed from laboratory prototypes into practical light sources, capable of accessing difficult spectral regions and addressing real application areas beyond the reach of conventional lasers. With an exceptionally broad wavelength coverage from a single device, temporal flexibility from the continuous-wave (cw) to femtosecond time-scales, high output power and efficiency, and compact solid-state design, OPOs are now firmly established as truly viable alternatives to conventional lasers and other technologies for the generation of coherent light in difficult spectral and temporal domains.

In the femtosecond time-scales, the absence of viable ultrafast solid-state lasers has confined the choice of laser pump source for OPOs to the Kerr-lens mode-locked Ti:sapphire laser, providing ultrashort pulses in the 1-5 μm spectral range. In the cw regime, the deployment of cw semiconductor diode lasers, high-power Nd-based solid-state lasers and fiber lasers in combination with new QPM materials has similarly led to the realization of a new generation of coherent cw light sources with unprecedented performance capabilities for the 1-5 μm spectral range. On the other hand, extension of operation of ultrafast and cw OPOs to shorter wavelengths below 1 μm has been more challenging because of increased demands on nonlinear materials and the absence of short-wavelength laser pump sources to achieve wavelength generation in the visible and UV using direct parametric down-conversion. However, through application of novel schemes based on frequency up-conversion in combination with parametric down-conversion, it is now also possible to access short wavelengths into the UV and across the visible, making OPO technology a powerful tool for practical generation of coherent radiation across an expansive spectral range from the UV to mid-IR. Here, we describe such techniques for spectral extension of ultrafast femtosecond and cw OPOs into the visible and UV, review the important developments in OPO sources in the near- and mid-IR, and highlight new applications in science and technology.