Practical laser sources will unlock important applications in the mid-IR

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Optically pumped semiconductor disk lasers at 1 and 2μm provide ideal optical pump power platforms for a wide variety of compact and tunable intracavity pumped laser systems.

The mid-IR spectral region is increasingly important for a wide range of applications in the industrial, environmental, security, medical, and scientific sectors. Examples include sensing and spectroscopy; biomedical imaging and tissue processing; industrial monitoring and process control; materials processing; and trace molecular detection for environmental study and security. These applications represent a vast array of different source requirements in tunability and energy. But all are limited in some way by current laser source format and availability.

A number of approaches have been effected to address these limitations, such as lead-salt lasers, high-power diode-pumped solid-state lasers, quantum cascade lasers (QCLs), and optical parametric oscillators. Many of these systems require multi-stage resonators, complex growth and processing, or cryogenic cooling to achieve significant performance and/or tunability. The most significant developments have been, and so far continue to be, in QCLs. For instance, in the GaInAs/AlInAs-on-InP (gallium indium arsenide/aluminum indium arsenide on indium phosphide) material system, an impressive wavelength coverage over 3.5–12μm has been demonstrated, with output powers in excess of 1W over most of this range. Current research and development challenges seek to extend the spectral coverage to shorter wavelengths while increasing power efficiency.

Optically pumped semiconductor disk lasers (SDLs)1–3 based on InGaAs/(Al)GaAs and (AlGaIn)(AsSb, arsenic antimonide), emitting in the 1 and 2μm spectral ranges, respectively, are among the powerful technologies to have emerged. These lasers provide high beam quality, continuous-wave outputs with maximum output powers in the 1–10W range (and in some special cases many tens of watts). Their properties make SDLs ideally suited as pump sources for mid-IR and terahertz laser systems. SDL technology has been a key focus of our team at the Institute of Photonics, University of Strathclyde, Glasgow, UK, and the Fraunhofer Institute for Applied Solid State Physics (IAF) at Freiburg, Germany. We have demonstrated, with collaborators—specifically, the Nonlinear Optics Group at the University of St. Andrews, St. Andrews, UK—the potential of SDL technology to efficiently pump mid-IR dielectric laser materials, Raman lasers, optical parametric oscillators, and difference-frequency-generation-based terahertz systems in compact and practical arrangements.

The semiconductor disk laser allows high-power, multi-watt output performance to be obtained from a compact (external cavity semiconductor) laser arrangement, critically at diffraction- or near-diffraction-limited beam quality. Moreover, structurally and compositionally, these disk laser sources are much simpler than other mid-IR semiconductor lasers, are wavelength flexible, and can be tailored to meet the demands of a wide range of applications. Companies such as Coherent...
Inc. have used the key characteristics of SDLs to great effect, replacing legacy optical pumps and fundamental laser source technologies to achieve greater compactness and economy.

The typical format (see Figure 1) of an SDL is a thin (few microns) active region containing quantum wells (or dots) grown on a highly reflective Bragg mirror. The structure forms an ‘active mirror’ that is optically pumped in a traditional free-space resonator. This feature allows the resonator mode and the pumped volume to be carefully matched and consequently to provide power-scalable devices with high spatial mode quality. For high-power operation, device thinning through substrate removal or bonding to transparent high thermal conductivity heat-spreading layers is employed. In this way, we have demonstrated high output powers of up to the order of 100W around 1µm using the thinning approach, and wide tunability (in terms of device composition) at 1–10W output power using heat spreading.2

Through the European Union project VERTIGO, we have also developed widely tunable (~150nm) and high-power (6W) (AlGaIn)(AsSb)-based SDLs grown on GaSb substrates in the 1.9–2.8µm wavelength region.3 We initially designed these sources for eye-safe, long-range free-space optical communications systems, and we are now extending them to highly compact solid-state laser pumping of Cr2+:ZnSe (chromium-doped zinc selenide) lasers4 providing stable watt-level output powers (see Figure 2). At the Fraunhofer IAF, we have also further developed these systems to perform, for example, materials processing and etching/marking operations on transparent plastic materials. Finally, we have shown 2µm SDLs to be excellent high-power, narrow-linewidth sources that produce kilohertz linewidths in a straightforward fashion when stabilized to a simple external reference cavity.5

The ubiquitous applicability and flexibility of SDLs is now widely accepted, and they have been commercially exploited to produce compact, high-power and high-brightness sources. More recently, these devices have transformed the technology of intracavity pumping of secondary linear and non-linear color conversion resonators. Here, the ‘planar’ gain medium

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and short carrier lifetimes crucially provide a flexible intracavity power platform for stable, low-noise conversion and subsequent application. Key examples in this area are intracavity frequency doubling, \(^6\) sum-frequency mixing, \(^7\) difference frequency generation, \(^8\) and Raman \(^9\) and optical parametric oscillation. \(^10\) Specifically, in the case of non-linear intracavity conversion, a number of systems have been reported that effectively exploit the short carrier lifetimes to negate the deleterious effects of noise, mode coupling, and relaxation oscillations typically found in diode-pumped dielectric equivalents. We have developed \(^10\) the first intracavity SDL-pumped optical parametric oscillator (ICOPO) with a 1.0\(\mu\)m SDL and a magnesium-doped, periodically poled lithium niobate crystal as the non-linear medium (see Figure 3). We also demonstrated excellent noise performance for an ICOPO in a compact resonator arrangement (see Figure 4).

We expect the family of novel and practical laser sources based on intracavity converted 1 and 2\(\mu\)m SDL power platforms to continue to grow in scientific and commercial relevance and applicability in the coming years. The collaboration between the Institute of Photonics and Fraunhofer IAF has led to the recent announcement of the first Fraunhofer center in the UK: the Fraunhofer Centre for Applied Photonics. This center provides a hub for industry-driven laser research and technology for a variety of sectors, including health care, security, energy, and transport. In the future, we will expand the wavelength coverage of mid-IR (and THz) sources based on intracavity SDL pumping. We also plan to develop these sources in close collaboration with industrial and research partners to meet the needs of important applications in several market sectors.

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References