

Broadly Tunable Mid-Infrared Fiber-Bulk Hybrid Lasers

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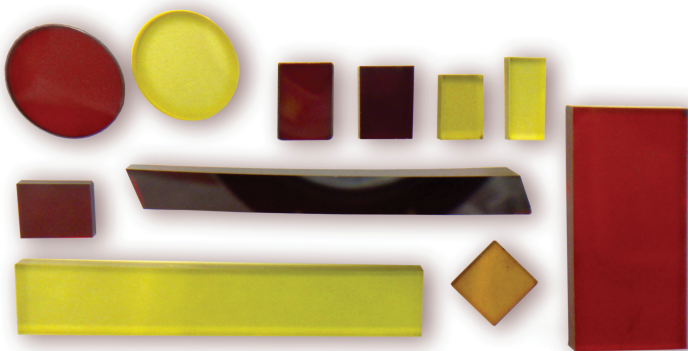
Middle-infrared (mid-IR) laser sources operating over the “molecular fingerprint” 2-15 μm spectral range are in great demand for a variety of applications including molecular spectroscopy, non-invasive medical diagnostics, skin rejuvenation and laser surgery, processing of plastic materials, industrial process control, environmental monitoring, atmospheric sensing and free space communication, oil prospecting and numerous defense related applications.

Mid-IR wavelengths are usually generated using relatively complex nonlinear optical conversion techniques or by means of direct generation in hetero-junction lead-salt, antimonide or quantum

absorption and emission bands in the mid-IR (σ approximately 10^{-18} cm^2 , gain bandwidth up to 50% of the central wavelength) and do not have excited-state absorption. Heavy anions in the crystals provide a very low energy optical phonon cutoff enabling high room-temperature fluorescence yield.

Since their introduction in the late 1990s by Dr. Krupke’s group at Lawrence Livermore National Laboratory (LLNL; Livermore, CA), Cr^{2+} and Fe^{2+} doped II-VI semiconductor lasers were demonstrated with laser efficiency >70%, maximum continuous-wave (CW) power >18 W, short pulse oscillation <70 fs, peak power >1GW,

output energy >400 mJ and overall tunability over 2-6 μm , leading some researchers to call them the “mid-IR analogs of Ti:sapphire lasers”. These lasers are now commercially available from IPG Photonics in the form of fiber-bulk hybrid systems.



cascade semiconductor lasers featuring limited output power and tuning range. Impurity doped crystalline lasers constitute another viable route for mid-IR coherent sources. Many mid-IR solid-state laser sources do not operate at room-temperature due to the deactivation of energy accumulated in the gain media via non-radiative phonon-assisted decay. But a new class of impurity doped crystalline lasers based on transition-metal (chromium, Cr^{2+} or iron, Fe^{2+}) doped binary (ZnSe , ZnS , CdSe , CdS) and ternary (e.g. CdMnTe) chalcogenide crystals represents a viable route for room-temperature mid-IR lasing and expand the capabilities of other mid-IR coherent sources. These gain media can be pumped by commercially available erbium (Er) and thulium (Tm) fiber lasers, feature strong and ultra-broad

Three major types of fiber-bulk hybrid lasers convert CW radiation from fiber lasers either in the spectral domain (broadly tunable radiation), the temporal domain (mode-locked or short Q-switched, high peak power and energy pulses) or simultaneously in the spectral and temporal domains.

For the first series of lasers with 1000 nm tunability from 2000-3000 nm, (and rapid-tuning capability of <0.7 $\mu\text{s}/\text{nm}$), an Er or Tm CW randomly polarized fiber laser with output power 1-30 W pumps an external-cavity tunable laser based on $\text{Cr}:\text{ZnS}/\text{Se}$ bulk crystals. The result is CW mid-IR tunable, narrow-linewidth (<0.05 nm) or single-frequency radiation with output power in excess of 10 W and real optical-to-optical efficiency of up to 50%.

Temporal domain conversion models are divided in two groups capitalizing on a) the ultrabroadband gain profile of the pumped medium, enabling short pulse duration in the mode-locked regime or b) long lifetime of the optical centers (Er or holmium, Ho) in the excited states, enabling effective accumulation of population inversion and efficient Q-switching.

Fiber-pumped mode-locked $\text{Cr}:\text{ZnS}/\text{Se}$ lasers are pretty similar to green-laser pumped femtosecond Ti:sapphire lasers and can provide short (<10 fs) mode-locked operation with Watt-level output power, but in the spectral range of molecular fingerprints of organic molecules.

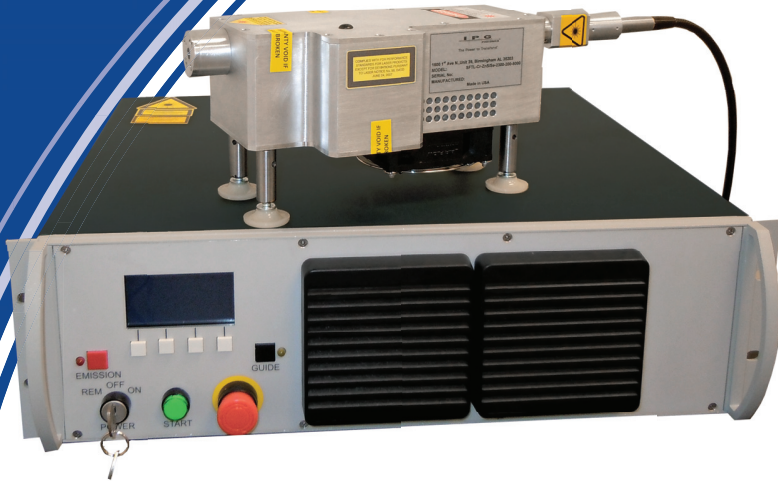
Fiber-pumped actively or passively Q-switched Er or Ho:YAG lasers efficiently (up to 90%) convert CW radiation of Er or Tm fiber lasers into high-energy (0.5-20 mJ) Q-switched radiation of Er:YAG (1.6 μm) or Ho:YAG (2.1 μm) lasers with a variable pulse duration (5-200 ns) and repetition rate (10-80,000 Hz).

Combinations of temporal/spectral conversion models can create $\text{Cr}(\text{Fe}):\text{ZnS}/\text{Se}$ gain-switched lasers with output energy up to 10 mJ, pulse duration 10-100 ns, repetition rate 50-5000 Hz and tunability over the 2-3 μm and 3.5-5.2 μm spectral ranges.

IPG is also offering different solutions in the form of saturable absorbers and gain elements. IPG’s fabrication process allows low cost mass production of a large variety of diffusion doped $\text{Cr}/\text{Co}/\text{Fe}:\text{ZnSe}/\text{ZnS}$ crystals with low losses, uniform distribution of impurity, good reproducibility and reliability. These crystals are ideal saturable absorbers for passive Q-switching of near- and mid-IR laser cavities and gain materials for mid-IR lasers broadly tunable over 1.9-5.2 μm .

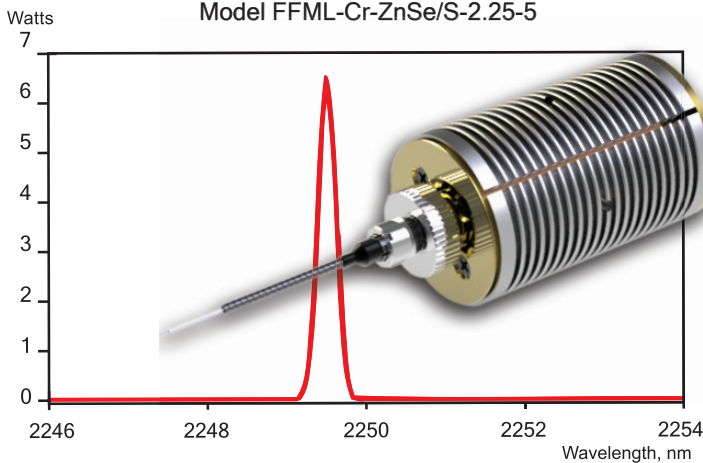
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Finally... Simple, Reliable Mid-IR Lasers



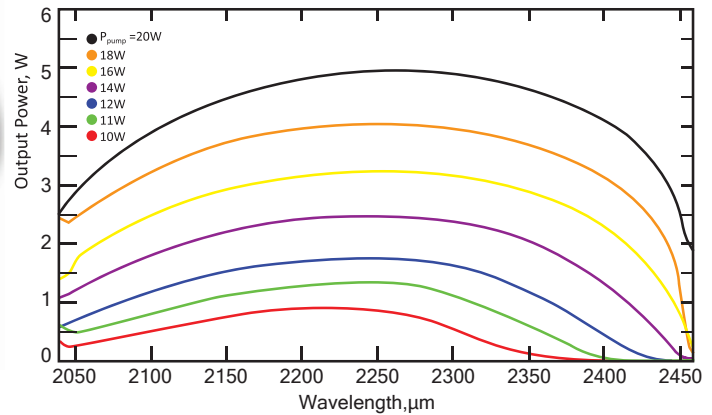
IPG's newly developed Mid-IR lasers offer cost-effective solutions for sensing, spectroscopy, material processing, and medical applications.

Sample Spectrum of the High-Power Mid-IR Laser Module
Model FFML-Cr-ZnSe/S-2.25-5

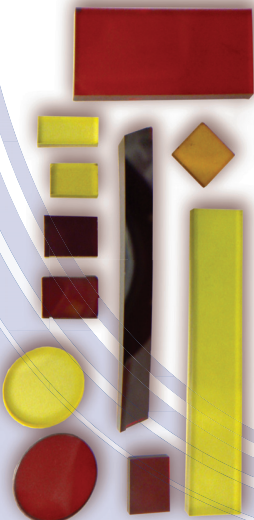


- Multi-Watt Output Power
- Narrow-line fixed wavelength
- Wavelengths within 2000 - 3000 nm available

Output Power vs Wavelength for
Different Levels of Pump Power



- Multi-Watt Output Power
- Narrow Linewidth, <10 MHz available
- Large tuning range with single set of optics (any wavelength within 2000 - 3000 nm tuning range is available upon request)



IPG is also offering additional solutions in the form of Saturable Absorbers and Gain Media:

Passive Q-switches for cavities of near and mid-IR solid state lasers Cr²⁺: ZnSe, Cr²⁺: ZnS, Co²⁺: ZnS and Fe²⁺: ZnS

Saturable absorbers are ideal materials for passive Q-switches of eye-safe solid state lasers operating over 1.5-4.0 μm spectral range.

Mid-IR Gain Media Cr²⁺: ZnSe and Cr²⁺: ZnS

Gain materials of choice when one needs a compact fiber or diode pumped CW system with continuous tunability at room temperature over 1.9-3.3 μm, high output power and efficiency.

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