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Demonstrations of Diode-Pumped and Grating-Tuned ZnSe:Cr^{2+} Lasers

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A diode-side-pumped ZnSe:Cr^{2+} laser operated with a 1.65 μm InGaAsP/InP pump array. With a grating tuner and MgF_2:Co^{2+} laser pumping, it spanned the 2134 - 2799 nm range.

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Within the last few years, the divalent-transition-metal-doped II - VI material class has been proposed as source of new tunable mid-IR lasers. These new lasers could presumably find many applications, including those currently filled by parametric oscillators, lead-salt diode lasers, etc. Spectroscopic evaluation[1] exposed Cr^{2+} as a prime laser candidate on account of its high luminescence quantum yield and the expectation that ESA would be absent. ZnSe and ZnS were host media that gave laser action in a confocal cavity when pumped with a ~1900 nm MgF_2:Co^{2+} laser;[2, 3] untuned operation centered around 2350 nm, the wavelength of maximum emission cross section. Three different doping methods (melt growth, seeded physical vapor transport, and diffusion doping) have produced ZnSe:Cr^{2+} crystals that lase. Use of an intracavity birefringent filter initially allowed tuning throughout the 2280 - 2530 nm range. Several development opportunities remained to be addressed, including construction of a diode-pumped laser system, extension of the laser's tuning range, and improvement of the laser material quality (and hence, the slope efficiency.)

Spectroscopic parameters (see Table I) have a decisive impact on the choice of laser design. ZnSe:Cr^{2+} has been referred to as "the Ti-sapphire of the mid-IR" on account of its similar electronic transition symmetry, short energy-storage lifetime (~9 µsec,) and broad emission linewidth (implying a wide tuning range of ~2000 - 3000 nm.) A salient difference is the much larger transition cross section, which, together with the longer fluorescence lifetime and smaller transition energy, combine to give a much smaller (by over two orders of magnitude) saturation intensity $I_{sat} = h\nu/\sigma\tau$ ~14 kW/cm^2. Generally, efficient laser operation mandates a pump intensity on the order of I_{sat}, although lower intensities also can work well in side-pumped configurations. The first ZnSe:Cr^{2+} laser demonstrations were conducted in an end-pumped geometry with a tightly-focused (~0.2 mm spot) MgF_2:Co^{2+} laser beam, for a peak pump intensity well over 100 kW/cm^2, so laser threshold was easily reached. Upon "radiance conditioning," available diode arrays for the preferred 1.8 µm pump wavelength deliver more modest intensities of only a few kW/cm^2, so the low I_{sat} value can be considered a crucial factor enabling efficient diode-pumped laser performance.

Our diode-pumped laser design (Figure 1) is based on that of a previously-reported diode-pumped Nd:YVO_4 laser.[4] The output of four microlensed 1.65 µm InGaAsP/InP diode bars is combined in a cylindrical lens and focused onto a ~0.2 mm stripe on a ZnSe:Cr slab, whose end-faces are AR-coated for 2.5 µm. The single bounce at the "TIR interface" allows the resonated beam to sample the high-gain pump face region, yet enter and exit the crystal without aperture losses. Output energy and beam quality depend on the bounce angle and penetration depth of the pump light.[4] The diode array, when operated at a low duty cycle with a 50 μsec pulsewidth, gave the slope data of Figure 2; a maximum diode power of 75 W was obtained, and an array-integrated slope of 0.795 W/A corresponding to a slope for each diode bar of ~0.2 W/A. Slope-efficiency data for the integrated laser using a series of flat output couplers are shown in Figure 3. (The pump-energy scale has been normalized by a factor of 0.06, roughly representing the fraction of the pump energy absorbed in one resonated-mode diameter. Our lightly-doped crystal had a 1.65 μm pump absorption coefficient of ~2.2 cm^{-1}, half the 1.8μm value of $\alpha_{max} \sim 4.4$ cm^{-1}.) Here the threshold energy increases substantially for output coupling values above 10%, reflecting a crystal passive loss estimated at $\alpha_{loss} \sim 15\%/cm$. The maximum peak output power of 0.34W was achieved with the 90% -reflecting output coupler. A "figure of merit" FOM $\equiv \alpha_{max}/\alpha_{loss}$ can be used to describe crystal quality; in this case, FOM ~ 27. Our crystal-growth efforts are aimed at raising the doping level and pump absorption without increasing the passive loss.

Grating-tuning experiments were done by replacing the cavity high-reflector with a 420 line/mm diffraction grating on a rotation stage, and using curved output couplers. The diode array was removed and a pump beam from a $MgF_2:Co^{2+}$ laser was focused onto the crystal using the same cylindrical lens. Output wavelengths were checked with a monochromator. According to Figure 4, the long-wavelength limit of operation was 2799 nm, most likely due to the decline in emission cross section (and gain.) The short-wavelength cutoff was 2134 nm; even though the emission cross section remains substantial, self-absorption inhibits laser operation.

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References

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		$Ti^{3+}:Al_2O_3$	$ZnSe:Cr^{2+}$
Transition		$^2E \rightarrow {}^2T_2$	$^5E \rightarrow {}^5T_2$
Upper-level lifetime	τ_{em} (μsec)	3	9
Peak fluorescence wavelength	λ_{max} (nm)	800	2300
Fluorescence linewidth (RT)	$\Delta\upsilon$ (cm^{-1})	4300	1700
	$\Delta\lambda$ (nm)	300	1000
Relative bandwidth	$\Delta\lambda/\lambda_{max}$	0.38	0.43
Peak pump cross- section	σ_{abs} (10^{-20} cm^2)	6.5	87
Pump saturation intensity	I_{sat} (kW/cm^2)	2000	14

Table 1. Spectroscopic properties of Ti^{3+} in Al_2O_3 and Cr^{2+} in II-VI hosts; the low I_{sat} value for the latter enables diode-pumped laser operation.

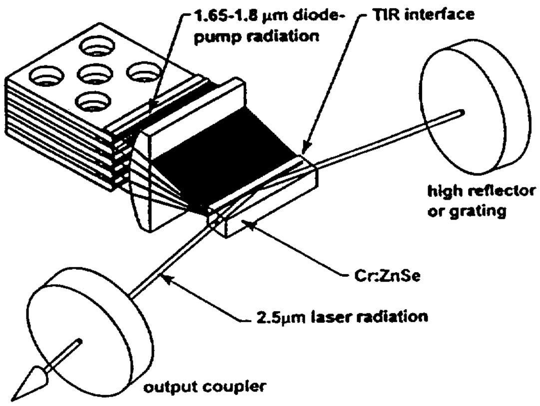

Fig. 1. Diode-side-pumped laser design, which facilitates integration of a ZnSe:Cr slab and a multiple-bar diode array.

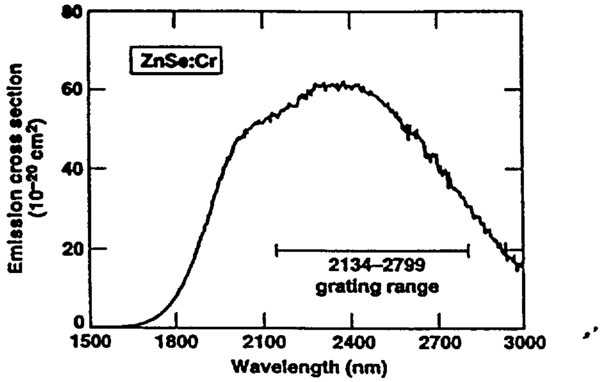

Fig. 4. Emission spectrum and tuning range demonstrated with $MgF_2:Co^{2+}$ laser pumping of ZnSe:Cr, tuned with a diffraction grating. Two different output couplers were used to obtain the indicated coverage.

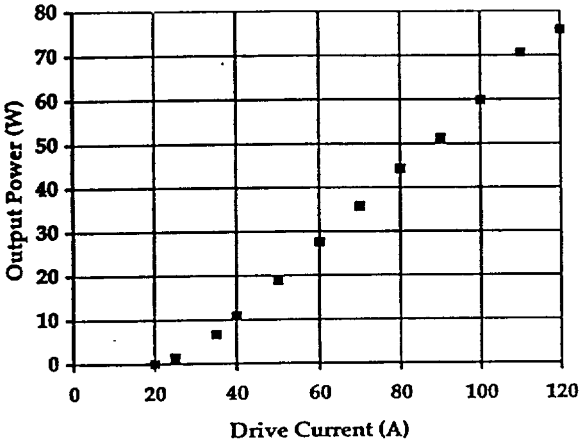

Fig. 2. Slope data for a 4-bar InGaAsP/InP pump array operating at 1.65 μm. The threshold and slope are respectively 24.4 A and 0.795 W/A.

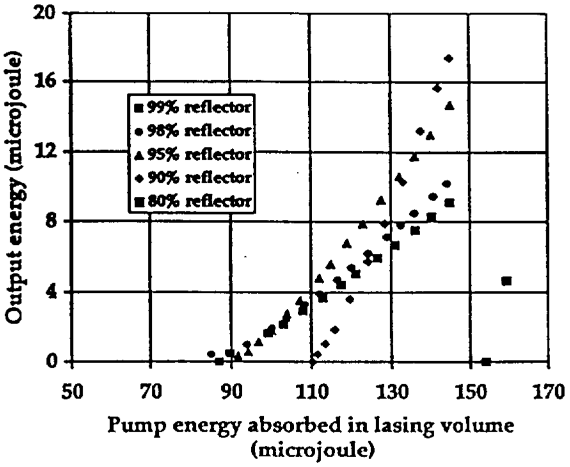

Fig. 3. Slope data for the diode-pumped ZnSe:Cr laser operating with several different flat output couplers. The pump-energy axis has been scaled to account for an estimated mode fill of 0.06.

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