InP diode-pumped Cr:ZnS and Cr:ZnSe highly-efficient, widely-tunable, mid-IR lasers

Igor S. Moskalev[a], Vladimir V. Fedorov[b], and Sergey B. Mirov[*a,b]

[a]Center for Optical Sensors and Spectroscopies and the Department of Physics, University of Alabama at Birmingham, CH 310, 1300 University Blvd., Birmingham, AL 35294, USA;
[b]Photonics Innovations, Inc, 1500 1st Ave N, Unit 39, Birmingham, AL 35203-9642,USA

ABSTRACT

We present compact, highly-efficient, widely-tunable CW lasers based on Cr^{2+}:ZnS and Cr^{2+}:ZnSe gain media longitudinally pumped by a single-emitter, 1.5 W, 1685 nm InP semiconductor laser. The Cr^{2+}:ZnSe laser demonstrates 35% slope, and 24% real optical efficiency, respectively, up to 400 mW of output power, and is tunable from 2200 to 2700 nm. The Cr^{2+}:ZnS laser shows 44% slope, and 31% real optical efficiency, respectively, up to 500 mW of output power, and is tunable over 2100-2700 nm. The single-emitter diode pumping of chromium-doped chalcogenides allows for fabrication of middle-infrared tunable laser sources where low- or mid-range output powers are sufficient, while low footprint and miniature packaging are strictly required. In our presentation we will discuss the laser design issues specific to diode pumping, demonstrate the performance of the Cr:ZnS and Cr:ZnSe laser systems with different transmissions of the output couplers, describe several approaches for convenient wavelength tuning, and perform a comparison of diode pumping efficiency to that of fiber-laser pumping.

Keywords: Cr:ZnSe, Cr:ZnSe, middle infrared laser, solid-state laser, tunable laser

1. INTRODUCTION

Significant progress in fabrication of high-quality transition metal doped II-VI semiconductor gain media (TM:II-VI) [1] has recently resulted in demonstration of record output powers and wavelength tuning ranges for the middle-infrared solid-state laser systems, which operate within the molecular fingerprint spectral interval of 2-3 µm [2-5]. Traditionally, Cr^{2+}:ZnSe and Cr^{2+}:ZnS laser systems were pumped with 1.5-1.9 µm fiber lasers due to their exceptionally good output characteristics such as: extremely high beam quality (M^2<1.05), practically unlimited output power (e.g., up to 1 kW is commercially available from IPG Photonics), very high reliability, great portability, and high cost-efficiency. Due to their inherent properties, the Er/Tm-fiber lasers are unbeatable pump sources for Cr^{2+}:ZnS/ZnSe gain media when one considers high mid-IR output powers, ultranarrow output linewidths, and widest wavelength tenability ranges. There is, however, a narrow range of applications where low output powers (tens of milliwats) and narrow tuning ranges are sufficient, while compactness and highest possible wall-plug efficiencies of mid-IR laser sources are vital. Until the direct electrical pumping of TM:II-VI semiconductors [6] is practically demonstrated, such applications can greatly benefit from compact, integrated mid-IR laser sources based on diode-pumped TM:II-VI gain media [7]. In this work we demonstrate our first prototypes of mid-power, tunable Cr^{2+}:ZnS and Cr^{2+}:ZnSe lasers, longitudinally pumped with a collimated 1.5 W, 1685 nm semiconductor laser. We show our first results on the performance of these laser systems in terms of power efficiency and wavelength tuning ranges, discuss further steps for building an ultra-compact integrated laser sources of this type, and make a comparison to the fiber laser pump sources.

2. EXPERIMENTAL SETUP

A schematic diagram of the experimental setup is shown in Fig. 1. The laser is based on a simplest linear configuration of the laser resonator with flat input/output couplers and an AR-coated an intracavity lens. The laser consists of: (1) flat input mirror AR-coated for 1500-1900 nm, and HR-coated for 2100-2600 nm wavelength ranges, respectively; (2) plane-parallel Cr^{2+}:ZnS/ZnSe slab gain element, AR-coated for 1500-2800 nm; (3) CaF_2 intracavity lens, AR-coated for 2000-3000 nm spectral range; (4) flat output coupler with or diffraction grating in Littrow configuration. The parameters of the resonator were found experimentally to be the most efficient for this particular laser configuration. The Cr^{2+}:ZnS/ZnSe laser is pumped by a 1.5 W 1685 nm diode laser with a collimated output beam (purchased from AKELA Laser Corporation). The output beam of the diode laser has the output dimensions of 5×3 mm and divergences of 3×0.3 mrad (horizontal×vertical, respectively). It must be mentioned here that one must arrange much tighter pump focusing of the diode laser pump beam than the fiber-laser pump beam. For this particular laser system, shown schematically in Fig. 1, a pump lens with focal length of 15 mm was required for the diode pump laser to obtain thresholds and efficiencies comparable to fiber laser pump beam of 1.6 mm diameter focused into the gain element with a 40 mm pump lens. The tighter focusing of diode laser beam is required because it emits a non-symmetrical, non TEM_{00} beam with relatively low beam quality. This also leads to a poorer mode-matching as in comparison to the fiber laser beam, further reducing pump power laser efficiency.

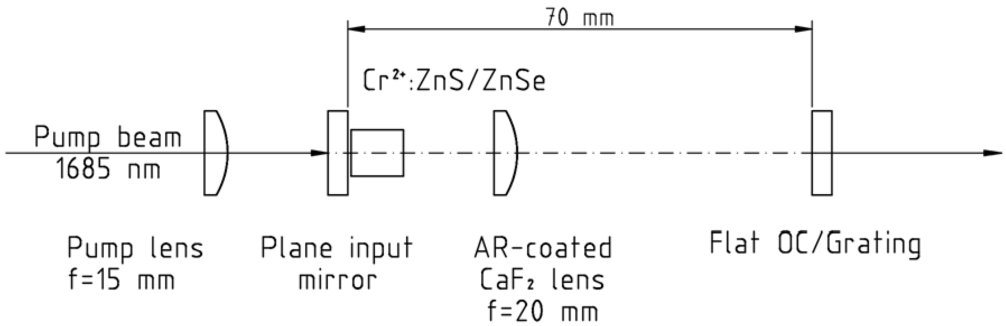

Fig. 1. Schematic diagram of the experimental setup. For the wavelength tuning experiments the output coupler is replaced with a 600 g/mm Littrow grating which has the first order diffraction efficiency of about 90% within the spectral range of 2300-2600 nm.

3. EXPERIMENTAL RESULTS

Two sets of experiments have been performed with each gain material (Cr^{2+}:ZnSe and Cr^{2+}:ZnS): (1) measurements of input-output characteristics with several output couplers; (2) investigation of wavelength tuning ranges using a simple Littrow grating arrangement. The input-output characteristics of the laser systems are demonstrated in Fig. 2, where the dependencies of output power on the incident pump power for different transmissions of OC are shown for each laser system. One can see from the figures that Cr^{2+}:ZnSe laser demonstrates the maximum output power of 370 mW at ~1.55 W of incident pump power and a slope efficiency of ~34% with the optimal OC transmission of ~27%. The Cr^{2+}:ZnS laser demonstrates a significantly better performance under the same conditions, emitting the maximum of 480 mW at 1.55 W pump with slope efficiency of 44%.

The wavelength tuning curves of these laser systems are shown superimposed in Fig. 3, where the measured output power vs measured output wavelength are demonstrated for each laser system. One can see that the Cr^{2+}:ZnS laser outperforms its Cr^{2+}:ZnSe counterpart in the wavelength tuning range as well as in the maximum output power: the tuning range of the Cr^{2+}:ZnSe laser spans 2200-2700 nm with the maximum output power of ~120 mW near 2450 nm, while Cr^{2+}:ZnS laser is tunable over 2100-2700 nm spectral range with the maximum of 320 mW near 2400 nm. The tuning range of the Cr^{2+}:ZnS laser almost coincides with the bandwidth of the HR coating of the input mirror, while the Cr^{2+}:ZnSe laser doesn't reach the lasing threshold bellow 2200 nm. In both cases the measured output linewidth was less than 1 nm FWHM within the entire tuning range.

There are several reasons why the Cr^{2+}:ZnS laser systems performs much better than the Cr^{2+}:ZnSe laser in our arrangement. First of all, the emission wavelength of the pump diode is 1685 nm, which is practically at the maximum of absorption curve of Cr^{2+}:ZnS gain media. Secondly, the Cr^{2+}:ZnS gain element has about 1.65 times higher Cr^{2+} concentration that the Cr^{2+}:ZnSe gain element used in the experiments. As a result of these two factors more pump power is absorbed by the Cr^{2+}:ZnS gain crystal than by the Cr^{2+}:ZnSe gain element and we observe higher overall efficiency on the incident pump for the Cr^{2+}:ZnS laser system. Undoubtedly, more careful design of the Cr^{2+}:ZnSe gain element will allow one to obtain similar output characteristics as for the Cr^{2+}:ZnS diode pumped laser.

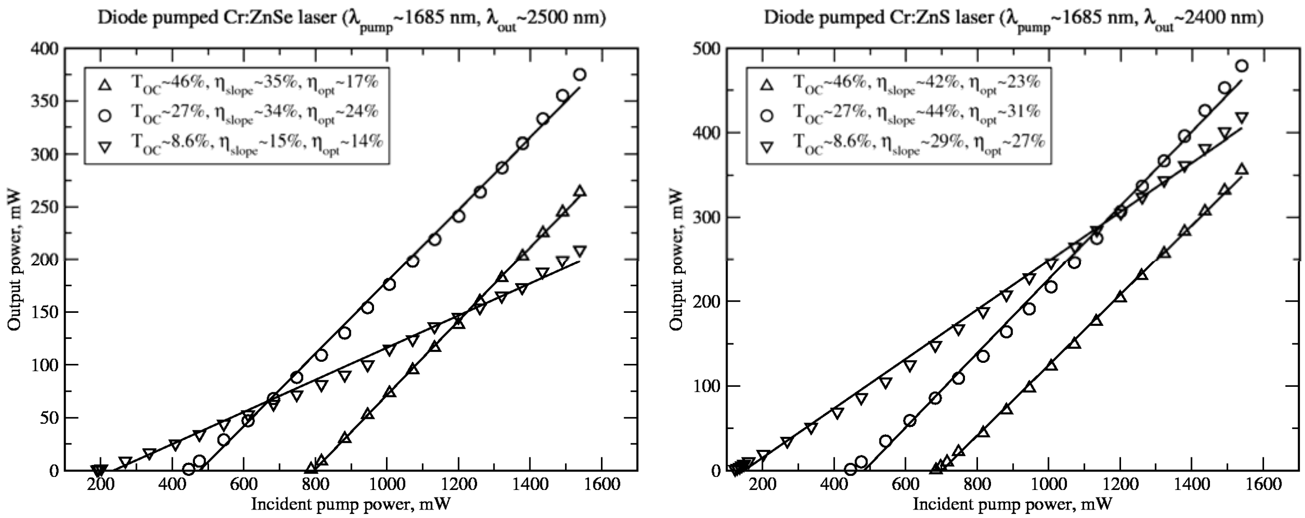

Fig. 2. Input-Output characteristics of the diode pumped Cr^{2+}:ZnSe (left graph) and Cr^{2+}:ZnS (right graph) lasers for different transmissions of output couplers.

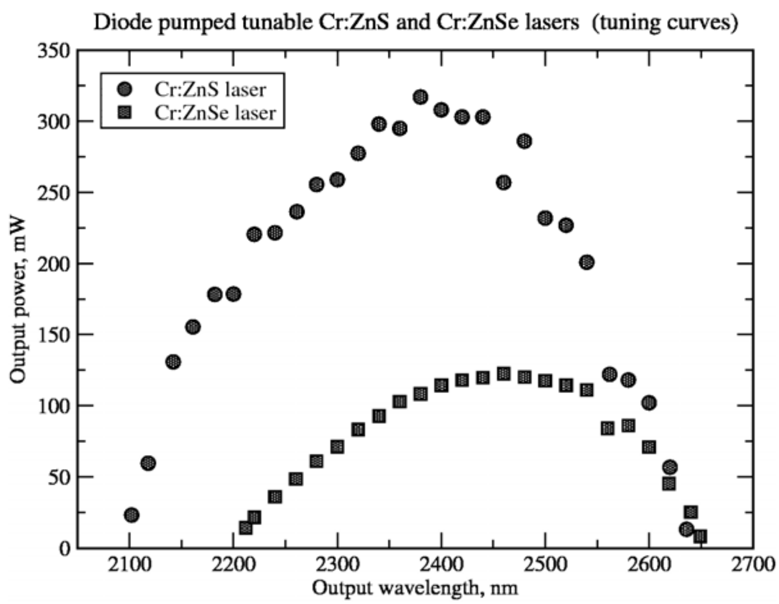

Fig. 3. Tuning curves of the diode pumped Cr^{2+}:ZnSe (square symbols) and Cr^{2+}:ZnS (circle symbols) lasers. Measured output power vs measured output wavelength dependencies are shown for each laser system.

4. CONCLUSIONS

We have demonstrated mid-power, tunable Cr^{2+}:ZnSe and Cr^{2+}:ZnSe lasers longitudinally pumped by a InP 1.5 W semiconductor collimated laser. We obtained up 370 mW of output power at 2500 nm with slope efficiency of 35% for the Cr^{2+}:ZnSe laser, and up to 480 mW output power with 44% slope efficiency for Cr^{2+}:ZnS laser. We also demonstrated 2100-2700 nm and 2200-2700 nm wavelength tuning ranges for the Cr^{2+}:ZnS and Cr^{2+}:ZnSe lasers, respectively.

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