Broadly tunable, longitudinally diode-pumped Alexandrite laser

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ABSTRACT

We present design and first performance data of a broadly tunable Alexandrite laser longitudinally pumped by a newly developed high brightness single emitter diode laser module with output in the red spectral range. Replacing the flashlamps, which are usually used for pumping Alexandrite, will increase the efficiency and maintenance interval of the laser. The pump module is designed as an optical stack of seven single-emitter laser diodes. We selected an opto-mechanical concept for the tight overlay of the radiation using a minimal number of optical components for collimation, e.g. a FAC and a SAC lens, and focusing. The module provides optical output power of more than 14 W (peak pulse output in the focus) with a beam quality of $M^2 = 41$ in the fast axis and $M^2 = 39$ in the slow axis. The Alexandrite crystal is pumped from one end at a repetition rate of 35 Hz and 200µs long pump pulses. The temperature of the laser crystal can be tuned to between 30 °C and 190 °C using a thermostat. The diode-pumped Alexandrite laser reaches a maximum optical-optical efficiency of 20 % and a slope efficiency of more than 30 % in fundamental-mode operation ($M^2 < 1.10$). When a Findlay-Clay analysis with four different output couplers is conducted, the round-trip loss of the cavity is determined to be around 1 %. The wavelength is tunable to between 755 and 788 nm via crystal temperature or between 745 and 805 nm via an additional Brewster prism.

Keywords: Alexandrite lasers, tunable lasers, lidar

1. INTRODUCTION

The knowledge of temperature distributions in the atmosphere at altitudes between 80 and 110 km is important to validate numerical simulations of the Earth's climate. One approach to provide such data is to measure the Doppler width of the potassium resonance line at 770 nm and of the iron resonance line at 386 nm by means of resonance lidar systems [1, 2]. In such systems flashlamp-pumped Alexandrite ring lasers in Q-switched single-frequency mode are used as laser emitters. Typical operational conditions of the laser may include measurements on board a research ship in rough seas or under polar conditions in the Antarctic (Fig. 1). Due to harsh environmental conditions and the laser's remote operating locations, it would be very helpful to extend maintenance-free operating times and optimize the wall-plug efficiency of the Alexandrite lasers.

a) b)

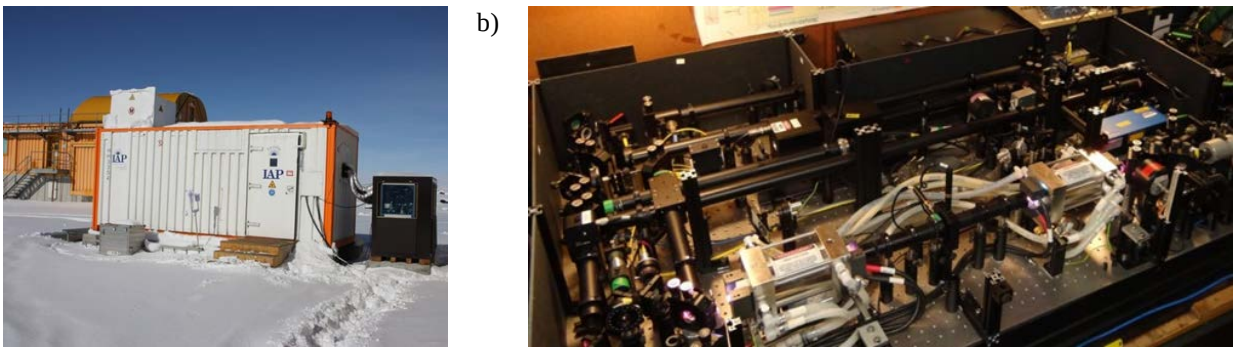

Figure 1. Mobile iron Doppler lidar (Leibniz IAP) for temperature profiling in the Antarctic Mesopause region (about 80 – 110 km): a) Antarctic measuring station. b) Flashlamp-pumped alexandrite laser as lidar transmitter.

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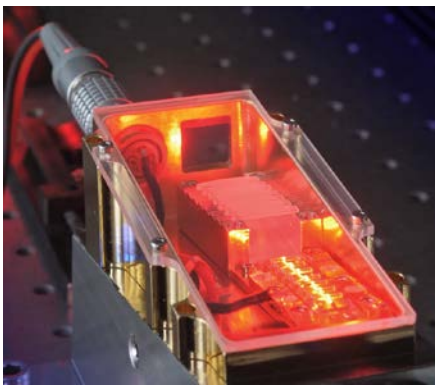
The storage time of the upper laser level in Alexandrite is about 260µs at room temperature, which is long compared to other tunable solid state laser media in this spectral range, like Ti:Sapphire (τ_f = 3.2 µs), and in the same order as for Nd:YAG. Therefore, replacing the flashlamp pumps by diode lasers seems to be a promising approach to reach these aims [3]. However, very little progress has been made in the field of longitudinally, diode-pumped Alexandrite lasers since early investigations in 1990 [4, 5]. While single emitter laser diodes with high brightness and competitive life time have recently been developed, the main limitation of this approach is the availability of diode lasers with sufficient power in the red spectral range (6XX nm). To overcome this shortage, a new pump module design based on single emitter laser diodes has been developed [6] and tested for longitudinal pumping of a broadly tunable Alexandrite laser [7].

2. SINGLE EMITTER PUMP MODULE

The pump module is designed as an optical stack of seven single-emitter laser diodes. The emitters are stacked staircase-shaped in the vertical direction, i.e. the fast axis (FA) on a common heat sink. A fast-axis collimation (FAC) lens for each emitter is mounted on the heat sink and a slow-axis collimation (SAC) lens is mounted on a staircase-shaped lens holder. No additional reflective elements, (e.g. step mirrors made of copper) which usually limit the wavelength region and the efficiency of the design, are necessary. In order to ensure a minimal spectral width, an even temperature among the emitters is required. To this end, the bottom side of the heat sink is inclined by about 10° with respect to the optical axis (Fig. 2a).

a)



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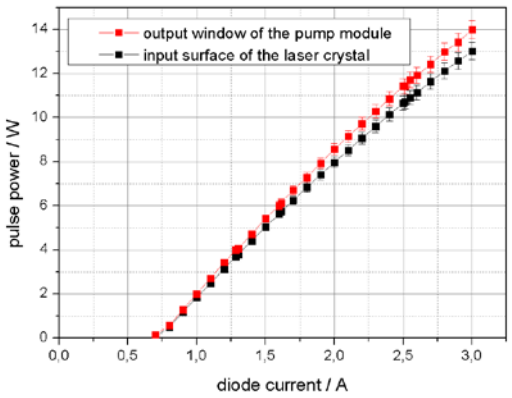
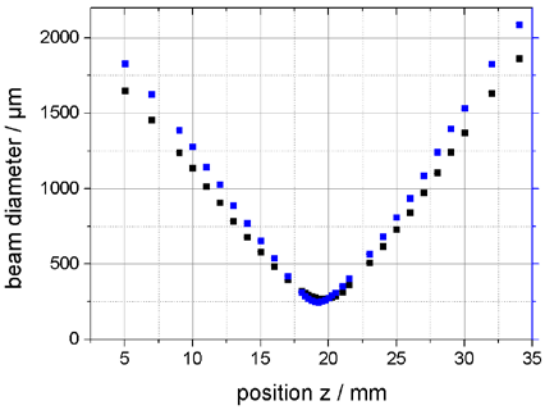


Figure 2. Design and performance of the diode laser: a) Photograph of the diode pump module. b) Current-power characteristic at 35 Hz operation.

a)



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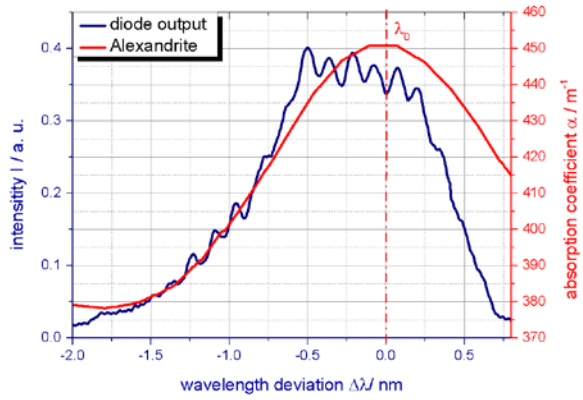

Figure 3. Diode laser output characteristics at 35 Hz operation: a) Beam propagation with M^2 = 41 in fast axis and M^2 = 39 in slow axis. b) Spectral distribution of the pump laser output and spectral overlap with the side peak of the Alexandrite absorption at λ_0.

A diode laser module with an optical output power of more than 14 W (peak pulse output in the focus) was set up. The characterization of the module was carried out at a repetition rate of 35 Hz corresponding to the working point of the projected new diode-pumped Alexandrite laser and of an existing system at Leibniz Institute of Atmospheric Physics (IAP). The beam quality is M^2 = 41 in the fast axis and M^2 = 39 in the slow axis (Figure 3a). The spectral width at 2.2 nm corresponds to the statistical dispersion of the individual emitters (Figure 36). 96.5 % of the output power is linearly polarized.

3. LASER RESULTS

3.1 Experimental setups

Three different cavity configurations were set up to investigate the characteristics of the diode-pumped Alexandrite laser.

The first configuration (Fig. 4a) was used for fundamental investigations of the laser performance, including measurements of the output energy and efficiency as well as the spectral, spatial and temporal properties of the generated laser radiation for different pumping levels and different temperatures of the laser medium. This basic setup comprises three mirrors: a plane output coupler, a plane, dichroic folding mirror with high transmission for the pump light and a curved highly reflective end mirror. The overall length of the folded V-shaped cavity is 190 mm.

In the second configuration (Fig. 4b) the cavity length is doubled. Here, the curved mirror is used as a folding mirror forming a Z-shape configuration which allows integration of a Brewster prism and a tuning mirror in the new arm of the resonator. This allows for tuning the output wavelength not only by means of the crystal temperature, but also by tilting the tuning mirror.

The third configuration (Fig. 4c) is similar to the second one, but the Brewster prism is replaced by a thin-film polarizer and a retardation plate. With an additional Pockels cell placed inside the resonator, this design will allow for Q-switching.

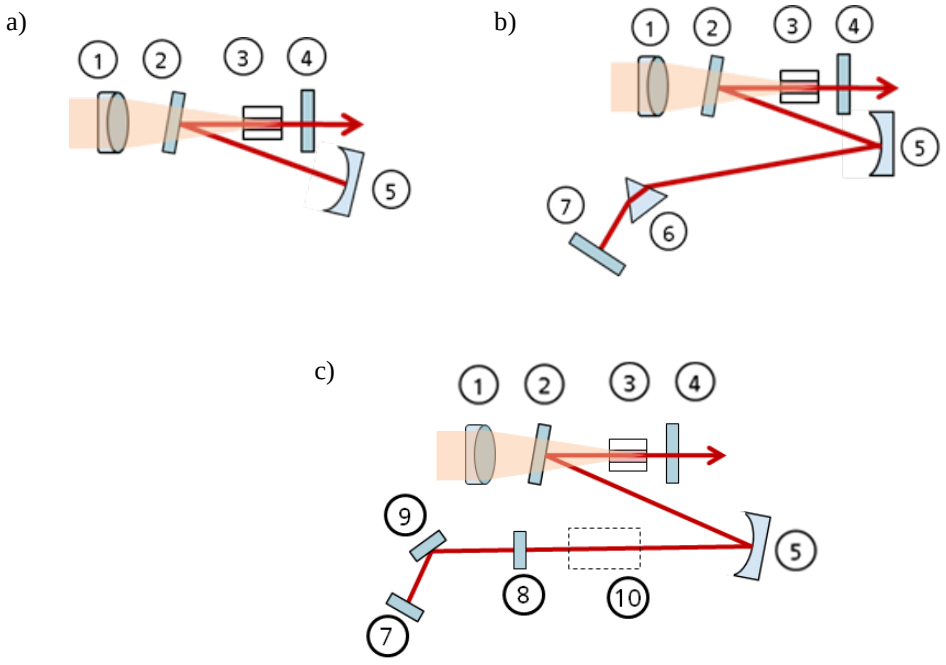

Figure 4. Setups of the longitudinally pumped Alexandrite lasers: a) Basic cavity (V-shaped): (1) Pump optics, (2) pump mirror, (3) Alexandrite crystal with temperature control, (4) output coupler and (5) curved HR mirror. b) Prism cavity (z-shaped): With tunable cavity configuration, comprising the additional parts (6) Brewster prism and (7) tuning mirror. c) z-shaped Cavity for later Q-switching: (8) λ/2-waveplate, (9) TFP, (10) Position to place the Pockels cell. Components (1) to (5) in figure 4b) and 4c) are similar to figure 4a).

The diode module described above is used as pump source, providing 200µs long laser pulses. All setups utilize a 15 mm long Alexandrite crystal as laser medium wherein more than 98 % of the pump light is absorbed. The temperature of the laser crystal can be tuned to between 30 °C and 190 °C using a thermostat.

3.2 Investigation of basic performance parameters

Basic performance testing of the diode-pumped laser operation is conducted with the shorter resonator (the V-shaped cavity from Figure 4a). The round-trip loss is determined to be around 1 % by a Findlay-Clay analysis of this setup with four different output couplers (R = 95.3 %, 97.4 %, 98.1 % and 99.2 %) (Fig. 5a).

When the output coupler with a reflectivity of 98.1 % is used, the laser performance has been investigated for different temperatures of the laser crystal (Fig. 5b). The highest pulse energy has been achieved in a temperature range between 70°C and 85°C with maximum optical-optical efficiency of 17.8 % and a slope efficiency of more than 30 % in fundamental-mode operation ($M^2 < 1.10$, Fig. 6a).

In free-running operation the temporal output characteristics of the Alexandrite lasers do not reach steady state operation during the pump pulse length, neither with the short (Fig. 6b) nor with the longer cavity, but show clear spiking.

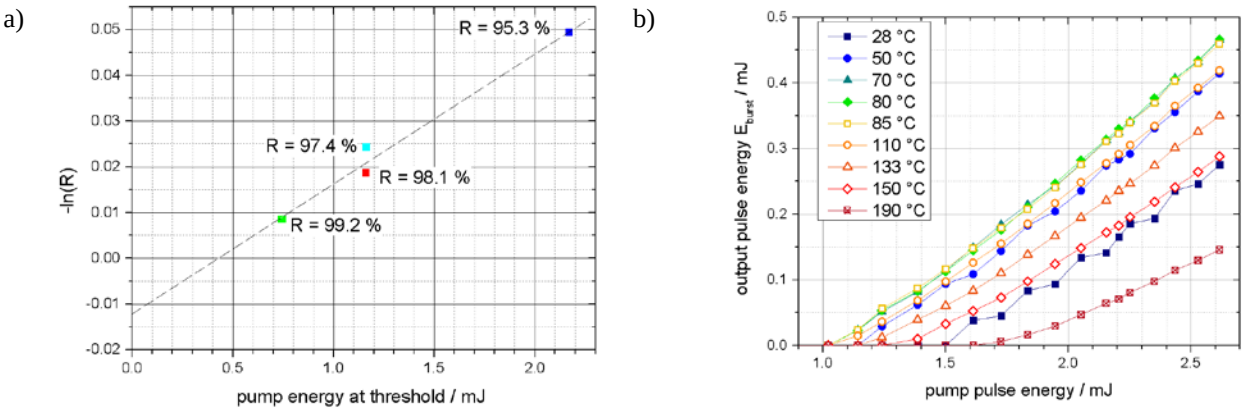

Figure 5. Experimental results measured with the shorter cavity (see Figure 4a): a) Findlay-Clay analysis. b) Energy of the Alexandrite laser output pulse burst vs. pump pulse energy for different crystal temperatures.

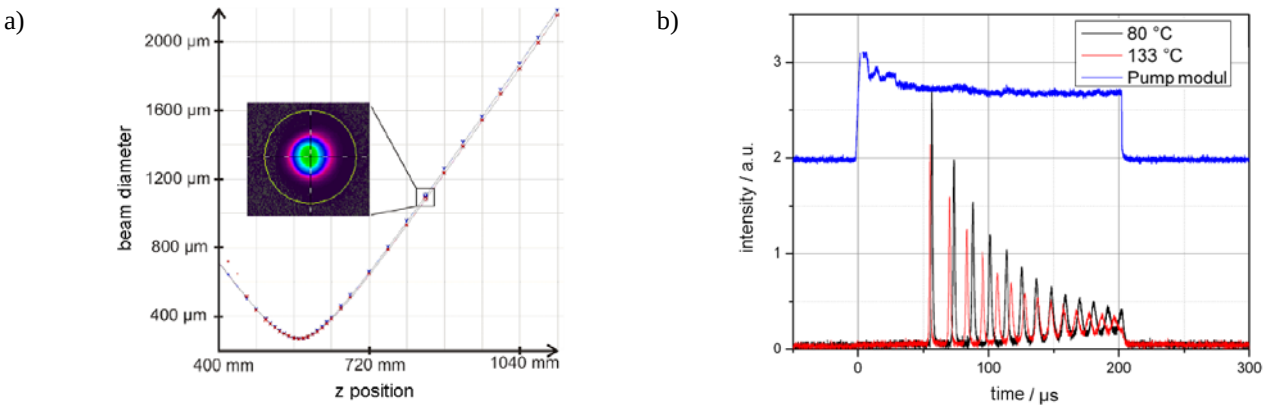

Figure 6. Experimental results measured with the basic laser setup (see Figure 4a): a) Caustic at 763nm and maximum output power. b) Dynamics of the Alexandrite laser at different crystal temperatures.

3.2 Wavelength tuning

For the V-shaped laser resonator without a prism or similar wavelength selective optical element implemented, the laser output shifts to longer wavelengths with rising crystal temperatures due to an increase of the thermal population of the lower laser level. The output wavelength of this setup can be tuned to between 755 nm and 788 nm. Output energy of the pulse burst and laser wavelength as a function of the crystal temperature are shown in Fig. 7a.

With the second cavity configuration (Fig. 4b) the laser wavelength can be tuned by tilting the tuning mirror (7) in the prism arm of the resonator. This allows for optimizing the output energy and output wavelength independently. The tuning characteristic of this setup is shown in Fig. 7b; it includes output energy and optimum crystal temperature with addressable wavelengths from 745 to 805 nm.

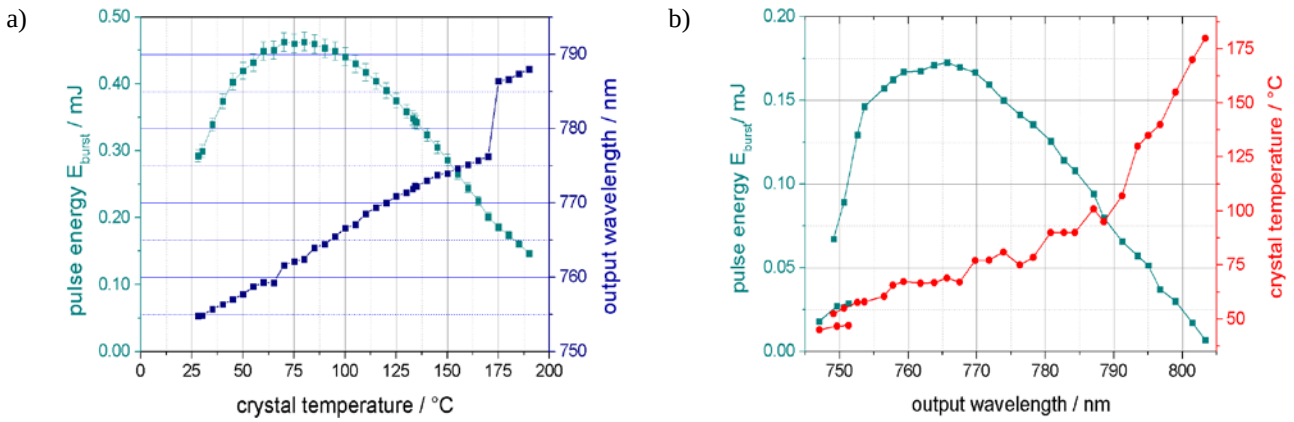

Figure 7. Investigation of the tunability: a) Of the basic setup (see Fig. 4a): Output energy of the pulse burst and output wavelength at different crystal temperatures. b) Of the second setup (Fig. 4b): Output energy of the pulse burst and optimum crystal temperature for different output wavelengths.

3.3 Improved Operation at 772nm

Finally, we investigated the performance of the diode-pumped laser with the z-shaped cavity optimized for future Q-switching at 772 nm (Fig. 4c), i.e. the fundamental of the resonance wavelength of iron at 386 nm.

The energetic and spectral properties of the laser radiation were measured for different levels of pump-pulse energy between 0.9 and 2.8 mJ (Fig. 8). With this setup the efficiency and energy of the output pulses are comparable to the best

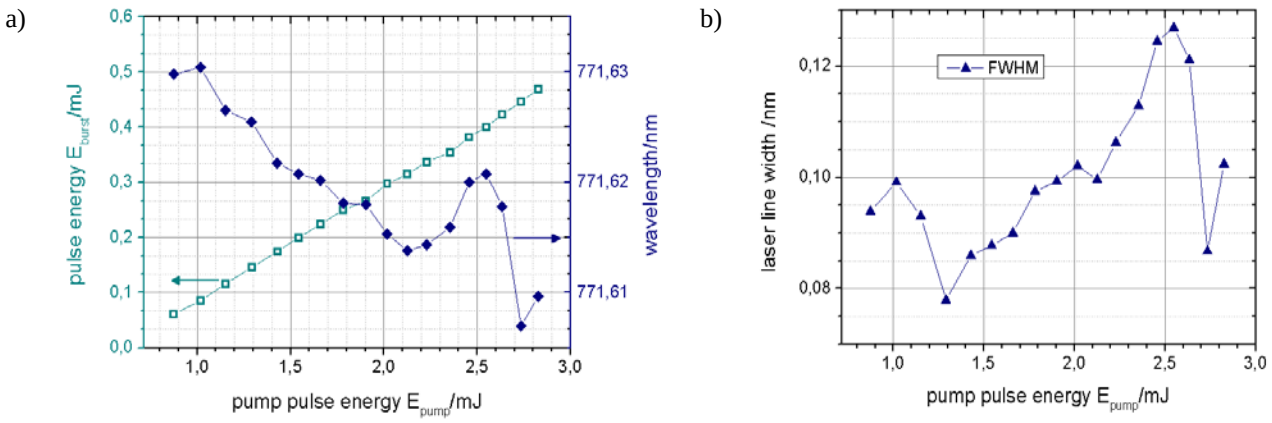

Figure 8. Laser performance with the cavity configuration according to Fig. 4c: a) Pulse energy and center wavelength vs. pump pulse energy and b) laser linewidth.

results obtained with the short and less complex V-cavity (Fig. 4a). At a higher pump level a maximum pulse energy of 620 µJ was measured with an optical-to-optical efficiency of 20%.

The full width at half maximum of the laser line is about 100 pm; the changes do not show a clear correlation to variations of the pump power. The center wavelength is about 771.6 nm and varies less than 25 pm for a pump pulse energy between 0.9 mJ and 2.8 mJ.

The measurement shows that it should be possible to lock the laser output to the resonance of the iron line by means of a single-frequency seed laser without adding spectral filters into the cavity, which would increase the roundtrip losses.

4. SUMMARY AND OUTLOOK

The results presented here demonstrate the feasibility of a longitudinally diode-pumped Alexandrite laser oscillator with output parameters relevant to many spectroscopic applications. Additionally, the investigation provides initial insight into the right choice of meaningful design parameters to obtain optimum performance of a diode-pumped Alexandrite laser for mobile resonance lidar systems.

More knowledge on the detailed design of such a laser will be gained after demonstrating Q-switch and single frequency operation of this laser in the future. Subsequent experiments will also address the issue of power and energy scaling of the Alexandrite laser by increasing the pulse repetition rate, the number of pump modules and laser crystals inside the oscillator and by means of MOPA configuration.

REFERENCES

[1] J. Hoeffner und C. Fricke-Begemann: “Accurate lidar temperatures with narrowband filters”. Opt. Lett., 30(8), 890-892, 2005.

[2] J. Lautenbach, J. Hoeffner, P. Menzel, P. Keller: “The new scanning iron lidar, current state and future developments”. Sandefjord05, 327-329, 2005.

[3] M. Damzen: “Diode-pumped Alexandrite laser: a bright prospect for future space Lidar missions”. SPIE 8534-43, Technical Abstracts, 2012.

[4] R. Scheps, B. M. Gately, J. F. Myers, J. S. Krasinski und D. F. Heller, “Alexandrite laser pumped by semiconductor lasers,“ Appl. Phys. Lett., 56-23, 2288-2290, 1990.

[5] R. Scheps und J. F. Myers: “Monochromatic end-pumped operation of an alexandrite laser”. Optics Communications, Bd. 97, Nr. 5-6, p. 363-366, 1993.

[6] U. Witte, S. Hengesbach, M. Traub, M. Strotkamp, B. Jungbluth and D. Hoffmann: “High Brightness Diode Laser Module in the Red Spectral Range for Pumping Applications”. IEEE, High Power Diode Lasers and Systems Conference (HPD), 2013

[7] M. Strotkamp, U. Witte, A. Munk, A. Hartung, S. Gausmann, S. Hengesbach, M. Traub, J. Hoeffner, B. Jungbluth. ”Broadly tunable, diode pumped Alexandrite laser”. Advanced Solid State Lasers (ASSL) Congress 2013, Paper: ATu3A.42. 2013.