

Diode-pumped, Q-switched Alexandrite laser as emitter for general purpose atmospheric Lidar systems

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Abstract: We present design and performance of four prototypes of narrow-bandwidth emitters based on diode-pumped Alexandrite lasers for atmospheric Doppler-Mie, -Rayleigh and -resonance lidar systems. Furthermore, lab results for efficient frequency-doubling into the UV are presented.

Collecting wind velocity and temperature distribution data in the atmosphere at altitudes > 5 km is crucial for developing and enhancing detailed atmospheric models. Lidar systems capable of monitoring these parameters have become increasingly important, especially following the successful AEOLUS mission, which profiles Earth's wind from space. Different scattering processes can be used to obtain such data: Doppler-Mie (aerosols: < 25 km), -Rayleigh (air molecules: 25-80 km) and -resonance (metal atoms: 80-120 km) scattering. With a suitable laser emitter, it is possible to use a single lidar instrument like VAHCOLI, which combines the mentioned scattering mechanisms [1]. For a compact and portable lidar system with high accuracy, a beam source with high electro-optical efficiency is needed. Additionally, the laser beam source must have a very narrow bandwidth (< 10 MHz) to effectively separate the Mie and Rayleigh signals. During the last ten years, the Leibniz Institute of Atmospheric Physics (IAP) and the Fraunhofer Institute for Laser Technology (ILT) have developed a technology for a compact multi-frequency Doppler lidar instrument that occupies a volume of only 1 m^3 . The key component of this system is a diode-pumped Alexandrite laser that emits at the potassium resonance line (770 nm), with a bandwidth of ~ 3 MHz and a pulse energy of up to 3.2 mJ and average power of 2.4 W [2].

For enhanced daylight operation and Rayleigh signal, the iron resonance wavelength in the UV is preferable, allowing for superior performance over the current wind lidar technology like AEOLUS. By an adaption of the laser concept without changing the basic characteristics, one benefits from the heritage of the IR lasers and the wide continuous tuning range of Alexandrite (700-800 nm). Following that approach an intra-cavity frequency-doubled Q-switched diode-pumped Alexandrite laser directly emitting in the UV at 386 nm is presented [3].

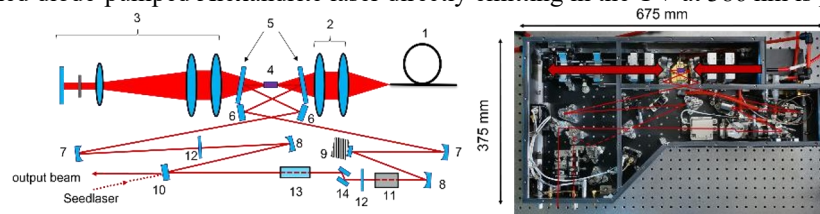


Figure 1: left: Schematic setup of the ring cavity with numbered cavity elements: optical fiber guiding the pump light (1), pump light collimation and focusing lenses (2), pump light back-folding unit (3), Alexandrite crystal (4), flat, dichroitic pumping mirrors (5), flat folding mirrors (6), curved mirrors ROC=1500mm (7), curved mirrors ROC=1200mm (8), flat folding mirror on piezo actor for stabilization of the cavity length (9), flat output coupler (10), Faraday rotator (11), half-waveplates (12), Q-switch (13), and thin-film polarizer (14). right: IR laser prototype without cover

A schematic setup and photo of the laser are shown in Figure 1. It contains one Alexandrite crystal that is end-pumped by a fiber-coupled laser diode module (@ 638 nm). As the absorption of the pump light is strongly polarization-dependent and the pump light is unpolarized, a pump light back-folding unit is used. A symmetric ring resonator, to avoid spatial hole burning, with a total length of 2 m is designed. The resonator mode size is matched to the pump diameter of $800 \mu\text{m}$ in the laser crystal and twice as large on the internal optical components. A Faraday rotator, two waveplates and TFPs guarantee unidirectional laser emission and an AOM is used for Q-switching. SLM operation is achieved by injection seeding with a narrow-bandwidth cw diode laser and an advanced cavity-control technique. Four rugged mobile Alexandrite laser prototypes operating at the resonance line of potassium (770 nm) were built and implemented in mobile lidar systems with a volume of $\sim 1 \text{ m}^3$ [2–4]. The laser beam source is housed in a closed but not air-tight enclosure.

For intra-cavity frequency doubling, the LBO crystal is placed between the AOM and the output coupling mirror. The output coupling mirror for the fundamental light in the IR ($R@770 \text{ nm} = 97\%$) is replaced by a mirror, highly reflective for the IR-light and highly transmissive for the frequency doubled light in the UV. Thus, the output coupling transmissivity of the resonator is given by the conversion efficiency while there is no other output coupling for the fundamental wavelength. The output coupling transmissivity of 3% for the IR laser is therefore the designated conversion efficiency for intra-cavity SHG. Such a low conversion efficiency is easy to achieve even with low pulse energies, large beam diameters, and short conventional nonlinear crystals. The experiments for the UV laser are conducted in the lab with a setup that is not housed and thereby, air turbulences from flow

boxes cause higher energy jitter and disturbance during cavity-controlled operation. The UV laser is currently operated with a repetition rate of 500 Hz and yields 3.0 mJ pulse energy in the UV with a pump pulse energy of 33 mJ, resulting in an optical-to-optical efficiency of 9.1 %. The efficiency is almost unchanged compared to the same laser without the LBO crystal (opt.-opt. eff. = 9.4%) emitting in the IR. The beam quality in x- and y-directions are consistently excellent with $M^2 = 1.1$. Measurements in seeded and unseeded operation are shown in [3]. The unseeded spectrum has a linewidth of 0.2 nm, and the seeded spectrum is < 20 pm, which is the limit of the spectrometer in the UV spectral region. The exact linewidth will be measured next with a matched narrow-bandwidth confocal etalon for this wavelength. These measurements require a high spectral stability of the laser emission which can only be achieved with an enclosed laser system that is not disturbed by air movement. For that a housed prototype operating in the UV at a resonance line of iron (@386 nm) will be built and integrated into an adapted lidar system.

The measured output parameters for the latest prototype operating in the IR and the laboratory setup operating in the UV are summarized in Table 1, additional information can be found in [2] and [3].

Table 1. Performance of the Alexandrite lasers

Parameter	latest IR prototype	UV lab setup
Wavelength	770 nm	386 nm
Pulse energy	3.2 mJ	3.0 mJ
Repetition rate	750 Hz	500 Hz
Average power	2.4 W	1.5 W
Energy stability (rms)	0.2 %	1 %
Pump energy	32.9 mJ	33 mJ
e-o efficiency	2.1 %	2.0 %
M^2 (x/y)	1.1/1.1	1.1/1.1
Pulse length	1040 ns	920 ns
Spectral bandwidth	~ 3 MHz	$\ll 20$ pm

Several measurement campaigns from summer 2022 to spring 2023 were conducted. To enhance the capabilities for monitoring dynamical phenomena in the atmosphere, the lidar system can be reconfigured with up to five telescopes to get a lidar system with several fields of view. First experiments with such a lidar system are shown in [5]. The technology transfer of the lidar instrument operating in the IR to a consortium of SMEs is prepared in the frame of the BMBF-funded Rubin project LidarCUBE (ID: 03RU2U08D). Based on the demonstrated UV laser design, rugged prototypes will be built to be integrated in novel general purpose lidar systems with multiple fields of view, currently also under development in the EU-funded project EULIAA (grant ID: 101086317). These lidar systems will be used to demonstrate the potential of a lidar array for simultaneous measurements with an extensive field campaign at different locations throughout Europe [6]. The technology is also advantageous for spaceborne lidar missions such as follow-on of AEOLUS [7] and is in line with the technology platform for spaceborne lasers developed by Fraunhofer ILT for the Merlin Mission [8].

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