Control of the alexandrite lasing spectrum

A G Putilov1,2, A A Antipov 1,2, A E Shepelev1,3, A A Lotin1, S M Arakelyan2

1ILIT RAS — Branch of FSRC “Crystallography and Photonics” RAS, 1 Svyatoozerskaya, Shatura, 140700, Moscow region, Russia
2Vladimir State University named after A. G. and N. G. Stoletovs, 87 Gorky, Vladimir, 600000, Russia
3Kovrov State Technological Academy named after V.A. Degtyarev, 19 Mayakovsky, Kovrov, 601910, Vladimir region, Russia

E-mail: putilov.iplit@ya.ru

Abstract. This paper discusses the use of dispersive optical elements as control devices for the wavelength of alexandrite laser. Some types of selective resonators are considered. The losses in the resonators with dispersive elements are described. The results of a dual-wavelength alexandrite lasing with an installed birefringent filter are presented.

1. Introduction
Alexandrite crystal - chrysoberyl BeAl2O4 doped with Cr3+ ions. High quality alexandrite is grown by Czochralski, Kyropoulos and horizontal directional crystallization methods. Passive Optical loss at the working wavelength is 0.001 - 0.003 cm⁻¹ [1].

Alexandrite provides intense emission between 0.7 and 0.85 µm with a maximum at around 0.75 µm. The corresponding stimulated-emission cross-section is relatively small, σSE = 0.7 • 10⁻²⁰ cm² (as compared to another state-of-the-art material for tunable lasers – Ti³⁺:α-Al₂O₃ or Ti:Sapphire), which is compensated by a relatively long lifetime of the upper laser level τ ~260 μs at room temperature [2].

One of the methods of laser radiation tuning is the use of dispersive resonators. The introduction of dispersive elements leads to frequency selective losses in the resonator, i.e. the conditions for mode generation are different. Thus, there is an effective limitation of the spectral band of the generated radiation. The narrowing of the emission spectrum occurs due to the deterioration of the quality factor of the resonator.

Total losses in the dispersive resonator can be represented as a sum of non-selective γ₀ and selective losses γc (1). Non-selective losses - the sum of the losses of the non-selective resonator γpr and the introduced dispersion element γd.

\[ \gamma_0 = \gamma_h + \gamma_c = (\gamma_{pr} + \gamma_d) + \gamma_c \] (1)

The power transmission of the resonator at each frequency is determined by the product of the transmission coefficients of the intracavity elements and the reflection coefficients of the mirrors. The spectral transmission profile of the selective resonator depends on the dispersion element, since the losses introduced by other optical elements are non-selective and affect the power loss.
Angle mode selection is a violation of the alignment of the resonator for modes that are not basic. The mode has the minimal losses, which coincides with the fundamental frequency of the resonator, while the other modes are distant from it in frequency and the resonator for them is misaligned.

2. Methods and equipment
According to the type of dispersion elements used, laser resonators can be divided into different groups. Imagine several types of resonators.

Prism dispersive resonators. The optical scheme of the simplest resonator using a transmission prism is shown in figure 1.

![Figure 1. Optical scheme of the rays in a prism dispersion resonator](image1)

In this type of resonator, the role of the dispersion element is performed by a prism mounted at an angle to the optical axis of the radiation. Tuning to a certain wavelength of radiation is performed by rotating the reflecting mirror (HR). Due to the different optical path in the prism for modes with different frequencies, their selection takes place in the resonator. The main types of non-selective losses include both absorption in the prism itself and reflection from its faces. To reduce the losses, the circuits are aligned with the minimum optical path length in the prism and the minimum deviation of the incident polarized radiation on the face of the prism, which is at an angle close to the Brewster angle.

The advantages of prism resonators include rearrangement in a wide spectral range and the high radiation resistance of a prism. The main disadvantage of prism resonators is low selectivity.

Dispersion resonators with diffraction gratings (figure 2).

![Figure 2. Optical scheme of the resonator with diffraction gratings](image2)
A moving volumetric diffraction grating placed in the resonator narrows the passband of the resonator, but the diffraction efficiency of the grating decreases. In the scheme shown figure 2, the efficiency of the bulk diffraction grating is maximum, and the FWHM can be less than 0.1 nm. The restructuring of the emission spectrum is carried out by turning around the axis of the bulk diffraction grating, which is set to transmittance while simultaneously turning the front mirror (OC). In this case, the Bragg diffraction is conserved consistently for all the resonator frequencies, ensuring mode selection.

The use of diffraction gratings in the cavity leads to its high selectivity, a large area of dispersion and the possibility of a smooth, linear adjustment of the emission spectrum. The main disadvantage of diffraction gratings is the low radiation resistance compared with the interferometric polarization filters and prisms, which limits their use in repetitively pulsed lasers with high pulsed energy at subnanosecond duration of the output radiation.

Lasers with birefringent filters (figure 3). In a resonator with a birefringent filter, the tuning of the radiation wavelength is performed by rotating the filter around an axis. In the free dispersion region, the displacement of the main transmission peaks occurs linearly.

The main advantages of birefringent filters include high radiation resistance, low non-selective losses.

3. Results and discussion
In the experiment, a three-element Lyot interference filter of quartz plates with a thickness ratio of 2:1:6 was used as a dispersive element of the resonator. Precise rotation of the foot plates was carried out by a stepper motor [3].

The active element from Alexandrite with a length of 60 mm and a diameter of 6.3 mm was pumped with two pulsed gas-filled lamps. The composition of the material of the lamp ensured the cut-off of the pumping UV radiation; for additional protection of the crystal, plates of yellow quartz were installed. A milky glass elliptical reflector provided even illumination of alexandrite crystal with pumping lamps.

Distilled water was used as a coolant. The design of the quantron provided a parallel coolant flow through the pump lamps and alexandrite crystal. The coolant temperature was controlled and heated in the range of 25 – 90 °C.

The laser resonator is plane-parallel with the reflection coefficient of the output mirror ~ 80% and the reflecting mirror > 99%.

A three-element interference-polarization Lyot filter was used as a dispersive element of the resonator. Precise rotation of the foot plates was carried out by a stepper motor.

In the stationary generation mode without the Lyot filter installed in the resonator, the radiation wavelength was 748 nm (figure 4).
Figure 4. Generation wavelength without Lyot filter

The main advantages of birefringent filters include high radiation resistance, low non-selective losses.

When installing and adjusting the Lyot filter, a smooth tuning of the emission spectrum in the range of ~ 720 - 800 nm was obtained.

The bandwidth of the Lyot filter ensures the passage of two boundary modes at once. In some positions, during the rotation of the Lyot filter, dual wavelength took place (figure 5) [4].

Figure 5. Dual-wavelength alexandrite lasing

The further development of the work will be dual wavelength alexandrite lasing in the Q-Switched with SHG.

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