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Passive *Q*-switching of a 1.66-μm $Er^{3+}:YAlO_3$ laser by means of a $Cr^{2+}:ZnSe$ crystal

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***Abstract*. The passive *Q*-switching of 1.66-μm $Er^{3+}:YAlO_3$ lasers with the help of some saturable absorbers is studied. Giant 200-ns pulses are generated by using a $Cr^{2+}:ZnSe$ crystal as a saturable absorber.**

Keywords: *IR laser, passive Q-switching, yttrium aluminate.*

1. Introduction

Zinc selenide (ZnSe) and magnesium aluminate spinel ($MgAl_2O_4$) crystals are known as saturable absorbers applied for passive *Q*-switching of 1.54-μm erbium glass lasers (the $^4I_{13/2} - {}^4I_{15/2}$ transition in Er^{3+} ions). Cr^{2+}-doped ZnSe crystals also can be used for this purpose [1]. In addition, these crystals can be efficiently employed as active media for laser tunable in the range from 2.12 to 2.93 μm. Chromium ions absorb radiation in the region between 1.4 and 2.2 μm and can be pumped by thulium-doped crystal lasers emitting the spectral region from $\lambda \sim 1.9$ to 2.0 μm. Recently a tunable $Cr^{2+}:ZnSe$ laser was pumped by a $Er^{3+}:YAlO_3$ laser emitting at the 1.66-μm $^4S_{3/2} - {}^4I_{9/2}$ transition [2] (see the energy level diagram in Fig. 1).

In this paper, we studied the possibility of using these saturable absorbers for *Q*-switching 1.66-μm $Er^{3+}:YAlO_3$ lasers. A specific feature of these lasers is that the laser transition is self-terminated (the lifetime of the lower $^4I_{9/2}$ laser level exceeds the lifetime of the upper $^4S_{3/2}$ laser level, which is about 100 μs at the typical erbium concentration $\sim 10^{20}$ cm^{-3}). Due to the self-contained nature of the laser transition and a low activator concentration (because of the concentration quenching of luminescence), the lasing efficiency is low (~ 0.1 % for free-running lasing upon flashlamp pumping). Although the efficiency of these lasers is low, they find some applications because of the absence of more efficient and convenient sources in this spectral region. We have failed to find in the literature any information on 'pure' *Q*-switching regimes in such lasers; however, the generation of a train of ultrashort pulses (with the envelope of duration 250 ns) by using a nonlinearly reflecting mirror was reported in [3].

The necessary condition for generating giant pulses (in the absence of radiation focusing in a *Q* switch) is a small ratio of the stimulated emission cross section σ_{gen} in the active medium to the absorption cross section σ_{abs} of a saturable filter. According to [1], the absorption cross sections σ_{abs} for $ZnSe:Cr^{2+}$ and $ZnSe:Co^{2+}$ crystals at 1.66 μm are $\sim 8 \times 10^{-19}$ and $\sim 5 \times 10^{-19}$ cm^2, respectively. The absorption cross section for non-stoichiometric spinel crystals ($Co^{2+}:MgO{\cdot}3.5Al_2O_3$) is $\sim 1 \times 10^{-19}$ cm^2, which is noticeably higher than that for stoichiometric $MgAl_2O_4$ crystals [1, 4]. Thus, a $Cr^{2+}:ZnSe$ crystal has the highest absorption cross section among the materials listed above as potential candidates for *Q* switches for 1.66-μm erbium lasers. We have failed to find in the literature the value of the efficient cross section for stimulated emission of erbium ions in a $YAlO_3$ crystal in the presence of the self-terminated

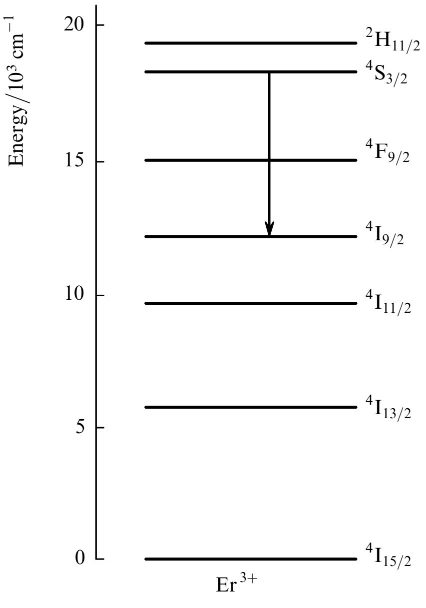

Figure 1. Energy level diagram of the Er^{3+} ion and the 1.66-μm $Er^{3+}:YAlO_3$ laser transition.

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transition. Therefore, the possibility of generating giant pulses by lasers with saturable absorbers under study was investigated experimentally.

The excited-state lifetimes in $Co^{2+}:MgAl_2O_4$, $Co^{2+}:ZnSe$, and $Cr^{2+}:ZnSe$ crystals are 0.35, 350, and 5.4 µs, respectively [1]. Therefore, these lifetimes in the two last crystals are much longer than the characteristic formation time and duration of giant laser pulses. However, the relaxation time of the bleached state of the $Co^{2+}:MgAl_2O_4$ Q switch can be comparable with the formation time and duration of giant pulses. This will result in the selection of the transverse modes of the laser by this passive Q switch, complicating the use of this crystal for Q-switching 1.54-µm erbium glass lasers. Such complications are absent in the case of $Co^{2+}:ZnSe$ and $Cr^{3+}:ZnSe$ Q switches.

2. Experiment

We studied a flashlamp-pumped laser based on a $\varnothing 5 \times 60$-mm yttrium aluminate crystal doped with 1 % of ytterbium and having antireflection coatings on its ends. The crystal was pumped by 100-µs pulses from an IFP-800 flashlamp. To avoid the production of colour centres in the crystal by the UV radiation from the flashlamp, the lamp was cooled by a 2 % potassium chromate solution in distilled water. The laser resonator of length 30 cm was formed by a plane highly reflecting mirror and a concave output mirror with the radius of curvature of 1 m and the transmission coefficient continuously varying from 10 % to 50 % from one edge of the mirror to another. The experimental data presented below were obtained for the position of the output mirror corresponding to the 20 % transmission. A plane–parallel plate (without antireflection coatings) used as a passive element was placed near the highly reflecting mirror perpendicular or at the Brewster angle to the optical axis of the laser resonator. The absorption coefficient of all the passive elements (for normally incident radiation) was in the range from 15 % to 17 %. An aperture placed inside the resonator provided lasing at the fundamental transverse mode.

When the $Co^{2+}:MgAl_2O_4$ and $Co^{2+}:ZnSe$ crystals were used, no Q-switching was obtained and the laser kinetics virtually coincided with the free-running lasing kinetics (random 50–100-µs trains of 1–2-µs spikes).

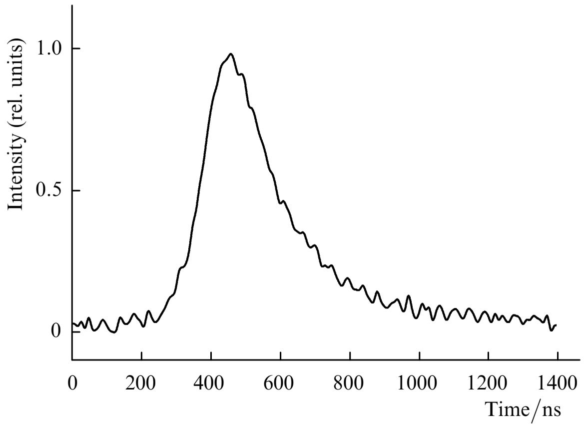

Figure 2. Oscillogram of a 1.66-µm giant laser pulse obtained with the passive $Cr^{2+}:ZnSe$ Q switch.

When the $Cr^{2+}:ZnSe$ crystal was placed perpendicular to the optical axis of the resonator, single giant pulses of duration ~200 ns were generated (Fig. 2). The pulse energy was 0.2 mJ (the free-running lasing energy obtained upon the same pumping was ~1 mJ). Note that, because the faces of the ZnSe crystal were not highly parallel (~4′) and had no antireflection coatings, the radiation losses were very large, resulting in the low output energy.

When the same crystal was oriented at the Brewster angle to the resonator axis (taking into account the polarisation of laser radiation), no giant pulses were generated. This is probably explained by the fact that the radiation density in the passive element oriented at the Brewster angle decreased by n times (where $n = 2.44$ is the refractive index of ZnSe). Thus, we can roughly estimate from these experiments the stimulated emission $\sigma_{\rm gen}$ cross section as $\sigma_{\rm abs}/n \approx 3 \times 10^{-19}$ cm^2.

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