Appl Phys B (2008) 92: 563–565
DOI 10.1007/s00340-008-3107-2

Applied Physics B
Lasers and Optics

Transversely pumped laser using F_3^+ and F_2 mixed color centers in a LiF crystal at room temperature

Lan Qi · Hongen Gu

Received: 23 March 2008 / Published online: 23 July 2008

Abstract A stable laser with F_3^+ and F_2 mixed color centers in LiF crystal is constructed using a transversely pumped cavity at room temperature. The mixed color center laser is pumped with a nitrogen-laser-pumped dye laser. A pulse output of the laser is 0.23 mJ. The pulse widths of the F_3^+ and F_2 color center lasers are about 12 and 8.5 ns, respectively. The optical–optical conversion efficiency is about 5.0%. The divergence of the F_3^+ color center laser beam is about 2.2 mrad and that of the F_2 color center laser beam about 3.5 mrad. The polarization of the mixed color center laser is about 0.97. The output of the F_3^+ color center laser extends from 515 to 575 nm and peaks at 540 nm, while that of the F_2 color center laser extends from 633 to 705 nm and peaks at 667 nm.

PACS 42.55.Rz · 42.60.-v · 61.72.jn · 78.55.Fv

1 Introduction

A longitudinally pumped LiF crystal F_3^+ and F_2 mixed color center laser was demonstrated by us at room temperature (RT) [1]. In the laser operation, the local temperature in the lasing crystal was increased under a higher pump level, which resulted in the laser output dropping over the whole bandwidth. So, circulating water was used to prevent the output drop. After using that method of cooling, the F_3^+ color center laser operated stably for about 10^5 pulses, but the F_2 color center laser operated only for about several hundreds of pulses. A lot of F_2^+ color centers in the lasing crystal were observed immediately after stopping the pump. The creation of the F_2^+ color centers decreased the density of the F_2 color centers, and the F_2^+ color centers absorbed the partial fluorescence of the F_3^+ and F_2 color centers in the laser operation and increased energy loss in the cavity. In addition, the energy density of longitudinally pumped light focused on the active material is very high, which can produce instantaneous high temperature and mechanical damage. Although low pump energy or defocusing could be used, the output laser intensity was decreased greatly.

In this work, a transversely pumped cavity is constructed at RT for the LiF crystal F_3^+ and F_2 mixed color center laser with high energy output and high stability, which can solve most of the problems resulting in the output dropping of the color center laser.

2 Preparation and spectral property of LiF lasing crystal

LiF crystals were grown in vacuum by our laboratory, and a slice of LiF crystal ($60 \times 8 \times 3$ mm^3) was cleaved from a single crystal and polished optically. The LiF crystal was bombarded by a 1.5-MeV electron beam at 150 K; color centers then aggregated and transformed in the dark at RT. The colored crystal simultaneously contained the F_3^+ and F_2 color centers in an appropriate proportion, and the color of the colored crystal is green touched with red. An absorption coefficient of the colored crystal at 450 nm was 45 cm^{-1}.

A typical fluorescence spectrum, measured at RT, of the lasing LiF crystal excited by 450-nm radiation at RT is

L. Qi (✉)
Department of Hydroelectricity, Tianjin University,
Tianjin 300072, China
e-mail: lqipaper@eyou.com

H. Gu
Department of Physics, Tianjin University, Tianjin 300072, China

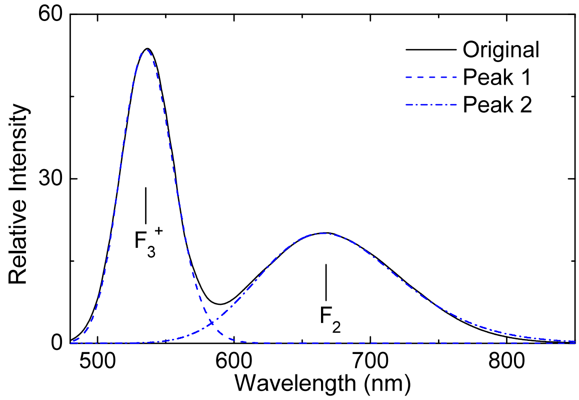

Fig. 1 Fluorescence spectrum (excitation wavelength 450 nm), measured at RT, of a LiF crystal bombarded by electrons at 150 K and irradiated by nitrogen laser at RT

shown in Fig. 1; there are two fluorescence bands at 535 and 670 nm, respectively. The fluorescence curve can be well fitted with two Gaussian fluorescence peaks at 535.5 (peak 1) and 665.2 nm (peak 2), respectively; the corresponding widths are 0.164 and 0.282 eV, respectively (herein, fitting is performed at energy). The two peaks correspond to the F_3^+ and F_2 color centers, respectively.

3 Laser details

The vertical-view scheme of the optical cavity of the color center laser is shown in Fig. 2. The mirror M_1 with curvature radius of 150 mm has 99.8% and 96.0% reflectivities for the F_3^+ and F_2 color center lasers, respectively. The plane mirror M_2 used as laser output mirror has 3% and 10% transmissions for the F_3^+ and F_2 color center lasers, respectively. The mirrors M_1 and M_2 are separated by 120 mm. The lasing LiF crystal is mounted between the two mirrors, and the two flanks are made and aligned to Brewster angles (54.3°) with respect to the laser beam. The focal length of the cylindrical pump lens is 120 mm. A nitrogen-laser-pumped dye laser (coumarin 1) operated at 450 nm with 1-Hz repetition rate is used as the pump light source. The maximum single pulse energy of the dye laser is 5.0 mJ and the pulse duration is 3.5 ns. The dye laser is unpolarized, and the focus profile on the lasing LiF crystal has a size of 60×0.25 mm^2.

4 Main results and discussion

In the operation of the LiF crystal F_3^+ and F_2 mixed color center laser, a big red dazzling spot inlaid with a green dot is observed on the screen and the spot sizes of the F_3^+ and F_2 color center laser beams have respectively diameters of 1.3 and 2.0 mm due to different divergences of the F_3^+ and F_2 color center laser beams. The divergences of the F_3^+ and

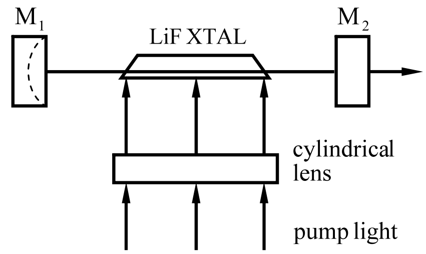

Fig. 2 Vertical-view scheme of mixed color center laser. M_1, mirror; M_2, output mirror

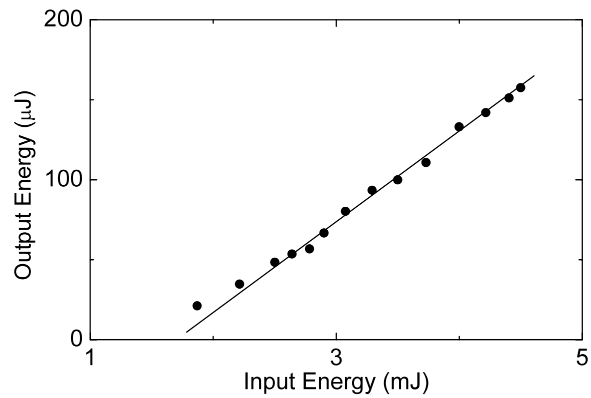

Fig. 3 Output energy of mixed color center laser as a function of input energy

F_2 color center lasers are 2.2 and 3.5 mrad, respectively. A pulse output energy of the mixed color center laser of about 0.23 mJ is obtained, in which the energy of the F_3^+ color center laser is 0.15 mJ and that of the F_2 color center laser 0.08 mJ. The optical–optical conversion efficiency of the mixed color center laser is 5.0% after deducting pump laser losses such as the absorption and reflectivity of the focal lens. Figure 3 shows the output energy of the mixed color center laser as a function of the input energy; the slope efficiency is about 7.2%. The excitation threshold is about 0.12 mJ for the F_3^+ color center laser and about 0.05 mJ for the F_2 color center laser. The polarization of the mixed color center laser is about 0.97. The output spectrum of the laser is shown in Fig. 4. The output of the F_3^+ color center laser extends from 515 to 575 nm and peaks at 540 nm, while that of the F_2 color center laser extends from 633 to 705 nm and peaks at 667 nm. The measured laser pulse widths are about 12 and 8.5 ns for the F_3^+ and F_2 color center lasers, respectively. The present pump energy is about 4.5 times bigger than the previous one of 1.1 mJ [1]. The mixed color center laser is stable under the above operating conditions and has no observable output drop after continuous operation for several hours without using any cooling equipment. The temporal evolution of the mixed color center laser during the pump is shown in Fig. 5. The position of the focus line on the lasing crystal does not appear any different in the laser operation. The absorption spectrum of the lasing LiF

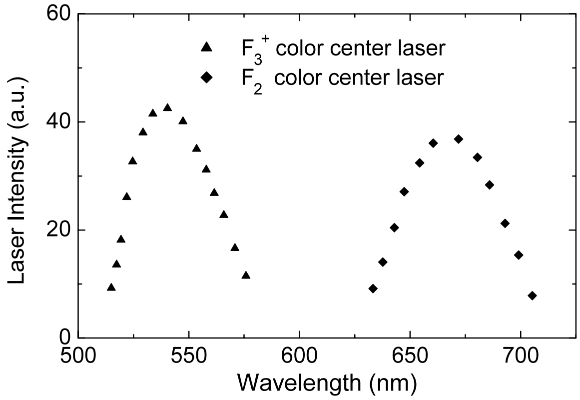

Fig. 4 Relative output intensity as a function of wavelength of mixed color center laser

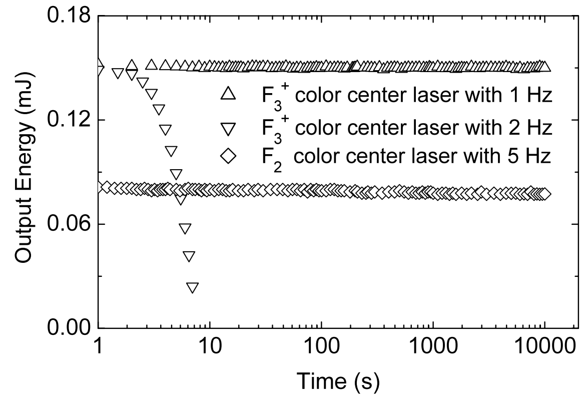

Fig. 5 Temporal evolution of mixed color center laser during pumps with three different repetition rates

crystal was measured immediately after stopping the pump, and there were no observable F_2^+ color centers from the absorption spectrum.

The mixed color center laser, as above described, operates stably at RT using the transversely pumped cavity and higher pump energy. The advantage of the used transversely pumped cavity is that the energy density of the pump light line on the lasing LiF crystal is much lower than that of the pump light spot on the lasing LiF crystal in the longitudinally pumped cavity [1], so that the instantaneous high temperature resulting in the laser output energy drop over the whole bandwidth [1] hardly appears under the present operation condition. An appropriate density (about 2.5×10^{17} cm^{-3}) of the F_2 color centers in the lasing LiF crystal is essential for increasing the stability of the F_2 color center laser through our optimization, although the accurate density of the F_2 color centers in the lasing LiF crystal is hardly confirmed because the absorption band of the F_2 color centers overlaps considerably that of the F_3^+ color centers. Moreover, the low pump density and appropriate density decrease greatly the photoionization probability of the F_2 color centers, so the inimical color centers such as the F_2^+ color centers are hardly produced. On the other hand, the F_3^+ color center laser disappears quickly when the repetition rate is increased from 1 Hz to higher than 1.5 Hz due to the electron trappers of the triplet levels near the singlet levels of the F_3^+ color centers [2–5]; the existence and trapping action of the triplet levels were investigated in detail by spectral analysis [6, 7]. The maximum repetition rate obtained in our previous work was 1.5 Hz [8]. Thereby, the repetition rate of the F_3^+ color center laser may be hardly increased by using the usual optical technique. However, the F_2 color center laser is not affected by the electron trappers, and still stable when the repetition rate is increased to more than 5 Hz.

In conclusion, a stable laser with F_3^+ and F_2 mixed color centers in LiF crystal can stably perform using a transversely pumped cavity at RT. The mixed color center laser is pumped with a nitrogen-laser-pumped dye laser. An appropriate density (about 2.5×10^{17} cm^{-3}) of the F_2 color centers in the lasing LiF crystal is essential for increasing the stability of the F_2 color center laser. A pulse output of the mixed laser is 0.23 mJ. The pulse widths of the F_3^+ and F_2 color center lasers are about 12 and 8.5 ns, respectively. The optical–optical conversion efficiency is about 5.0%. The divergence of the F_3^+ color center laser beam is about 2.2 mrad and that of the F_2 color center laser beam about 3.5 mrad. The polarization of the mixed color center laser is about 0.97. The output of the F_3^+ color center laser extends from 515 to 575 nm and peaks at 540 nm, while that of the F_2 color center laser extends from 633 to 705 nm and peaks at 667 nm.

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