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Room-temperature green laser emission of Er:LiYF₄

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Room-temperature green laser emission of Er:LiYF₄

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We report the first demonstration of a green erbium-doped crystal laser at room temperature. Excited with a pulsed dye laser, the erbium-doped LiYF₄ crystal emitted on the $^4S_{3/2}$ - $^4I_{15/2}$ ground state transition. As expected from fluorescence measurements, the emitted radiation was polarized parallel to the optical axis. Laser oscillation has also been observed in erbium-doped Y₃Al₅O₁₂ and Lu₃Al₅O₁₂ crystals.

Recently there has been considerable interest to provide all solid state lasers emitting in the visible spectral range. A promising method for this aim is upconversion pumping of rare-earth-doped crystals or optical fibers with suitable laser diodes. Upconversion pumping and visible lasing has been successfully demonstrated in Tm-doped crystals^{1,2} and in various rare-earth-doped fluorozirconate glass fibers at room temperature.³⁻⁵ Up to now erbium-doped crystal lasers in the green part of the spectrum have emitted at cryogenic temperatures only,^{6,7} which severely limits their range of applications. Neither by upconversion pumping nor by direct excitation room-temperature has operation of such a laser been achieved. Several problems connected with excited state absorption have been pointed out in Ref. 8. In order to clarify the situation in crystals we have directly pumped the Er³⁺ ion in the blue spectral region and achieved pulsed green laser emission in Er:LiYF₄ (YLF) at ambient temperature.

In initial measurements we have obtained the emission cross sections of Er:YLF on the $^4S_{3/2}$ - $^4I_{15/2}$ transition, which are in agreement with the observed laser polarization and wavelength. As this is a ground state transition, the reciprocity method⁹ can be employed for the determination of the emission cross sections. The basic assumption underlying this method is that the absorption and emission cross sections on a single Stark level transition of a rare-earth ion in a crystal are identical. This is not an entirely correct assumption. As pointed out in Ref. 10, it may be violated by vibronic interactions. For Nd:Y₃Al₅O₁₂ (Nd:YAG) a deviation of about 20% has been measured,¹⁰ which can be tolerated for our purposes. For both σ and π polarization, the absorption cross sections were measured with a Cary 17D spectrometer and emission cross sections were then calculated. In order to obtain the corresponding fluorescence data, we excited the crystal with an argon ion laser at 488 nm and recorded the spectra with a 0.5 m spectrometer and an S1 photomultiplier tube. Cross sections obtained from fluorescence measurements were then fitted to the calculated spectra and are shown in Fig. 1. No effort has been made to accurately confirm the erbium concentration of 1%. It can be seen that laser action in π polarization is clearly favored because of larger emission cross sections. Also, due to the longer wavelength, the relative reabsorption losses at 551 nm in π po-

larization are lower than the corresponding ones in σ polarization.

A conventional setup was employed for the laser experiments. Pumping was provided by an excimer laser pumped dye laser. The nearly concentric laser resonator consisted of two mirrors with a 5-cm radius of curvature. A lens with 5 cm focal length focused the elliptical pump beam into the laser crystal to an estimated spot size of about 50 $\mu\text{m} \times 100 \mu\text{m}$. To enable laser oscillation in π polarization, the 2.4 mm long Er(1%):YLF crystal was mounted with its optical axis perpendicular to the resonator axis. It was then excited at 486 nm, where it absorbed 75% of the pump radiation. As indicated by the spectroscopic data, laser emission occurred at 551 nm and was polarized parallel to the optical axis of the Er:YLF crystal. With a fast diode we recorded both the pump and laser pulse. A typical oscilloscope trace is presented in Fig. 2. Note that pump and laser pulses have arbitrary relative heights. The width of the laser pulse is about 50 ns and is, as well as its delay with respect to the pump pulse, varying with pump energy. With 2% of output coupling a slope efficiency of 6% was obtained for the Er:YLF crystal (Fig. 3). The maximum output energy of 30 μJ corresponded to a peak power of approximately 600 W. At repetition rates above 10 Hz the output energy decreased rapidly. Reabsorption losses are about 12% per roundtrip for the 2.4

FIG. 1. Polarized emission cross sections of Er(1%):YLF for the $^4S_{3/2}$ - $^4I_{15/2}$ transition. At 551 nm a cross section of $(2 \pm 1) \cdot 10^{-20} \text{ cm}^2$ has been obtained in π polarization.

FIG. 2. Time evolution of both pump pulse and laser pulse for the green Er:YLF laser.

FIG. 4. Spectra of the green Er:LiYF₄, Er:Y₃Al₅O₁₂ and Er:Lu₃Al₅O₁₂ laser pulses.

mm long crystal. We believe that the efficiency of this laser can be significantly improved with optimized output coupling, crystal length, and mode matching.

We have also observed laser action in Er:Y₃Al₅O₁₂ (YAG) and Er:Lu₃Al₅O₁₂ (LAG) crystals, which were pumped at 487.6 nm. Spectra of the pulsed laser output were detected with an optical multichannel analyzer (OMA) attached to a 0.25 m spectrometer with a resolution of approximately 0.4 nm. They are shown in Fig. 4. In agreement with their fluorescence spectra, the output of the garnet lasers is shifted towards longer wavelengths and was detected at 561 nm for Er:YAG and Er:LAG. Compared to Er:YLF these garnet lasers benefit from lower reabsorption losses and correspondingly lower thresholds. The upper laser level lifetime of about 15 μs in Er(1%):YAG and Er(1%):LAG is considerably shorter than the 400 μs lifetime in the Er(1%):YLF sample, but still long compared to the delay and width of the laser

pulse (Fig. 2). Consequently, the reduced quantum efficiency compared to YLF is irrelevant to our experiments. There are indications that the ceasing of laser oscillation after a few shots in YAG and after about half an hour of laser operation in LAG may be caused by the formation of stationary color centers. However, such effects are not present in the case of Er:YLF.

In conclusion we have demonstrated room-temperature laser operation of Er(1%):YLF at 551 nm in π polarization. Pumped with a pulsed dye laser at 486 nm the laser reached threshold at 75 μJ of absorbed pump energy. The slope efficiency was 6%. Additionally, laser action was observed in erbium-doped YAG and LAG at 561 nm. However, further work is required to stabilize the operation of these garnet lasers. For the purpose of upconversion pumping the low thresholds of these lasers look very promising.

FIG. 3. Er:YLF 551 nm output energy plotted against absorbed 486 nm pump energy.

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