1-1-1994

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Recommended Citation

Heine, F.; Heumann, E.; Danger, T.; Schweizer, T.; Huber, G.; and Chai, B., "Green Up-Conversion Continuous-Wave Er3+Liyf4 Laser At Room-Temperature" (1994). *Faculty Bibliography 1990s*. 2947.
https://stars.library.ucf.edu/facultybib1990/2947

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Applied Physics Letters

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Cite as: Appl. Phys. Lett. **65**, 383 (1994); https://doi.org/10.1063/1.112335
Submitted: 05 January 1994 . Accepted: 09 May 1994 . Published Online: 04 June 1998

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AIP Publishing

Appl. Phys. Lett. **65**, 383 (1994); https://doi.org/10.1063/1.112335 **65**, 383

Green upconversion continuous wave Er^{3+}:$LiYF_4$ laser at room temperature

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(Received 5 January 1994; accepted for publication 9 May 1994)

We report room-temperature upconversion pumped continuous wave laser emission of 1% Er^{3+}:$LiYF_4$ at 551 nm excited by a Ti:sapphire laser at 810 nm. Output powers of up to 40 mW with output coupling of 6.6% have been obtained by using nearly concentric resonator design.

Visible continuous wave solid-state lasers are of interest for high density data storage and display applications. Up to now continuous wave (cw) blue or green output of solid-state lasers at room temperature was realized by upconversion pumping in Tm^{3+}:YLF,[1,2] rare-earth-doped fiber lasers,[3] frequency doubling of near infrared lasers like Nd^{3+}:$Y_3Al_5O_{12}$(YAG), and under direct excitation (by an argon laser) of Pr^{3+} (see Ref. 4) and Er^{3+} (see Ref. 5). Very recently, room temperature pulsed green upconversion lasing was demonstrated in Er:YLF.[6]

Using an upconversion or excited state absorption (ESA) process it is possible to obtain laser emission at wavelengths shorter than the pump wavelength. Especially diode laser radiation, which is available in high power modules around 800 and 970 nm wavelengths, is advantageous for compact and reliable all solid-state lasers.

In our experiment we utilized a two step single ion pumping scheme as shown in Fig. 1 evaluated from ESA measurements using pump and probe technique.[6] The real interionic upconversion process requires Er^{3+} concentrations higher than those used in our experiment.

There are two different ways of upconverting the infrared pump power to the upper laser level $^4S_{3/2}$. The first possibility is dual wavelength pumping, using the 970 nm absorption for populating the $^4I_{11/2}$ and 810 nm for efficient population of the upper laser level. The second way is to use 810 nm pump radiation alone, which is a more simple arrangement. However, the disadvantage of the latter pump scheme is the very weak ground state absorption at 810 nm which is 15 times smaller than the 970 nm absorption. The absolute value for the ground state absorption coefficient α at 810 nm is 0.08 cm^{-1} for 1% Er^{3+}:YLF in π polarization. The low concentration was used to minimize reabsorption losses which are ~10% at the laser wavelength, with an absorption cross section of $\sigma_{abs}=0.2\times10^{-20}$ cm^{-2} and an emission cross section of $\sigma_e=2\times10^{-20}$ cm^{-2}. In order to increase the absorbed pump power we used output couplers for the Er laser resonator with high reflectivities ($R\approx97\%$ at 810 nm) for the Ti:sapphire laser. In addition, this also yields a feedback into the Ti:sapphire laser and a resonance enhancement of the pump power (see below).

The laser crystal was grown by the Czochralski method at CREOL and the experiments were carried out at the Hamburg University. The setup consisted of a concentric cavity (radii of mirrors $R=50$ mm) with the input mirror coated to be high reflective at the laser wavelength and high transmissive in the 800 nm spectral region ($T\geqslant90\%$). The output couplers were highly reflective at the pump wavelength ($R\approx97\%$) and had transmissions between 0.5% and 6.6% at the laser wavelength.

Focusing of the Ti:sapphire beam was accomplished by a 50 mm focal length lens. The pump power level was up to 3 W incident in the cavity (measured with blocked feedback). Although the YLF crystal (length was 4 mm) was not cooled, thermal problems have not been noticed under true cw operation.

The wavelength of the Ti:sapphire laser was tunable by a one plate birefringent filter (quartz of 170 μm thickness). The wavelengths and the linewidths of the Er laser and the pump laser have been determined by an 1 m spectrometer. The linewidth of the pump laser was 0.4 nm, that of the Er^{3+}:YLF was 0.1 nm. The total optical to optical efficiency was about 1.4% with respect to the pump power without feedback. Input-output measurements yielded a maximum slope efficiency of 10% by using 6.6% output coupling, if we consider again the input pump power measured by blocking the feedback (see Fig. 2).

In order to determine the absorbed pump power in the Er:YLF crystal we have also measured the actual pump power in the Er laser resonator in the aligned system with feedback by two independent methods.

One measurement was made by the insertion of a tilted glass plate into the pump beam path between the Ti:sapphire laser output coupler and the Er-laser resonator. From the two reflections at the glass plate the forward and backward circulating pump power could be determined with and without

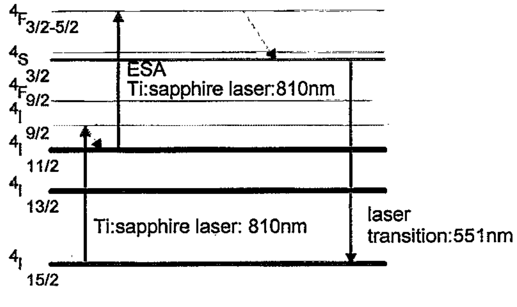

FIG. 1. ESA pump mechanism used in the laser experiments.

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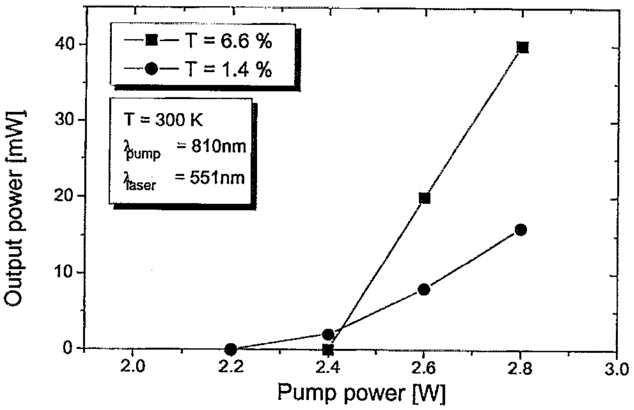

FIG. 2. Input-output curve for two different output couplings (1.4% and 6.6%) at 551 nm when pumped with a Ti:sapphire laser. The pump power was measured without feedback.

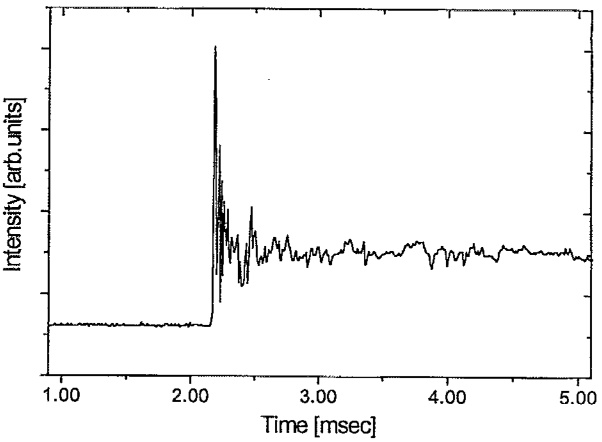

FIG. 3. Laser output with chopped pump laser beam showing relaxation oscillations.

feedback. The resulting power enhancement under feedback conditions was a factor of 4 giving a maximum circulating pump power of approximately 12 W in the Er-resonator and a maximum absorbed pump power of about 400 mW in the crystal. A second set of measurements of the transmitted pump power behind the Er resonator yielded the same results. Thus, at the maximum output of 40 mW the efficiency with respect to absorbed pump power is in the order of 10%.

The laser showed pronounced relaxation oscillations at the beginning of the laser process under chopped excitation of the Ti:sapphire pump laser (see Fig. 3). The first relaxation spike had a duration of typically 750 ns. The frequency of the oscillations was 20 kHz at high pump power levels and 6.6% output coupling. The laser output mode was TEM_{00}. The lifetime of the upper laser level of 400 μs should allow high repetition rate Q switching.

Several other crystals have been tested with lower and higher Er concentrations (0.5% and 2%), but 1% Er seems to be the best compromise between absorption coefficient and lifetime of the upper laser level, which strongly decreases with increasing concentration due to cross relaxation processes.

In conclusion, we have demonstrated what we believe to be the first cw upconversion laser emission of Er:YLF in the green spectral region at room temperature. We have pumped with a two step excitation process with one wavelength at 810 nm. The maximum output power of the green laser at 551 nm was 40 mW at 400 mW absorbed pump power of a Ti:sapphire laser.

The wavelength of pumping at 810 nm is ideal to replace the Ti:sapphire laser by a high power laser diode. However, it is necessary to decrease the input pump power by codoping of a sensitizer and/or by more advanced resonant pump techniques.

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