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Up-conversion luminescence of Er^{3+} -doped yttrium, scandium, gallium garnet at different temperatures

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Abstract

The up-conversion luminescence in the visible region (400–700 nm) from (30% Er^{3+} -doped YSGG laser crystal was investigated in the temperature range of 77–300 K, when the crystal was pumped by a diode laser at ~ 790 nm. The spectra were compared with those under an Ar ion laser (~ 488 nm) pumping. The difference between the two sets of spectra and possible up-conversion processes were discussed.

Keywords: Up-conversion; Luminescence; Er^{3+} , Er; YSGG

1. Introduction

There has been great interest in laser materials for efficient conversion of infrared light into visible light (called up-conversion). One of the important applications of the up-conversion is to make up-conversion lasers that emit short-wavelength light, pumped by long-wavelength light sources such as diode lasers. Up-conversion lasing at 551 nm has been demonstrated in Er^{3+} -doped YLiF_4 under a diode laser (791 nm) pumping [1]. It was found that various up-conversion processes played important role in lasing in an Er^{3+} -doped system. They may provide an enhancement of the laser emission, or may result in the quenching of the emission. In this paper, we present our results on

the investigations of the up-conversion luminescence in the visible region (400–700 nm) in $\text{YSGG}:\text{Er}^{3+}$ (30%) in the temperature range of 80–300 K, pumped by a diode laser at ~ 790 nm. The luminescence spectra, pumped by an Ar ion laser at ~ 488 nm, in the same region were also measured and compared with that under the diode pumping. This work should provide more information on the up-conversion processes in $\text{YSGG}:\text{Er}^{3+}$ (30%) and on how the temperatures affect those processes.

2. Experimental

The sample of Er^{3+} -doped YSGG was about $15 \times 8 \times 5 \text{ mm}^3$ and the Er^{3+} concentration was 30%. The luminescence was measured by exciting the

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sample either with the diode laser (~ 790 nm) or with the Ar ion laser (~ 488 nm). A 1 m McPherson Model 2051 scanning monochromator with a 600 lines/mm grating blazed at $1.25 \mu\text{m}$ was used with a slit width of $300\text{--}600 \mu\text{m}$. A Hamamatsu R1387 (S-20) photomultiplier was used to detect the luminescence signals. The output was amplified by a Lock-in amplifier and finally displayed on a computer. Appropriate filters and lenses were used in the optical system.

3. Results and discussions

We measured the luminescence spectra in the region of $500\text{--}700$ nm from 89 to 300 K (one

measurement every 30 K) under the diode and Ar pumping, respectively. Some of the spectra are shown in Figs. 1(a) and (b). According to the Er^{3+} energy level diagram [2] shown in Fig. 1(c), we can see that the diode laser pumps Er^{3+} directly to the $^4\text{I}_{9/2}$ level and the Ar ion laser pumps Er^{3+} directly to $^4\text{F}_{7/2}$ and $^2\text{H}_{11/2}$ which are above the $^4\text{S}_{3/2}$ level. The group of emission lines around 560 nm are due to $^4\text{S}_{3/2} \rightarrow ^4\text{I}_{15/2}$ transitions and the lines around 675 nm are due to $^4\text{F}_{9/2} \rightarrow ^4\text{I}_{15/2}$. Under either diode or Ar pumping, we observed that the emission around 560 nm was much stronger than the emission around 675 nm at 89 K, but the ratio of the intensity at ~ 560 nm to that at ~ 675 nm decreased with increasing temperatures. We believe that it is due to the lifetimes of $^4\text{S}_{3/2}$ and $^4\text{F}_{9/2}$

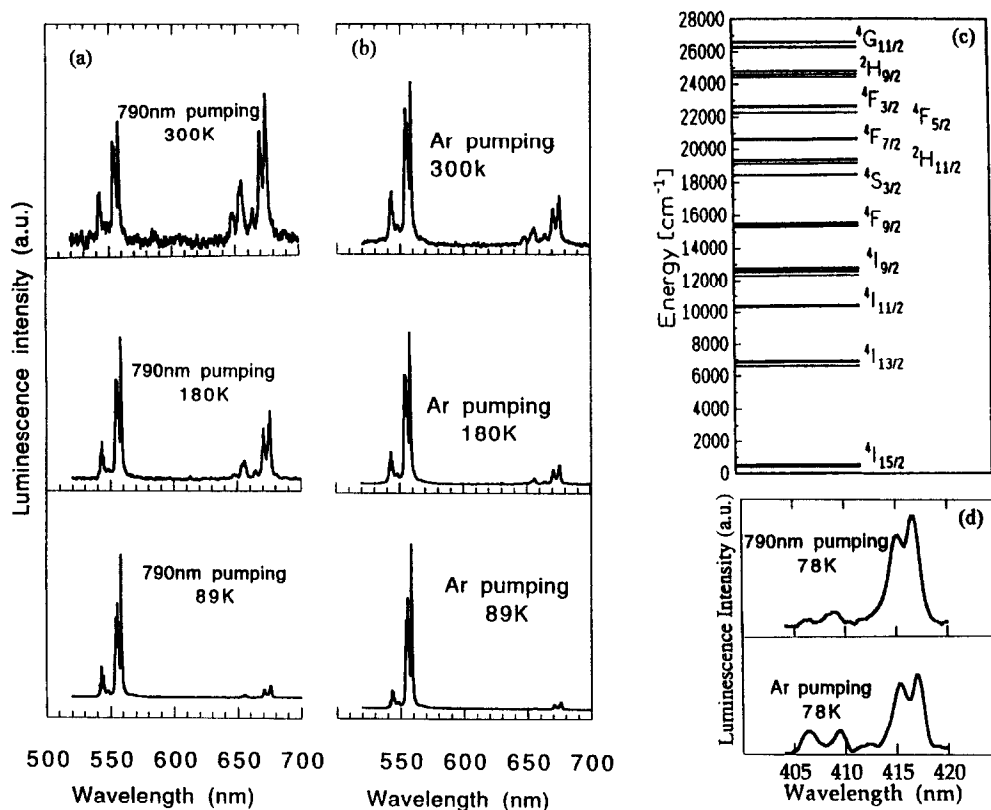


Fig. 1. (a) Up-conversion luminescence spectra from $\text{YSGG}:\text{Er}^{3+}$ (30%) at different temperatures under the diode laser (~ 790 nm). (b) Luminescence spectra from $\text{YSGG}:\text{Er}^{3+}$ (30%) at different temperatures under the Ar ion laser (~ 488 nm) pumping. (c) The energy level diagram of Er^{3+} . (d) The up-conversion spectra from $\text{YSGG}:\text{Er}^{3+}$ (30%) at 78 K under the diode and Ar pumping, respectively.

which are about the same (31 μs) at 77 K, but the lifetime of $^4\text{S}_{3/2}$ decreases to $\sim 1.8 \mu\text{s}$ and the lifetime of $^4\text{F}_{9/2}$ increases to $\sim 14 \mu\text{s}$ at 300 K [3].

When comparing the two sets of the spectra (Fig. 1(a) and (b)), we found that there was a difference between the diode-pumped spectra and the Ar-pumped spectra. The ratio of the luminescence intensity at $\sim 675 \text{ nm}$ to that at $\sim 560 \text{ nm}$ was always greater with the diode pumping than with the Ar pumping over the entire temperature range (89–300 K). It seems that under the diode pumping there are some processes that only populate the $^4\text{F}_{9/2}$ level, not the $^4\text{S}_{3/2}$ level. According to Ref. [4], at high Er^{3+} concentration, the main mechanism to populate the $^4\text{S}_{3/2}$ and $^4\text{F}_{9/2}$ levels is energy transfer up-conversion, not excited state absorption. We tried to identify the possible up-conversion processes that were responsible for the population of the $^4\text{S}_{3/2}$ and $^4\text{F}_{9/2}$ levels under the diode pumping: (a) ($^4\text{I}_{9/2}$, $^4\text{I}_{9/2}$) \rightarrow ($^2\text{H}_{9/2}$, $^4\text{I}_{15/2}$) followed by nonradiative decays of $^2\text{H}_{9/2} \rightarrow ^4\text{S}_{3/2}$, $^4\text{F}_{9/2}$; (b) Nonradiative decay of $^4\text{I}_{9/2} \rightarrow ^4\text{I}_{11/2}$ followed by the up-conversion ($^4\text{I}_{11/2}$, $^4\text{I}_{11/2}$) \rightarrow ($^4\text{F}_{7/2}$, $^4\text{I}_{15/2}$), and then nonradiatively decays $^4\text{F}_{7/2} \rightarrow ^4\text{S}_{3/2}$ and $^4\text{F}_{9/2}$; (c) One ion nonradiatively decays from $^4\text{I}_{9/2}$ to $^4\text{I}_{11/2}$ and another ion (nearby) is at $^4\text{I}_{9/2}$. The ion at $^4\text{I}_{9/2}$ can transfer its energy of $^4\text{I}_{9/2} \rightarrow ^4\text{I}_{13/2}$ nonradiatively to the ion at $^4\text{I}_{11/2}$ to bring it up to $^4\text{F}_{9/2}$. Both processes (a) and (b) populate both $^4\text{S}_{3/2}$ and $^4\text{F}_{9/2}$ levels and should not cause the difference mentioned above. However, the process (c) populates only the $^4\text{F}_{9/2}$ level, not the $^4\text{S}_{3/2}$. It is likely that the process (c) is the main process that is responsible for the ratio Intensity @ $\sim 675 \text{ nm}$ /Intensity @ $\sim 560 \text{ nm}$ with the diode pumping to be greater than Intensity @ $\sim 675 \text{ nm}$ /Intensity @ $\sim 560 \text{ nm}$ with the Ar pumping.

We also observed that the luminescence intensity at $\sim 560 \text{ nm}$ decreased with increasing temper-

atures at a much higher rate under the diode pumping. It indicates that the up-conversion processes to populate the $^4\text{S}_{3/2}$ level at room temperature is not as efficient as at liquid nitrogen temperature. From the 300 K spectrum in Fig. 1(a), we can see that the line $\sim 675 \text{ nm}$ is the best choice to make a room-temperature up-conversion laser in the visible region using YSGG:Er (30%) under the diode pumping at $\sim 790 \text{ nm}$.

At room temperature, we got luminescence lines only around 560 and 675 nm in the visible region. At 78 K, however, we got additional luminescence lines in the violet region from 405 to 420 nm. Fig. 1(d) shows the up-conversion luminescence spectra under the diode ($\sim 790 \text{ nm}$) and Ar ($\sim 488 \text{ nm}$) pumping, respectively. Those emission lines are likely due to the transitions $^2\text{H}_{9/2} \rightarrow ^4\text{I}_{15/2}$. The main up-conversion process to populate to $^2\text{H}_{9/2}$ level is probably due to the reabsorption of the energy of $^4\text{S}_{3/2} \rightarrow ^4\text{I}_{13/2}$ from the metastable level $^4\text{I}_{13/2}$ to have $^4\text{I}_{13/2} \rightarrow ^2\text{H}_{9/2}$, since there are strong emissions at $\sim 560 \text{ nm}$ due to the transition $^4\text{S}_{3/2} \rightarrow ^4\text{I}_{15/2}$ at 78 K under either pumping light. This can also explain why we could not observe the luminescence in this violet region at room temperature. The reabsorption process cannot be efficient since the emission around 560 nm is much weaker at room temperature.

More work, especially dynamics experiment, needs to be done to confirm what we have proposed in this paper for the up-conversion channels.

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