Contributed paper

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Infrared-to-visible upconversion in erbium fluoride (ZBLAN:Er^{3+}) optical fiber: competition between the parasitic 850-nm fluorescence and the green laser emission at 544 nm

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The role of 850-nm fluorescence, amplification, and laser emission in ZBLAN:Er^{3+} optical fiber was first investigated by Whitley et al. [1,2] and Allain et al. [3]. In the case of a green upconversion fiber laser at 544 nm, the 850-nm fluorescence is a parasitic component, so it should be minimized or eliminated. Two pumping wavelengths are usually applied to excite the green upconversion laser: 970 nm or 800 nm. It has been already observed that 800-nm pumping favours, to some extend, the 850-parasitic emission, and the 970-nm one makes this emission negligible [1–3].

We have studied the role of 800-nm pumping in more detail and observed a dependence of the pumping wavelength ~800 nm on the intensity of the 850-nm parasitic fluorescence.

Keywords: infrared-to-visible upconversion and lasers.

1. Introduction

For a long time we have been using a diode laser pumping at about 806–808 nm of a ZBLAN:Er^{3+} optical fiber, and have not observed the parasitic 850-nm radiation, accompanying the laser emission at 544 nm. To find the reason for this, we have replaced the diode pumping by a tunable Ti:sapphire laser, and studied the 850-nm fluorescence as a function of the pumping wavelength around 800 nm.

First of all, let us draw a simplified energy level diagram (Fig. 1) of Er^{3+} in ZBLAN glass, taking the values obtained earlier by Mortier *et al.* [4]. Lifetimes of the main energy levels involved in the process of infrared-to-visible upconversion are: $^4S_{3/2}$ – 530 µs, $^4I_{11/2}$ – 7 ms, and $^4I_{13/2}$ – 9 ms. Due to the ground state absorption (GSA), followed by excited state absorption (ESA), high population of the $^4S_{3/2}$ level is easily feasible in ZBLAN:Er^{3+} glass. The main fluorescence or laser emission at 544 nm is due to the $^4S_{3/2} \rightarrow {}^4I_{15/2}$ transition (Fig. 2). However, as it can be seen in Fig. 2, the parastic fluorescence at 850 nm is also possible. According to Boltzmann statistic, the $^4I_{13/2}$ level is empty at room temperature. As soon as the $^4S_{3/2} \rightarrow {}^4I_{13/2}$ transitions start to populate the terminal level $^4I_{13/2}$, the inversion between these two levels decreases, and because of a large lifetime of this level (9 ms), the fluorescence is largely quenched. However, the pumping with ~800 nm, due to ESA from $^4I_{13/2}$ to $2H_{11/2}$, causes a depopulation of the $^4I_{13/2}$ level and, as a consequence, the inversion between $^4S_{3/2}$ and $^4I_{13/2}$ increases.

The other mechanism that depopulates the $^4I_{13/2}$ level is the strong infrared $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition at 1.55 µm, very interesting for optical communication. So, the inversion between $^4S_{3/2}$ and $^4I_{13/2}$ can be sustained by ESA $^4I_{13/2}$ – $2H_{11/2}$ transition (at 800 nm), and emission at 1.55 µm, due to the $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition. In this way, the desired

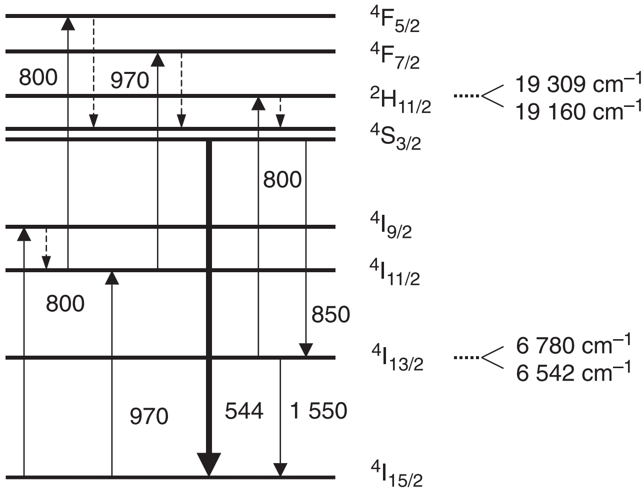

Fig. 1. Simplified energy level diagram of Er^{3+} in ZBLAN-glass. Arrows indicate the main transitions responsible for infrared-to-visible upconversion and ESA processes.

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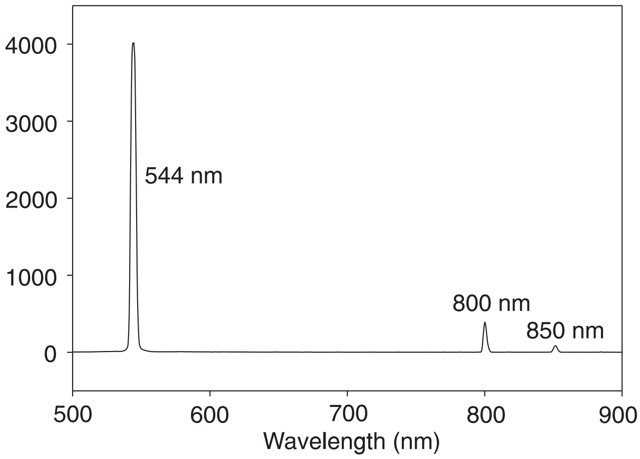

Fig. 2. Laser emission at 544 nm, pumping at 800-nm and 850-nm fluorescence.

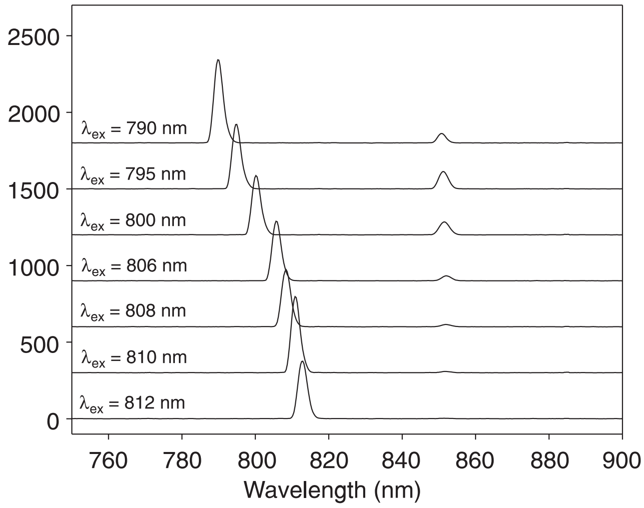

Fig. 3. 850-nm fluorescence of erbium-doped ZBLAN optical fiber as a function of pumping wavelength at about 800 nm.

$^4S_{3/2} \rightarrow {}^4I_{15/2}$ transition, generating the green beam at 544 nm, cannot be completely isolated from the two parasitic fluorescences. Using very narrowband dichroic mirror, one can decrease these emissions, however, amplified spontaneous emission (ASE) still exists, especially when the optical gain is very large. We have not studied the infrared emission at 1.55 µm.

Referring to the diagram in Fig. 1, the maximum and minimum wavelengths for the $^4I_{13/2}$–$2H_{11/2}$ transitions are: 807 nm and 783 nm, respectively. So, there are no available transitions between those two levels for pumping wavelengths above about 807 nm. For this reason, the 850-nm fluorescence was negligible or even absent when pumping above 807 nm wavelengths.

2. Experimental

The used ZBLAN: Er^{3+} optical fibers had the following characteristics: core diameter 1.9 µm or 10 µm, cladding 125 µm, Er^{3+} doping 570 or 1000 ppm. To pump the fiber, Spectra Physics Tsunami laser tuned from 790 to 812 nm was used. The emitted fluorescence at 850 nm, as dependent on the pumping wavelength, is shown in Fig. 3.

According to the above discussion, there is almost negligible 850-nm parastic fluorescence for pumping above 807–808 nm.

The point is that laser diodes with small emitting areas (1×3 µm^2), suitable for pumping of optical fibers, are hardly commercially available, and one has to use the diodes emitting at 812 nm and then, by cooling the diode, the wavelength decreases by a few nm. This pumping wavelength does not generate the parasitic 850-nm fluorescence, however, the pumping away from the centre of the absorption band is much less effective. The threshold power density for laser emission at 544 nm may be increased even to about 1 MW/cm^2 [5]. Much more effective is the pumping at 970 nm which does not depopulate the $^4I_{13/2}$ level. However, suitable diodes emitting exactly at 970 nm are also hardly available, contrary to the 980-nm diodes, commonly used to excite the erbium-doped fiber amplifiers (EDFA).

3. Conclusions

We have investigated the influence of pumping wavelength around 800 nm on the existence of 850 nm parasitic fluorescence that is usually associated with the main green laser emission at 544 nm. To eliminate the 850-nm radiation, one has to pump the laser at the wavelengths above 807 nm, or, with much better results, to apply the 970-nm pumping.

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