Optica Applicata, Vol. XXXIV, No. 3, 2004

Upconversion fluorescence and laser emission in the visible under Ti:sapphire laser pumping at 800 nm in the ZBLAN:Er^{3+} optical fiber

FRANCISZEK KACZMAREK[1], JERZY KAROLCZAK[1, 2]

[1]Quantum Electronics Laboratory, Department of Physics, Adam Mickiewicz University, ul. Umultowska 85, 61-614 Poznań, Poland

[2]Center for Ultrafast Laser Spectroscopy, Adam Mickiewicz University, ul. Umultowska 85, 61-614 Poznań, Poland

Infrared-to-visible upconversion in rare-earth doped optical fibers is a very interesting phenomenon, but its application in building a practically useful laser requires much more experimental work. In this paper, infrared-to-visible upconversion fluorescence observed perpendicularly to the fiber and laser emission in ZBLAN:Er^{3+} fiber under 800 nm excitation from a Ti:sapphire laser are described. Absorption at the pump wavelength, threshold power pumping density, and output power dependence *vs.* fiber length have been measured. The output power in the green (544 nm) amounts to 22 mW. Important technical details of the experiment are described.

Keywords: fiber laser, upconversion fluorescence.

1. Introduction

Infrared-to-visible upconversion fluorescence and laser emission in optical fibers have been intensively studied since 1989 [1], [2]. A review article of JOUBERT [3] presents a summary of the results obtained up to 1999. Later on, the number of papers dealing with lasers operating on the upconversion principle slowly decreased in time. To our knowledge, no lasers of that kind are now commercially available. There are several reasons for this. Let us mention only a few of them. Upconversion lasers are not very stable, the wall-plug efficiency is very low (only several percent). The main difficulty in constructing a Fabry–Perot (FP) cavity lies in the attachment of the fiber terminals to the dichroic mirrors. To overcome this problem one can evaporate these mirrors directly onto the fiber ends. However, to ensure cleanness of the mirrors they have to be kept in vacuum! The point is that the core diameter (several μm) is of the order of a typical dust particle, commonly present in the air. Attaching the fiber ends directly to the mirrors (butt coupling) removes this problem, however, the optical contact must

be almost perfect and stable in time. We have applied this method by pushing slightly the fiber terminal to the mirrors and then the fiber was mechanically clamped.

We have studied the infrared-to-visible fluorescence and laser emission at 544 nm under 800 nm pumping.

2. Technical details of the experiment

The ZBLAN:Er^{3+} optical fiber used had the following parameters: erbium dopping – 580 ppm, core diameter – 10 μm. The fiber was multimode at both pump and laser wavelength. Pumping source: Ti:sapphire laser, Tsunami-Spectra Physics, operating at 800 nm with maximum output power of 600 mW. The pumping beam was focused onto the fiber terminal using a Thorlabs AR coated lens of $f = 7.5$ mm. The launching efficiency obtained was quite satisfactory (73%). The entrance AR coated dichroic mirror transmits almost totally the pump beam, and reflects, also almost totally, the green radiation at 544 nm. The output mirror reflects back to the fiber the pump power that has not been absorbed, and transmits a fraction of the generated beam. In our case, we have used output mirror with 25% transmission for the green beam.

3. Experimental results

The experimental arrangement used is shown in Fig. 1. The ZBLAN:Er^{3+} fiber was 85 cm in length in this case.

The green fluorescence observed perpendicularly to the fiber, below and above the threshold for laser emission is shown in Fig. 2. Its overall shape does not change with increasing pumping power and when crossing the threshold for laser emission. A large

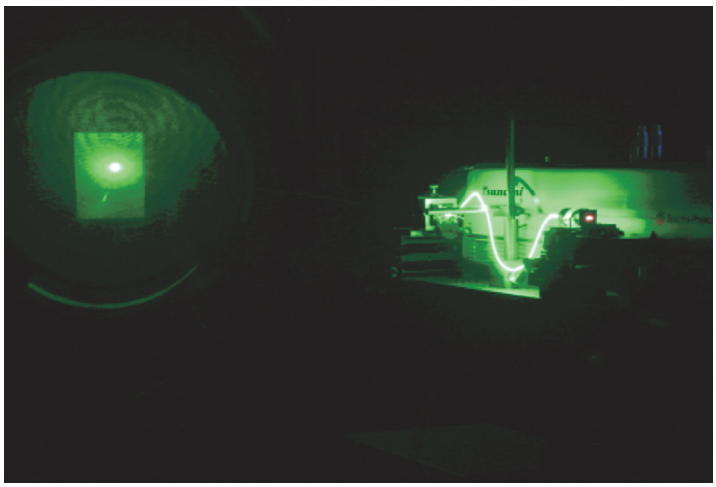

Fig. 1. Infrared-to-visible upconversion fiber laser at 544 nm pumped by Tsunami Spectra Physics Laser at 800 nm.

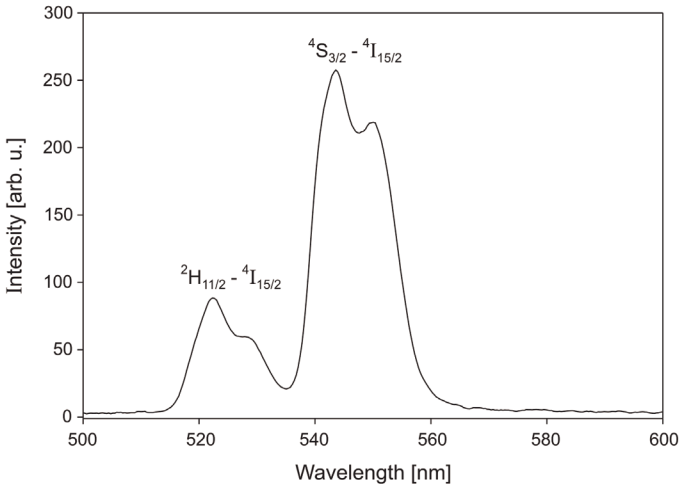

Fig. 2. Fluorescence in the green observed perpendicularly to the fiber. Transitions $^4S_{3/2} \rightarrow {}^4I_{15/2}$ correspond to the 544 nm band, and that of $^2H_{11/2} \rightarrow {}^4I_{15/2}$ – to the 522 nm band. For a complete energy level designation of Er^{3+} in ZBLAN glass see, *e.g.*, MORTIER *et al.* [9].

amount of green radiation is not being kept within the fiber core and it is purely spontaneous.

The parasitic fluorescence at 850 nm clearly seen when the fiber is pumped at 800 nm causes the emission at 544 nm to be strongly saturated. Lasers and amplifiers at this wavelength were studied by WHITLEY *et al.* [4] and MILLAR *et al.* [5]. Competition between generated beams at 544 nm and 850 nm was first observed by ALLAIN *et al.* [6]. The spectrum of the pumping beam and fluorescence at 544 nm and 850 nm is shown in Fig. 3 (no output mirror in place). In the case of laser operation, the mirror transmits 25% of the green beam, and only a very small fraction of the 800 nm and 850 nm beams. Of course, this mirror does not prevent oscillation at 850 nm. According to ALLAIN *et al.* [6], pumping at 970 nm removes the undesired 850 nm lasing. Unfortunately, our Tsunami laser cannot be tuned to that wavelength.

The decrease in pumping power along the fiber length, $P = P_o \exp(-\alpha l)$, was calculated with measured α (at the pump wavelength) equal to 0.004 cm^{-1}. The output power of the laser strongly depends upon the fiber length (see Fig. 4). Absorption of the pump power within the fiber core does not explain totally this dependence, because the threshold for laser emission is kept up to the end of the fiber, when, of course, the input pumping power is strong enough (*e.g.*, $P_{\text{input}} = 3P_{\text{threshold}}$). Output power in the green amounts to 22 mW when pumped at 800 nm with 408 mW input power. So, the efficiency is very low and amounts to 5.4%, however, we did not optimize the system. The drawback of green radiation and oscillation at 850 nm, as observed by ALLAIN *et al.* [6] may be partially responsible for this length dependence. Careful examimation of the optimum output mirror transmission and fiber length can yield better efficiency. In an earlier paper of the present author [7], we obtained maximum

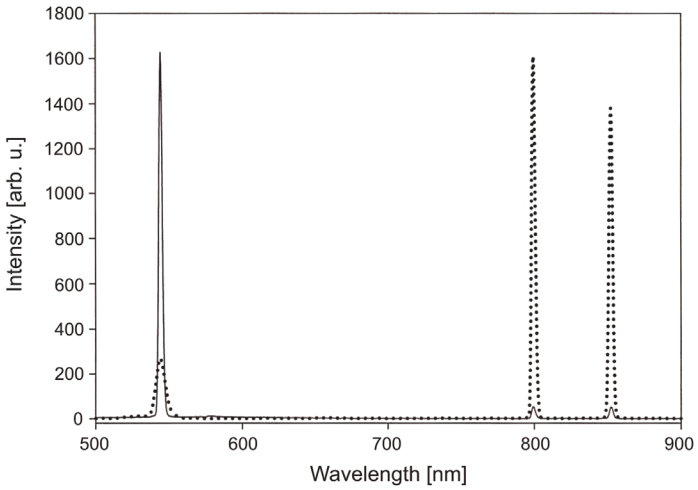

Fig. 3. Spectrum of the pumping beam at 800 nm, and fluorescence at 544 nm and 850 nm, measured at the fiber end, with no output mirror in place (dashed line). Laser emission at 544 nm with output mirror of 25% transmittance at that wavelength. The mirror reflects almost totally the beams at 800 nm and 850 nm (solid line).

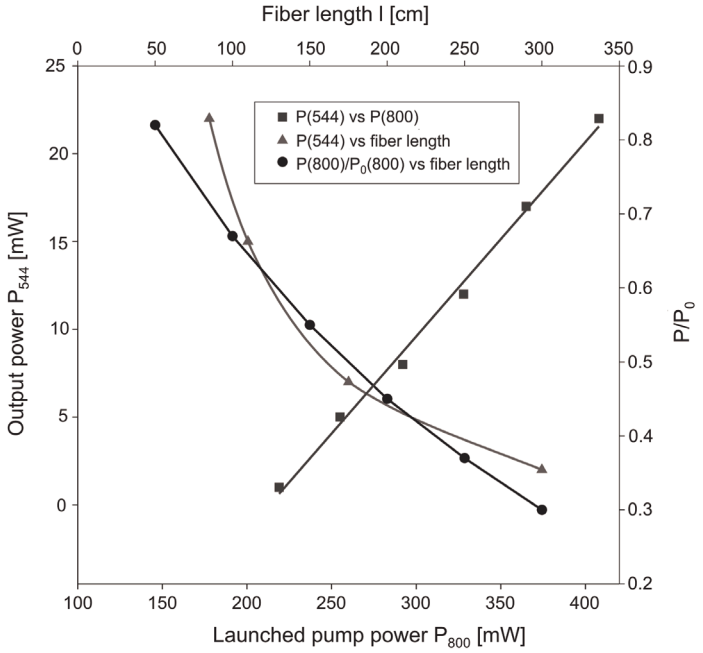

Fig. 4. Output power in the green as a function of the launched pumping power (squares) and the fiber length (triangles). A decrease of the pumping power along the fiber length due to absorption (circles).

laser power with no output mirror in place. The ZBLAN:Er^{3+} optical fiber (1000 ppm of Er^{3+} in weight) had a core diameter of 1.9 μm in this case. In an other paper of KACZMAREK *et al.* [8] we had studied the kinetics of the fluorescence and laser emission, and found that the excited state absorption (ESA) is fully responsible for the process involved. Further experiments with pumping at 970 nm, and with dichroic mirrors evaporated directly onto the fiber terminals are now in progress.

Acknowledgment – The authors would like to thank dr. Jerzy Ciosek of the Institute of Electron Technology in Warsaw for preparing the dichroic mirrors used in our work.

References

[1] MONERIE M., ALLAIN J., POIGNANT H., AUZEL F., 15-th ED CC, Gothenburg, paper TuB 12-6.
[2] WHITLEY T.J., MILLAR C.A., WYATT R., BRIERLY M.C., SZEBESTA D., Electron. Lett. **27** (1991), 1785.
[3] JOUBERT M.F., Opt. Mat. **11** (1999), 181.
[4] WHITLEY T.J., MILLAR C.A., BRIERLY M.C., CARTER S.F., Electron. Lett. **27** (1991), 184.
[5] MILLAR C.A., BRIERLY M., HUNT M.H., CARTER S.E., Electron. Lett. **26** (1990), 1871.
[6] ALLAIN J.Y., MONERIE M., POIGNANT H., Electron. Lett. **28** (1992), 111.
[7] KACZMAREK F., JENDRZEJCZAK A., Opt. Appl. **29** (1989), 371.
[8] KACZMAREK F., STRYŁA Z., JENDRZEJCZAK A., Appl. Phys. **B73** (2001), 125.
[9] MORTIER M., HUANG Y.D., AUZEL F., J. Alloy. Compd. **300–301** (2000), 407.

Received November 25, 2003