

# Lifetime measurements of the fluorescent level, $^4S_{3/2}$ , of erbium-doped silica optical fibers

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It is well known that effective infrared-to-visible upconversion can be easily obtained in ZBLAN (fluoride glass) doped with rare earth ions. The visible fluorescence is extraordinary strong in ZBLAN optical fibers, leading to laser operation when the fiber terminals are butt coupled to the resonator mirrors. On the other hand, the standard silica fibers doped with these ions exhibit very weak infrared-to-visible upconversion because of extremely large quenching of the appropriate fluorescence levels. The aim of this work was to measure the lifetime,  $^4S_{3/2}$ , of erbium ion before and after the fiber has been drawn from the silica based preform.

## 1. Introduction

The fibers under investigation were obtained using standard procedure (MCVD) at the Laboratory for Optical Fiber Technology at the University in Lublin. The  $SiO_2$  fiber core was doped with erbium (from 700 to several thousand ppm). In the first step, a preform of a diameter of a few millimeters has been prepared, and then a sample of about 2 mm in thickness has been cut out and optically polished (Fig. 1). The remaining part of the preform was placed in a special gradient oven and the fiber was pulled off. In this way, we could compare the lifetime of the fluorescent level,

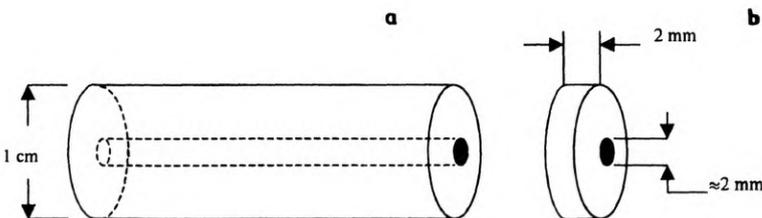


Fig. 1. Initial preform with erbium doped core (a), and the sample for fluorescence measurements (b)

$^4S_{3/2}$ , in a bulk medium, *i.e.*, in the preform core, and then in the fiber. Measuring of the lifetime in the fiber, and especially when the fiber is very thin, say of the order of a few microns, is not an easy task. On the other hand, measurement of this lifetime in a platelet cut out of the preform is very simple.

## 2. Experimental

A typical attenuation curve for erbium doped (about 1000 ppm) optical silica fiber containing also 10000 ppm of Al is shown in Fig. 2. The strong absorption bands around 800 nm and 1000 nm are widely used to excite the fiber with diode lasers (Fig. 3), and then to observe the infrared-to-visible upconversion.

Lifetime of the upper fluorescence level,  $^4S_{3/2}$ , has been measured using two different methods. The first one was the so-called frequency domain method, described in detail by LAKOWICZ [1], and the second one — with the help of an

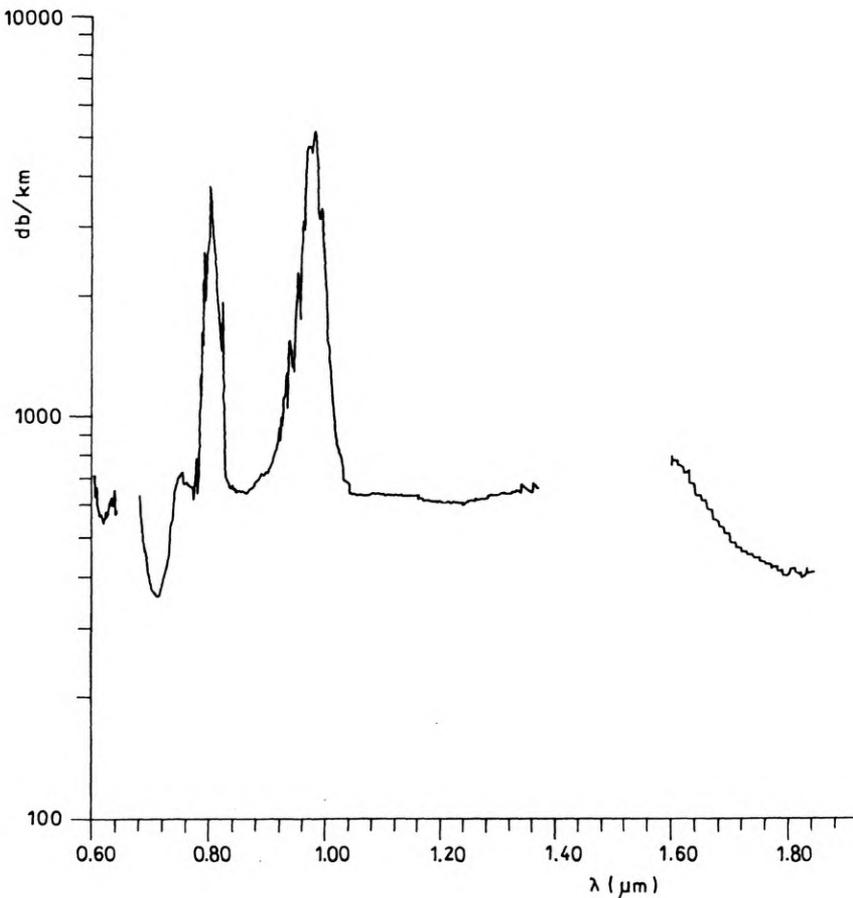


Fig. 2. Attenuation curve for erbium doped silica fiber

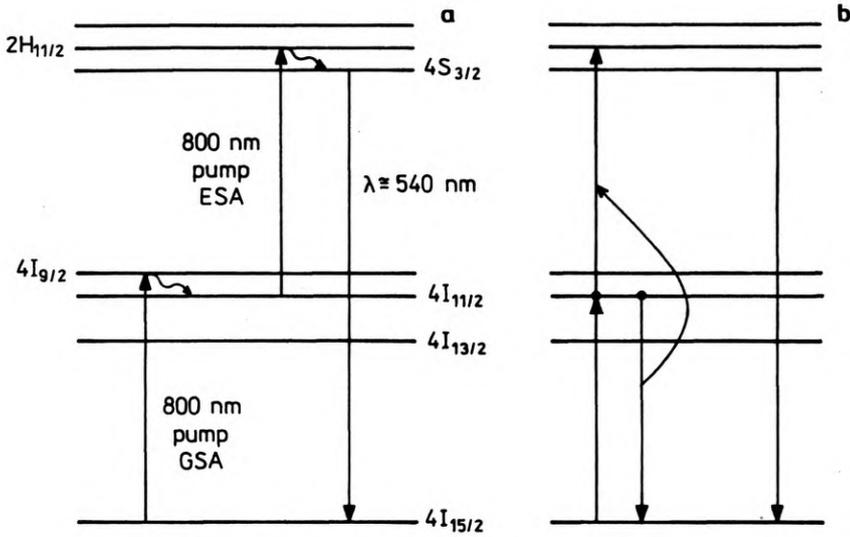


Fig. 3. Simplified energy level diagram of erbium doped silica illustrating infrared-to-visible upconversion. Population of the  $^4S_{3/2}$  fluorescence level may be caused by excited state absorption (GSA) – a, or by an ion pair cooperative process – b. Both processes can also be involved simultaneously

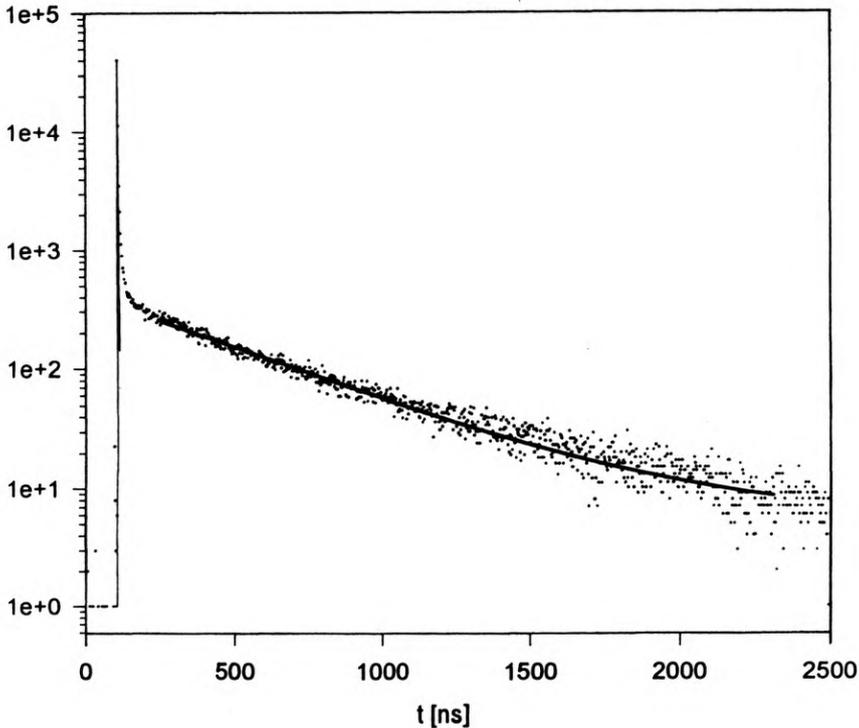


Fig. 4. Decay of the fluorescence level,  $^4S_{3/2}$  observed at 540 nm (in arb. units). Excitation – 800 nm nanosecond pulse

optical parametric oscillator (OPO) producing nanosecond pulses at any desired wavelength, and a very fast detecting system to observe the fluorescence decay in time. It is very important that both methods yielded the same results. Observing the weak fluorescence at about 540 nm (in comparison to ZBLAN glasses or fibers), we anticipated very strong quenching of the  ${}^4S_{3/2}$  level, and the results obtained fully certified this expectation. A typical fluorescence decay in the preform is shown in Fig. 4. An initial very fast decay is then followed by a relatively slow decrease. Precise computer fitting for the second part of this decay yielded a lifetime in the range from 460 to 480 ns, very weakly dependent upon doping from about 700 ppm to 1250 ppm of erbium.

The measurements were then repeated for the fiber drawn out of the preform, and the results obtained were the same (within a few tens of nanosecond). In this way, we can be sure that redistribution of the active ions within the core of the fiber, which obviously takes place when the fiber is being pulled out, does not change the interaction between the active ions and their surroundings, as compared to a bulk medium.

Lifetime of the  ${}^4S_{3/2}$  level less than 1  $\mu$ s, i.e., extremely large quenching of visible fluorescence in erbium doped silica, completely eliminates the medium for application as infrared-to-visible upconverters, and especially – for upconversion lasers. Fortunately, the fluoride glasses (ZBLAN), because of low energetic phonon spectra, exhibit relatively large lifetimes of the order of several hundred microseconds.

Summing up, we have shown that lifetime of the fluorescence level,  ${}^4S_{3/2}$ , of erbium doped silica fiber is extremely small and, furthermore, instead of measuring this lifetime in a fiber, one can use a preform sample, with equal results.

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#### Reference

[1] LAKOWICZ J., *Principles of Fluorescence Spectroscopy*, Plenum Press, New York 1986.

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