Influence of Hydrogen Loading on Active Fibers

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Abstract: Additional quenching of Er, Yb, Nd, and Bi luminescence in hydrogen impregnated silica optical fibers is revealed. Phenomenon is explained by deactivation of activators' excited states via collisions with hydrogen molecules migrating inside the glass network

OCIS codes: (060.2400) Fiber properties; (060.2410) Fibers, erbium

1. Introduction

Hydrogen loading is used for in-fiber Bragg gratings writing. Photo-chemical interaction of dissolved H_2 molecules with UV laser induced electronic excitations significantly quickens grating formation in Ge-doped silica-core fibers [1]. Similar photochemistry strongly slows down the rate of radiation-induced color center formation in undoped silica [2]. Positive impact of dissolved hydrogen on characteristics of EDFAs intended for operation in space radiation environment is found as well [3,4]. At the same time, it is known that dissolved H_2 molecules are able to deactivate excited defects. In particular, presence of H_2 molecules leads to the decrease of life time and steady state intensity of triplet luminescence associated with Ge oxygen deficient centers in fibers [5]. The effect quickly disappears with temperature decrease indicating its collisional origin. As it is known [6], hydrogen molecules dissolved in silica keep alive not only vibration modes but rotation ones as well. One can suppose therefore that above mentioned collisional deactivation is quite common phenomenon likewise for active fibers thus degrading effectiveness of their operation in fiber lasers and amplifiers. Current study provides for the first time to the best of our knowledge experimental evidence of collisional deactivation of optically pumped Er^{3+}, Yb^{3+}, Nd^{3+} ions as well as bismuth near-infrared luminescence centers in silica fibers by dissolved hydrogen molecules.
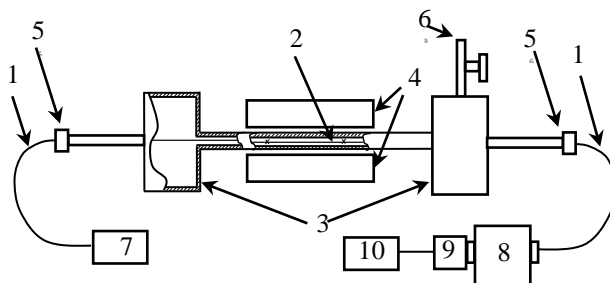
2. Experimental set up and active fiber samples

Fig. 1. Experimental set-up: 1 – pump/luminescence delivery fiber, 2 – active fiber, 3 – buffer capacities, 4 – local heater, 5 – sealed flanges, 6 – gas inlet/outlet, 7 – pump LD, 8 – grating monochromator with a pump wavelength reflecting notch filter at the entrance slit, 9 – photoreceiver, 10 – oscilloscope.

Experimental set-up is shown in Fig 1. Piece of active fiber under study of up to 5 cm in length is spliced with two pigtails forming a single line. Section of the line with active fiber sample is placed and sealed in a chamber hereafter filled by hydrogen at a pressure of 110 bars. Temperature inside the chamber section having active fiber inside is maintained at 403±0.3 K with the help of external heater. Photoluminescence is excited by LDs operating in a 30 ms meander mode at 975 nm or 808 nm wavelengths depending on activator type (see Table). Average power launched to the fiber does not exceed 1 mW. Luminescence through the opposite end of the fiber line is delivered to the input slit of a grating monochromator through a notched optical filter reflecting unabsorbed pump light. Luminescence decay is recorded at the output slit of monochromator by GaAs based photodiode connected to Tektronix DPO3012 oscilloscope. Operation speed of LDs pump modulation and photodiode recording systems makes it possible to measure luminescence decay time as short as 0.05 ms. The experiment consists of two stages. At the first one, immediately after filling in the chamber containing a fiber inside with hydrogen, luminescence decay curves are recorded from time to time while hydrogen enters the fiber core. Hydrogen concentration in the fiber core as a function of time is calculated in accordance with known formula for diffusion [7]. At the second stage luminescence decay kinetics is recorded as a function of temperature. To do that extracted from the chamber hydrogen loaded fiber

is quickly cooled down to liquid nitrogen temperature and then slowly warmed up to room temperature with continuous recording of luminescence decay curves at various temperatures. Polymer coated multimode alumosilicate-core silica fibers of 125 microns in outer diameter are used in all above mentioned experiments. The fibers are drawn from preforms fabricated by SPCVD [8]. The fibers are of step index profile with NA~0.1. Core diameters of all fibers including delivery one amount to about 20 microns.

Table. Specification of active fibers used in the experiments

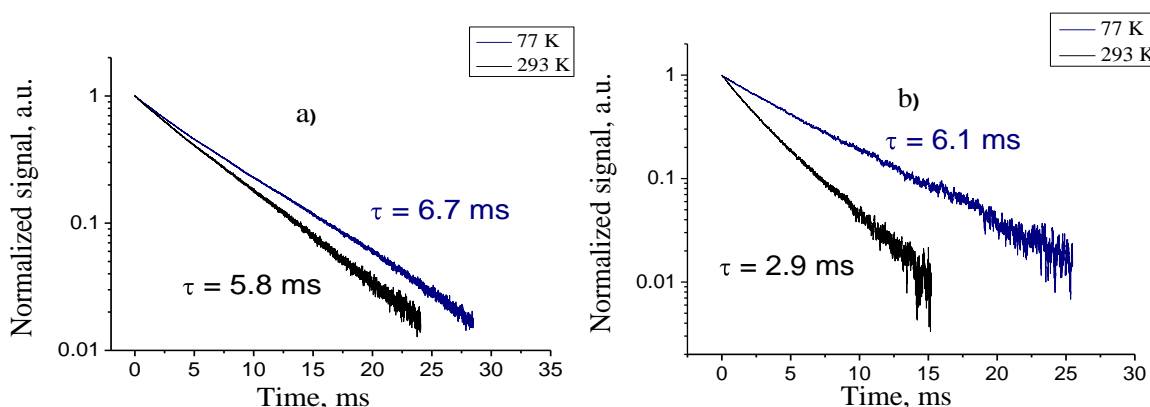| Activator	Pump wavelength, nm	Emission wavelength, decay time constant (nm/ms)	Absorption at pump wavelengths, dB/mm	Sample length, mm
Er	975	1532/5.75	0.08	40
Nd	808	1060/0.50	0.093	40
Yb	975	1020/0.88	1	10
Bi	975	1150/0.81	0.007	50

3. Results

Fig. 2. Luminescence decay kinetics of the $I_{13/2}$ - $I_{15/2}$ transition in Er^{3+} ions in unloaded (a) and hydrogen loaded (b) fibers recorded at 77K and 293K temperatures.

All samples show single exponential decay of luminescence. Fig. 2 presents the results of measurements for Er-doped fiber as an example. It is seen that at room temperature hydrogen loading adds to decay rate of the $I_{13/2}$ excited state of Er^{3+} ions.
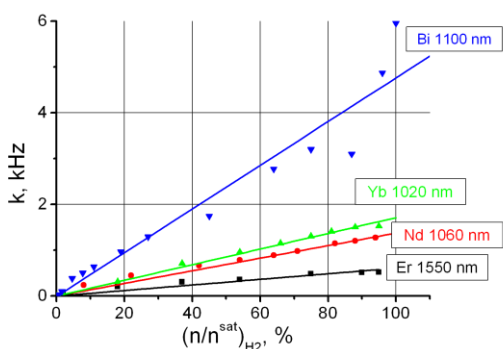

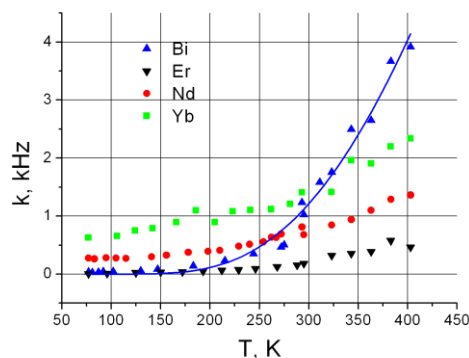Fig. 3. Deactivation rate *k* at a temperature of 430 K as a function of relative hydrogen concentration.

Fig. 4. Deactivation rate *k* at saturation as a function of temperature.

Assuming n_{H2} – concentration of hydrogen molecules, P – probability of collisional deactivation of excitation per unit time per one molecule in a unit volume, measured in the experiment luminescence decay time constant τ after [5] could be expressed as:

$$\tau^{-1} = \tau_{rad}^{-1} + P(T) * n_{H2} \qquad (1),$$

where τ_{rad} - decay time constant in the absence of hydrogen, T – temperature. Fig. 3 shows dependences of hydrogen associated collisional deactivation rate k defined as $k = \tau^{-1} - \tau_{rad}^{-1}$ on relative hydrogen concentration in fiber core. Fig. 4 illustrates dependences of k on temperature for $n_{H2} = n_{H2}^{sat}$, where n_{H2}^{sat} – hydrogen concentration in the fiber core at saturation. In conditions of our experiments, $n_{H2}^{sat} \sim 10^{20}$ cm^{-3} at room temperature.

4. Discussion

Collisions of interstitial hydrogen molecules experiencing Brownian motion inside glass network with active centers lead to energy transfer from excited electron subsystems of the latter to vibration degree of freedom of H$_2$ molecules. We tested that substitution of hydrogen by monatomic helium totally removes the above-described deactivation effect. As it is seen from Fig. 3, deactivation probabilities P defined according to (1) as slope coefficients of the k(n$_{H2}$) strait lines differ for different activators. The value of P is greater for bismuth active centers, likely due to their preferable location in glass voids [9]. Owing to non-uniformity of spatial distribution of hydrogen molecules inside silica network [10], one can expect greater collision frequency with interstitial H$_2$ molecules clustered in the voids. Closer vicinity of active centers to pathways of H$_2$ molecules in the process of their Brownian motion inside silica network could be a reason for sharper dependence of deactivation rate on temperature (Fig. 4). The other reason is proximity of excitation energy gap of a particular activator to the excitation energy of the second vibration overtone of an H$_2$ molecule. Inversely, greater energy mismatch between I$_{13/2}$ - I$_{15/2}$ transition of Er^{3+} ion and H$_2$ molecule vibration overtone yields smaller value of P(Fig.3).

5. Conclusion

We have demonstrated that the presence of hydrogen molecules in glass network provides additional way for non-radiative transitions of activators from excited-to-ground states and therefore negatively affects pump efficiency of fiber lasers and amplifiers. This means that advantages of hydrogen loading for radiation hardness reported in [3-4] are mainly associated with induced loss decrease, which richly compensates degradation of pump efficiency. Comparison study performed gives a ground to consider collisional deactivation of excitations as a useful tool to investigate nearest neighbor environments of different activators in silica based optical fibers. Technically experimenting with luminescence in hydrogen loaded active fibers could provide an extra way for deeper insight in specific features of hydrogen molecules motion inside various glass networks.

6. References

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