Spectroscopic properties of Yb^{3+} ions in $Li_6Y(BO_3)_3$ single crystals

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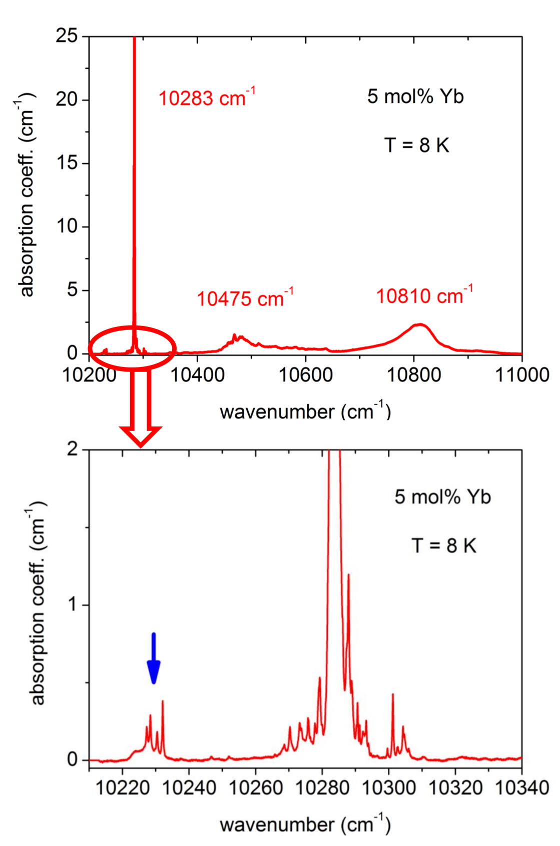
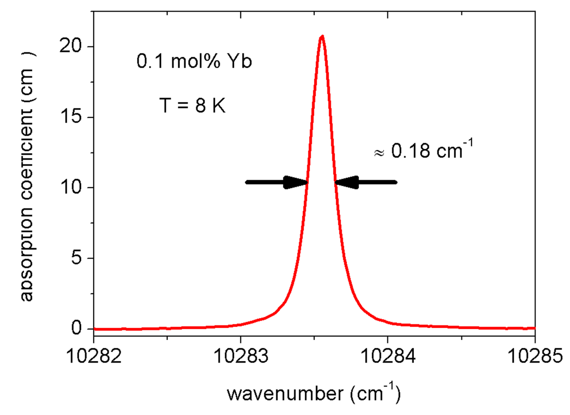
Introduction

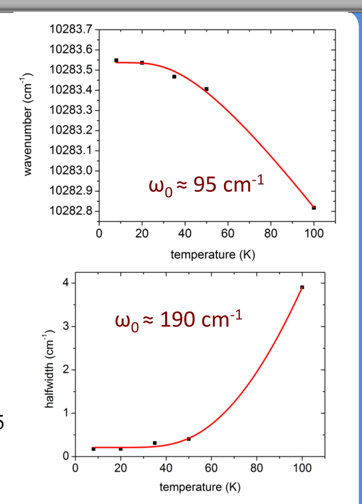
Lithium yttrium borate (LYB) crystals with a monoclinic structure of the $P2_1/c$ space group are excellent candidates for laser host due to their flexibility and the easy incorporation of rare earth dopants (e.g. Nd^{3+}, Er^{3+}, Yb^{3+}). Mode-locked and Q-switched laser operation near 1042 nm in Yb-doped LYB [1] and diode-pumped 1594 nm laser performance in Er and Yb co-doped LYB have been realized recently [2]. Absorption and emission spectroscopies have been used to determine the crystal field splittings of the 4f-type $^2F_{7/2}$ ground and $^2F_{5/2}$ excited states of Yb^{3+} [3, 4]. Two zero-phonon transition lines observed at about 10225 and 10283 cm^{-1} were interpreted as belonging to two kinds of Yb^{3+} defects present in heavily doped (26 mol%) single crystals: isolated Yb^{3+} ions substituting for Y^{3+}, and Yb-Yb pairs [5].

In the present work high resolution absorption and luminescence spectra of LYB:Yb^{3+} were measured between 8-300 K. The Stark levels of the $^2F_{7/2}$ and $^2F_{5/2}$ multiplets of the Yb^{3+} ion have been determined with high accuracy. For quantum optical experiments the lifetime of the excited levels (T_1) and the coherence times (T_2) of the involved ionic states have to be determined. Both time constants of the 10283.5 cm^{-1} transition of the Yb^{3+} ions have been measured by means of pump-probe spectral hole burning experiment.

Absorption spectroscopy





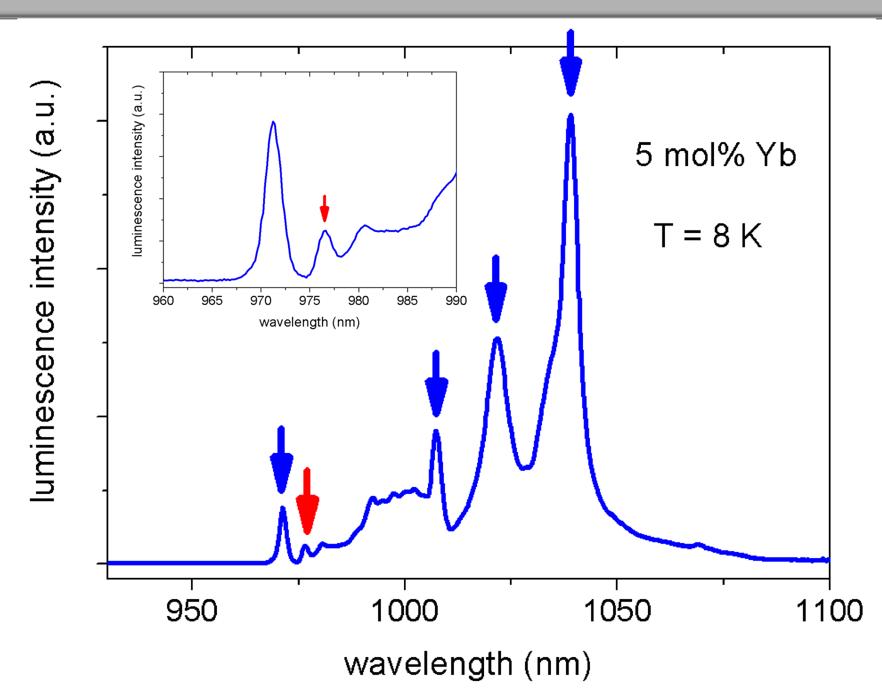


$\nu(T)=\nu_0+\delta\omega(\exp(\beta\hbar\omega_0)-1)^{-1}$

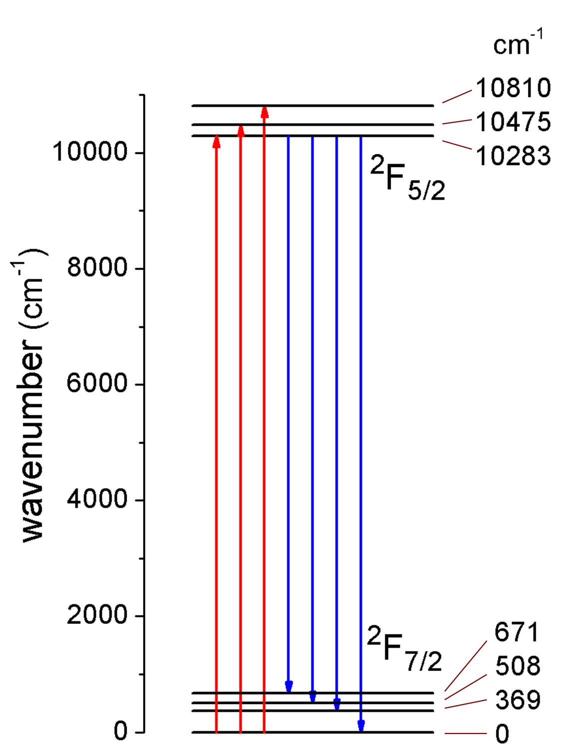
$\Delta\nu(T)=\Delta\nu_0+2(\delta\omega)^2\gamma^{-1}\exp(\beta\hbar\omega_0)(\exp(\beta\hbar\omega_0)-1)^{-2}$

The absorption spectrum exhibits the crystal field splitting of the $^2F_{5/2}$ excited state: a sharp line (FWHM≈0.18 cm^{-1}) at about 10283.5, and two broad lines at about 10475 and 10810 cm^{-1}. In LYB highly doped with Yb (5 mol%) a series of narrow lines appear close to the main transition at 10283 cm^{-1}. The lines may originate from Yb ions on Y sites slightly perturbed by lattice defects. The blue arrow indicates a group of lines between 10220-10240 cm^{-1} attributed earlier to Yb pairs [5] (see also the red arrow below on the luminescence spectrum at about 977 nm).

Luminescence spectroscopy



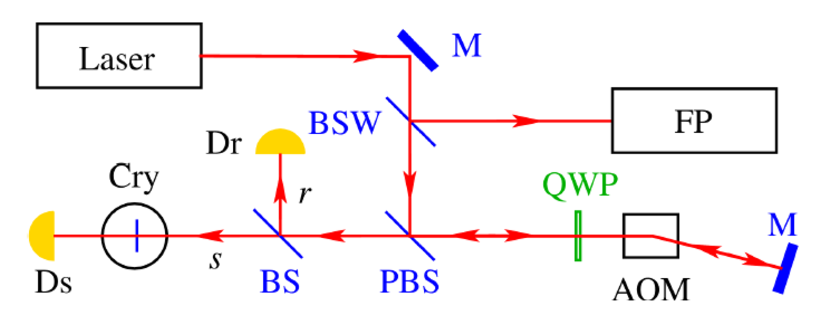
Emission spectrum excited at 917 nm. The four emission lines correspond to the Stark levels of the $^2F_{7/2}$ ground state. The red arrows indicate an additional line already observed in highly Yb-doped (26 mol%) LYB [5] and attributed to the presence of Yb-Yb pairs. We cannot exclude that the line at about 977 nm (≈10235 cm^{-1}) is due to the presence of other rare earth impurities (e.g. Dy).



Stark levels of Yb^{3+} in LYB

Experimental

LYB crystals doped with 0.1, 1 or 5 mol% Yb were grown by the Czochralski method [6]. High resolution absorption spectra were measured between 8-300 K by a Bruker IFS 120 HR spectrometer. The luminescence spectra were measured by a Horiba Jobin Yvon Fluorolog 3 spectrofluorometer. The schematic drawing of the experimental setup for spectral hole burning is shown here:

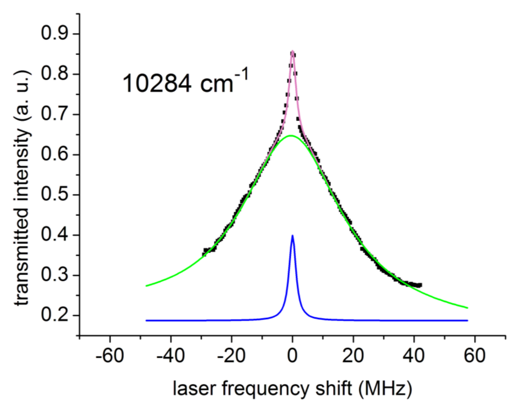


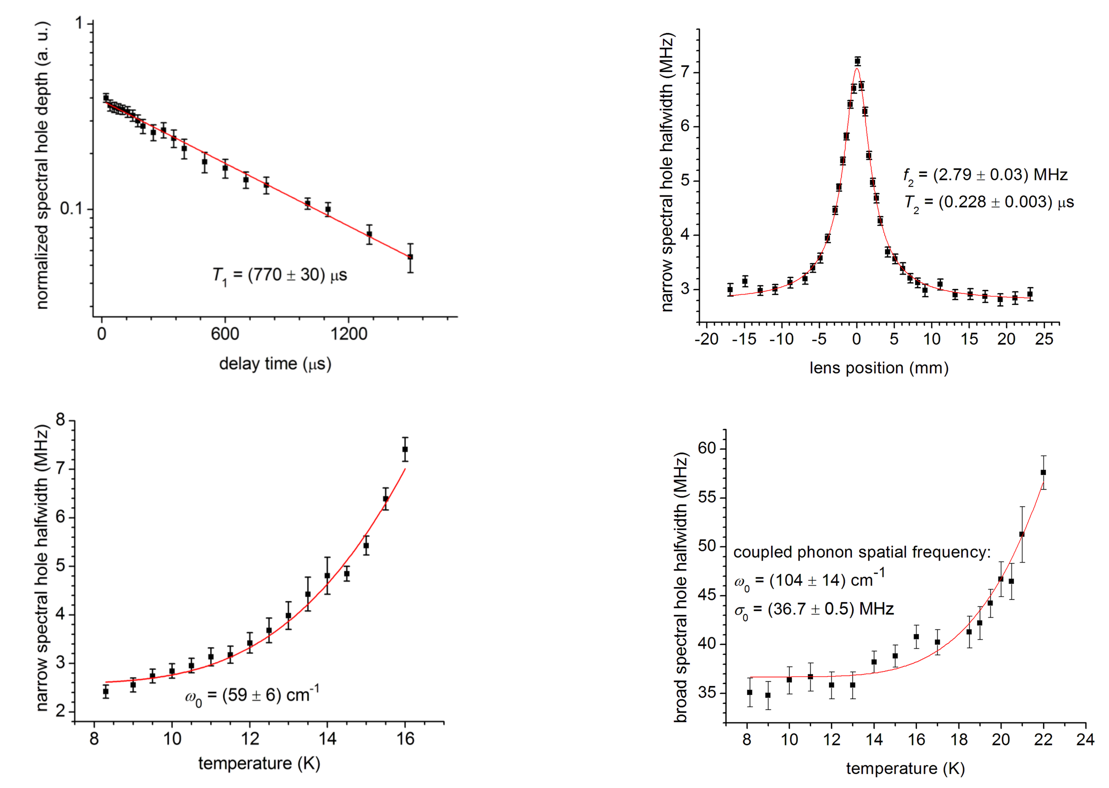
A temperature stabilized external cavity diode laser has been used as a light source with piezoelectric frequency scanning capability. An acousto-optic modulator (AOM) has been used in a double-pass configuration for two purposes: to chop the light to get pulses with several microsecond length, and to perform small range frequency scans (±50 MHz around the central frequency).

Spectral hole burning

A curious double peak structure has been found: a peak of 30-50 MHz width is superposed by a narrow peak of 1-2 MHz width. A similar effect with similar parameters has been obtained in lithium niobate crystals [7]. One may attribute this phenomenon to an isotope effect. Most of the stable natural isotopes of Yb have zero nuclear spin, but there is also an I=1/2 and an I=5/2 isotope with less abundance. The ions with non-zero nuclear spin presumably have homogeneous linewidths differing from those with zero spin, hence one observes the double peak spectral hole structure. An alternative explanation would be that despite the small inhomogeneous width there are different, non-equivalent environments of the dopant ions hence the Yb ions experience different local crystal fields.

	T_1 (μs)	T_2 (ns)	ω_0
narrow	770±30	228±3	59±6
broad		17±2	104±14





Summary

- The Stark levels of the $^2F_{7/2}$ and $^2F_{5/2}$ multiplets of the Yb^{3+} ion in $Li_6Y(BO_3)_3$ crystals have been determined with high accuracy.
- The high resolution spectra exhibit a number of lines originating either from Yb on Y sites perturbed by lattice defects or from other rare earth ions present in the crystal as unwanted impurities.
- The lifetime (T_1) and the coherence time (T_2) of the 10283.5 cm^{-1} transition have been determined by spectral hole burning experiment.
- A curious double peak structure of the spectral hole has been observed similarly to that found in Yb-doped $LiNbO_3$ [7].

Acknowledgements

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References

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