Spectroscopic Characterisation of Yb:LiLuF_4 between (63-293)K

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Abstract: Absorption and emission cross-section spectra for Yb:LuLiF_4 are reported for sub-ambient temperatures. Significant deviation from reciprocity between them highlights the importance of electron-phonon coupling in this material and benefits thereof for diode-laser pumping.

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1. Introduction

Yb-doped crystals have garnered much popularity in recent years as gain media for efficient solid-state lasers. Coupled with an enhancement in spectroscopic and thermo-optical properties when aggressively cooled, cryogenic ytterbium lasers systems offer high pulse energies with high average powers [1].

A relatively unexplored material, Yb:LuLiF_4, with similar properties to its isomorph Yb:YLiF_4, has very favourable characteristics in the cryogenic regime. Here we characterise its lifetime, absorption, and, emission cross sections for both π- and σ-polarisations, over the temperature range 293 K to 63 K. These results will be useful for future modelling, and engineering, of cryogenically-cooled Yb:LuLiF_4 lasers.

2. Methodology

The absorption cross section for both π- and σ-polarisations was throroughly characterised by means of a simple small signal absorption setup, as previously detailed in [2]. A white-light source, coupled to a 200 μm, 0.22 NA optical fibre was imaged, through a Glan-Thompson polariser, delivering ~ 3 mW to a 3.9%-doped 0.44 mm long crystal. The transmitted light was collected by an equivalent fibre attached to an Optical Spectrum Analyser (OSA). Setting the crystal's temperature within the range of $(293-63)$ K was achieved with a closed-loop cryostat (Q-Drive 2s132K). Absorption properties were then determined via standard means.

In order to measure the emission cross section, the output from a 960 nm fibre-coupled IPG diode-laser, operated in a QCW-regime (9 ms pulses, 2.25% duty-cycle, ~ 24 W incident peak power), was imaged to a spot-radius of ~ 450 μm overlaying the white-light probe. This setup was also used for later pump-probe measurements. Fluorescence, and its lifetime, were recorded using the OSA (or photodiode) immediately after the pump light vanished. Triggering of the OSA was synchronised by an Arduino to execute the measurements at set delays, which also defined the population inversion probed, determined with reference to the decay in fluorescence intensity. Emission cross section was then determined via the F-L method [3].

3. Experimental results and discussion

As shown in Fig. 1, the cross sections of the electronic transitions narrow and increase, displaying very slight shifts in energy, with decreasing temperature. The principal peak at 960 nm, for both polarisations, has an almost tenfold increase in amplitude and equivalent decrease in bandwidth. Of particular note however, is the broad ~ 20 nm vibronic absorption feature for σ-pol [4], which coincides with direct emission from commercially available high-power diode lasers. Although significantly weaker than the 960 nm peak, this broad plateau could simplify the pump configuration, eradicating the need for its wavelength stabilisation.

Using the measured lifetime (at 63 K) of (1.90 ± 0.02) ms, similar dependencies are observed for the emission cross section (Fig. 2), with regard to increasing transition strength and structured nature of the spectra. In common with the absorption there is strong electron-phonon coupling for the σ-pol, as previously discussed by [4,5], evident in the broad features around 1000 nm. Notwithstanding, the prime wavelength of interest is the 995 nm peak for π-pol, which bifurcates at low temperatures and has a near-tenfold increase going from 293 K to 63 K. Although the data in Fig. 2 agrees with cross section values reported in [4], the effective emission cross section estimated from the measured absorption cross section via the reciprocity method [6] weren't comparable within uncertainties with the former. This is explained by the breakdown in reciprocity when vibronic interactions are significant [7]. Pump-probe gain measurements are in progress to establish the actual gains achievable for this crystal.

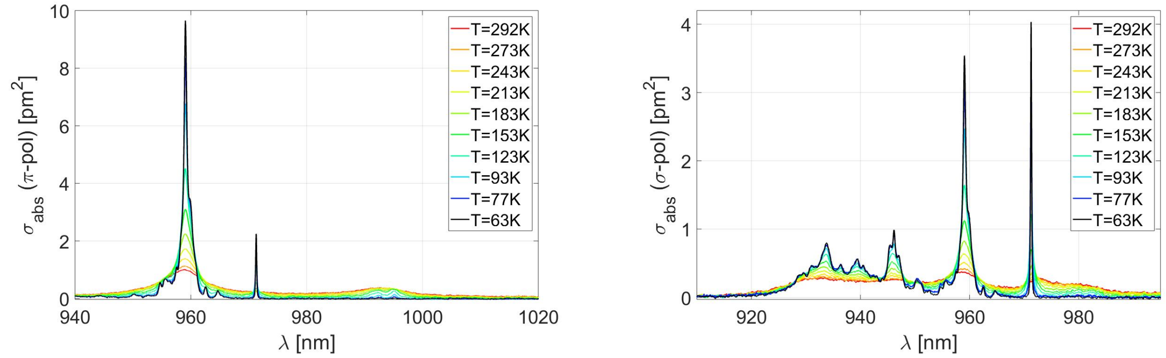

Fig. 1. π-pol and σ-pol absorption cross sections.

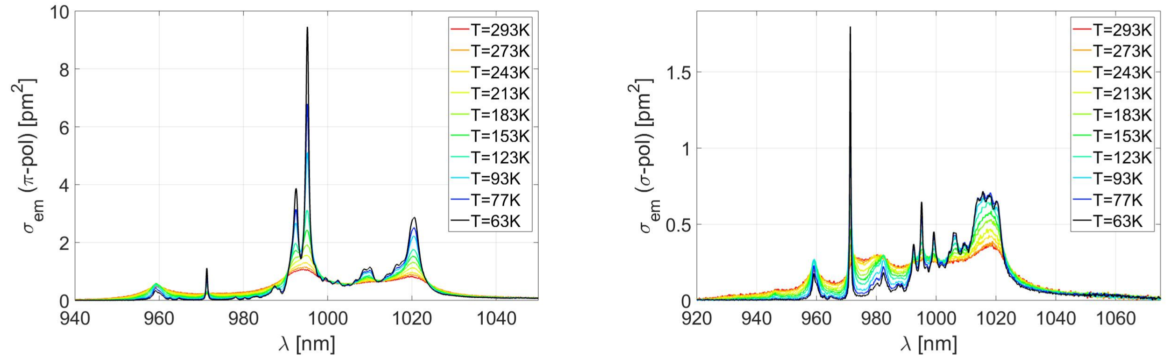

Fig. 2. π-pol and σ-pol emission cross sections.

4. Conclusions

In conclusion, we have characterised extensively the π- and σ-pol absorption and emission cross sections over temperatures from 293 K to 63 K via small-signal absorption measurements and the F-L method, respectively. The discrepancy between the results given by the latter and the reciprocity methods motivates a further, work-in-progress, investigation of the emission cross sections via pump-probe measurements.
These results will have further impact on the design of diode-pumped cryogenically-cooled Yb:$LuLiF_4$ lasers.

References

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