Temperature Dependence of Transition Cross Sections in Rare-earth-doped Laser Materials

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The transition cross sections on the pump and laser wavelength of rare-earth-doped materials are of crucial importance for their performance as amplifiers and lasers and for the understanding of their performance in a rate-equation model. Since typically part of the absorbed pump power is converted to heat, the temperature of the host material increases with increasing pumping. This implies a temperature-dependent change of the transition cross sections, which needs to be carefully quantified.

We investigate the temperature dependence of the absorption cross sections in $KRE(WO_4)_2$ thin films activated by Yb^{3+}. The change of the peak-absorption cross-sections at 981 nm with temperature is governed by the combination of two effects, the change of Stark-level population and the linewidth broadening due to intra-manifold single-phonon relaxation. The theoretical analysis is applicable to other rare-earth-doped crystals and will be valuable for assessing the temperature-dependent absorption of new gain materials.

The sample consists of a layer of $KYb_xGd_{1-x}(WO_4)_2$, with an Yb^{3+} concentration of 57.5 at.%, grown onto 1-mm-thick, **b**-oriented $KY(WO_4)_2$ substrates by liquid-phase epitaxy using a $K_2W_2O_7$ solvent at 920−925°C [1]. A dual-beam spectrophotometer with a spectral bandwidth of 1 nm is used together with a near-infrared polarizer with >400:1 extinction ratio to determine the absorbance with $E \| N_m$ and $E \| N_g$ polarization by wavelength scans from 900 nm to 1050 nm with data acquisition in 0.1 nm steps. A copper sample holder in contact with a Peltier element varies the temperature in steps of 10°C between 20 and 170°C. The sample temperature is determined using a thermoelectric temperature controller.

Figure 1(a) shows the evolution of the absorption cross section versus temperature. As the temperature is increased, the central absorption line near 981 nm reduces rapidly [2]. The wavelength corresponding to the peak is slightly blue-shifted from 980.8 nm to 980.5 nm. The multiple peak fitting is performed using a data analysis program. Representative fitted absorption curves measured at 20°C and 170°C are depicted in Figs. 1(b) and 1(c). We find that the peak-absorption cross section decreases with increasing temperature due to the temperature dependence of i) the Boltzmann factor of the starting Stark level and ii) the increase in absorption linewidth caused by intra-manifold transitions due to electron-phonon coupling on the fs time scale according to the Bose-Einstein statistics quantifying occupation of a phonon mode as a function of temperature [2]. Our experimental results show good agreement with the theory and confirm the strong influence of linewidth broadening on the reduction of peak-absorption cross-section values within the temperature range investigated.

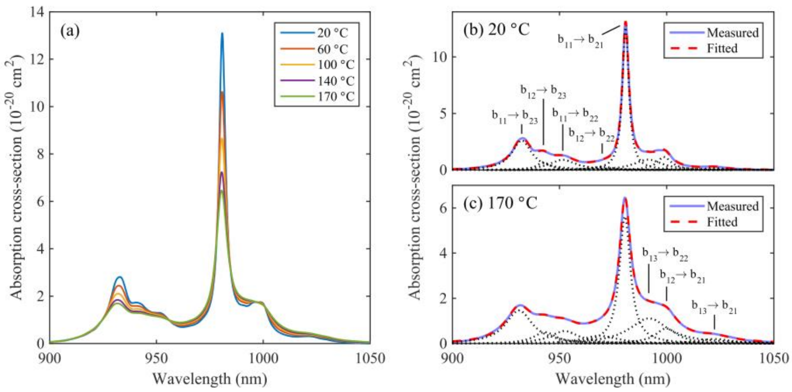

Fig. 1 (a) Temperature dependence of the absorption cross-section of the $KYb_{0.57}Gd_{0.43}(WO_4)_2$ sample. Multi-peak fitted absorption cross-section at (b) 20 °C and (c) 170 °C. The dotted lines show the decomposed peaks corresponding to different inter-Stark transitions. The eight transition wavelengths are labeled and positioned near to one of the curves where its decomposed peak is more pronounced.

References

[1] S. Aravazhi, D. Geskus, K. van Dalfsen, S. A. Vázquez-Córdova, C. Grivas, U. Griebner, S. M. García-Blanco, and M. Pollnau, "Engineering lattice matching, doping level, and optical properties of $KY(WO_4)_2$:Gd, Lu, Yb layers for a cladding-side-pumped channel waveguide laser," Appl. Phys. B 111, 433 (2013).

[2] Y. S. Yong, S. Aravazhi, S. A. Vázquez-Córdova, J. J. Carvajal, F. Díaz, J. L. Herek, S. M. García-Blanco, and M. Pollnau, "Temperature-dependent absorption of potassium double tungstates with high ytterbium content", Opt. Express 24, 26825 (2016).

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