Spectral characteristics of $Nd^{3+}/Yb^{3+}:YPO_4$ single crystal with strong multi-wavelength emission

Yang Che‡[a], Fei Zheng‡[a], Jingyao Lu[a], Yanzhen Yin[a], Zhen Wang[a], Degao Zhong[abc], Shijia Sun*[ab] and Bing Teng*[abc]

[a] College of Physics, University-Industry Joint Center for Ocean Observation and Broadband Communication, Qingdao University, Qingdao 266071, China

[b] National Demonstration Center for Experiment Applied Physics Education (Qingdao University), Qingdao 266071, China

[c] Shandong Provincial University Key Laboratory of Optoelectrical Material Physics and Devices, Qingdao 266071, China

* Corresponding author. E-mail: ssj1027@126.com (Shijia Sun), 5108tb@163.com (Bing Teng)

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‡ Yang Che and Fei Zheng contributed equally to this work.

Eqn. S1 $PbHPO_4$ decomposes chemical reaction equation.

Eqn. S2 $Nd_x:Yb_y:Y_{(1-x-y)}PO_4$ synthesis chemical reaction equation.

Calculations of emission cross-sections. (Equations S3-S5)

Calculations of I_{sat}, β_{min} and I_{min}. (Equations S6-S8)

Eqn. S1 $PbHPO_4$ decomposes chemical reaction equations.

$$2PbHPO_4 = Pb_2P_2O_7 + H_2O \qquad \textbf{(S1)}$$

Eqn. S2 Nd_x:Yb_y:$Y_{(1-x-y)}PO_4$ synthesis chemical reaction equation.

$$Pb_2P_2O_7+(1-x-y)Y_2O_3+xNd_2O_3+yYb_2O_3 = 2Nd_x{:}Yb_y{:}Y_{(1-x-y)}PO_4+2PbO \qquad \textbf{(S2)}$$

Where x=0.8 at.%, y=2.0 at.%.

Calculations of emission cross-sections.

We calculated the emission cross section of Nd^{3+} and Yb^{3+} ions by RM method formula (**S3**) and F-L method formula (**S5**), respectively.

$$\sigma_{em}^{i}(\lambda) = \frac{3\sigma_{abs}^{i}\exp(-hc/kT\lambda)}{8\pi n^2\tau_{rad}c\sum_j \lambda^{-4}\sigma_{abs}^{j}(\lambda)\exp(-hc/(kT\lambda))d\lambda} \qquad \textbf{(S3)}$$

h is the Planck constant, c is the speed of light in vacuum, k is the Boltzmann constant, T is absolute temperature, n is the refractive index, τ_{rad} is the radiation lifetime, which can be calculated by the following formula.

$$\tau_{\mathrm{rad}} = \frac{3}{8\pi n^2 c}\frac{Z_l}{Z_u}\frac{\exp(-hc/(k_BT\lambda))}{\sum_j \lambda^{-4}\sigma_{abs}^{j}(\lambda)\exp(-hc/(k_BT\lambda))d\lambda} \qquad \textbf{(S4)}$$

Z_u is the high energy level group, Z_l is the low energy level group, where g_k is the degeneracy of each sub level, k_B is Boltzmann constant.

$$\sigma_{em}^{F-L}(\lambda) = \frac{\lambda^5}{8\pi n^2 c}\frac{1}{\tau_{rad}}\frac{I(\lambda)}{\int \lambda I(\lambda)d\lambda} \qquad \textbf{(S5)}$$

$I(\lambda)$ represents the optical density.

Calculations of I_{sat}, β_{min} and I_{min}.

I_{sat} represents the pump saturation intensity, which is a measure of the ease with which the Yb^{3+} ions population must be bleached to overcome the ground state absorption, is given by the equation:

$$I_{sat}=hc/[\lambda_p \sigma_{abs}(\lambda_p)\tau_f] \qquad \textbf{(S6)}$$

Where λ_p is the pump wavelength, h is the Planck constant, $\sigma_{abs}(\lambda_p)$ is absorption cross-sections at the pump wavelength λ_p.

The minimum fraction of Yb^{3+} ions that must be excited such that the ground state absorption and the gain exactly balance, and there is net transparency at λ_{ext}. And the equation can be expressed by

$$\beta_{min}=\sigma_{abs}(\lambda_{ext})/[\sigma_{abs}(\lambda_{ext})+\sigma_{ext}(\lambda_{ext})] \qquad \textbf{(S7)}$$

I_{min} represents the minimum absorbed pump intensity required to reach the threshold. It can be obtained from the following equation:

$$I_{min}=\beta_{min}\times I_{sat} \qquad \textbf{(S8)}$$