

Spectral characteristics of Nd³⁺/Yb³⁺:YPO₄ single crystal with strong multi-wavelength emission

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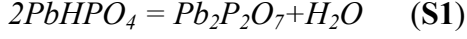
Eqn. S1 PbHPO₄ decomposes chemical reaction equation.

Eqn. S2 Nd_x:Yb_y:Y_(1-x-y)PO₄ synthesis chemical reaction equation.

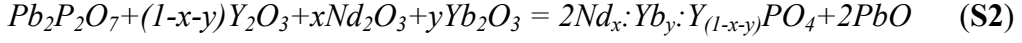
Calculations of emission cross-sections. (Equations S3-S5)

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

Eqn. S1 $PbHPO_4$ decomposes chemical reaction equations.



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



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.

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

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.

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

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.

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

$I(\lambda)$ 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:

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

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

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

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

$$I_{min} = \beta_{min} \times I_{sat} \quad (\text{S8})$$