

# NdP<sub>5</sub>O<sub>14</sub> 晶体的光谱强度参数

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## Spectral intensity parameters of NdP<sub>5</sub>O<sub>14</sub> laser crystals

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**Abstract:** Based on Judd-Ofeld theory, the spectral intensity parameters are calculated, including oscillator strength parameters  $\tau_{\lambda}$ , spontaneous radiative transition probability, radiative lifetime, fluorescent branching ratio  $\beta_0$ , and radiative quantum efficiency  $\eta$  etc. The sum of  $\tau_{\lambda}$  parameters obtained from the linear relation of  $P=a\Sigma_{\lambda}^2+b$  are in agreement with those obtained by J-O method.

**Key words:** neodymium pentaphosphate, spectral intensity parameters

### 一、引 言

关于高稀土浓度化学计量比的稀土五磷酸盐晶体已为人们所熟知, 国内外 NdP<sub>5</sub>O<sub>14</sub> 晶体已用作微小型激光器的工作物质。但对稀土五磷酸盐晶体的光谱参数报告得不多。我们生长了所有稀土离子的五磷酸盐晶体。并系统地研究了这类晶体的光谱性质<sup>[1]</sup>, 研究并报道了 Tb<sub>x</sub>Y<sub>1-x</sub>P<sub>5</sub>O<sub>14</sub>、Pr<sub>x</sub>La<sub>1-x</sub>P<sub>5</sub>O<sub>14</sub>、TmP<sub>5</sub>O<sub>14</sub>、SmP<sub>5</sub>O<sub>14</sub>、DyP<sub>5</sub>O<sub>14</sub>、ErP<sub>5</sub>O<sub>14</sub> 等稀土五磷酸盐的光谱参数。本文报道的是对 NdP<sub>5</sub>O<sub>14</sub> 晶体的振子强度、 $\Omega_{\lambda}$  参数、自发辐射跃迁几率、荧光寿命、荧光分支比与量子效率等光谱强度参数的研究结果。

### 二、实验与结果

#### 2.1 振子强度与 $\Omega_{\lambda}$ 参数

在 VSU-2G 型分光光度计上记录了 NdP<sub>5</sub>O<sub>14</sub> 晶体的吸收光谱。采用了从 <sup>2</sup>L<sub>15/2</sub> 至 <sup>4</sup>F<sub>3/2</sub> 谱项的 20 个光谱带, 9 个方程组, 用最小二乘法并利用下面(1)、(2)、(3)式

$$P_{exp} = 4.318 \times 10^{-9} \int \epsilon(\sigma) d\sigma \tag{1}$$

$$P_{exp} = P_{ed} + P_{md} \tag{2}$$

$$P_{ed} = \frac{8\pi^3 m c \sigma}{3h(2J+1)} \cdot \frac{(n^2+2)^2}{9n} \sum_{\lambda=2,4,6} \Omega_{\lambda} |\langle 4f^N(\alpha SL)J \| U^{(\lambda)} \| 4f^N(\alpha' S' L')J \rangle|^2 \tag{3}$$

拟合出 NdP<sub>5</sub>O<sub>14</sub> 晶体中 Nd<sup>3+</sup> 离子的实验振子强度与振子强度的计算值, 拟合的平均均方根

偏差为  $9.49 \times 10^{-7}$ 。所得的振子强度值列于表 1。三个  $\Omega_\lambda$  唯象强度参数为

$\Omega_2 = 0.704 \times 10^{-20} \text{cm}^2$ ;  $\Omega_4 = 2.45 \times 10^{-20} \text{cm}^2$ ;  $\Omega_6 = 4.50 \times 10^{-20} \text{cm}^2$ ; 或  $\tau_2 = 1.13 \times 10^{-9} \text{cm}$ ;  $\tau_4 = 3.93 \times 10^{-9} \text{cm}$ ;  $\tau_6 = 7.22 \times 10^{-9} \text{cm}$ ;  $\sum \tau_\lambda = 12.28 \times 10^{-9} \text{cm}$  (J-O 法)。

我们曾根据大量 Nd<sup>3+</sup> 离子的光谱数据, 总结出不同跃迁 ( $^4I_{9/2} \rightarrow ^{2S+1}L_J$ ) 的振子强度  $P$  和 Judd-Ofelt 强度参数的总和  $\sum \tau_\lambda$  之间存在如下的直线关系<sup>[3]</sup>:

$$\begin{aligned} P_1(^4G_{5/2}, ^2G_{7/1}) &= 961.1 \sum \tau_\lambda^{(1)} - 6.121 \times 10^{-6} \\ P_2(^4F_{5/2}, ^2H_{9/2}) &= 302.5 \sum \tau_\lambda^{(2)} + 2.74 \times 10^{-6} \\ P_3(^4G_{7/2}, ^4G_{9/2}, ^2K_{13/2}) &= 282.3 \sum \tau_\lambda^{(3)} + 1.486 \times 10^{-6} \\ P_4(^4F_{7/2}, ^4S_{3/2}) &= 265.7 \sum \tau_\lambda^{(4)} + 3.48 \times 10^{-6} \\ \sum \tau_\lambda &= \frac{\sum \tau_\lambda^{(1)} + \sum \tau_\lambda^{(2)} + \sum \tau_\lambda^{(3)} + \sum \tau_\lambda^{(4)}}{4} \end{aligned} \quad (4)$$

从而可将实验求得振子强度  $P_{exp}$  代入上式, 计算出强度参数的总和  $\sum \tau_\lambda$ 。利用表 1 的数据  $P_{exp}$ , 按 (4) 式求得了 NdP<sub>5</sub>O<sub>14</sub> 的  $\sum \tau_\lambda = 11.90 \times 10^{-9} \text{cm}$ , 与用 J-O 法求得的  $\sum \tau_\lambda = 12.28 \times 10^{-9} \text{cm}$  相符。

表 1 NdP<sub>5</sub>O<sub>14</sub> 晶体中 Nd<sup>3+</sup> 离子的振子强度

谱项跃迁	$P_{exp} \times 10^6$	$P_{cal} \times 10^6$
$^4I_{9/2} \rightarrow ^4F_{3/2}$	1.71	1.50
$^4F_{5/2}, ^2H_{9/2}$	6.16	5.87
$^4F_{7/2}, ^4S_{3/2}$	5.93	6.63
$^4F_{9/2}$	0.44	0.46
$^4G_{5/2}, ^2G_{7/2}$	6.60	6.74
$^4G_{7/2}, ^4G_{9/2}, ^2K_{13/2}$	5.40	3.53
$^2K_{15/2}, ^4G_{11/2}$	1.89	0.92
$^2P_{1/2}$	0.56	0.39
$^4D_{3/2}, ^4D_{5/2}, ^2I_{11/2}$	6.91	7.44
$^4I_{13/2}, ^4D_{1/2}, ^2I_{15/2}$		

注: 平均根方偏差 (RMS):  $9.49 \times 10^{-7}$

## 2.2 自发辐射跃迁几率、辐射寿命与荧光分支比

NdP<sub>5</sub>O<sub>14</sub> 中 Nd<sup>3+</sup> 离子的自发辐射几率用下式求得,

$$A_{ed} = \frac{64\pi^4 e^2 c^3}{3h(2J+1)} \cdot \frac{n(n^2+2)^2}{9} \sum_{\lambda=2,4,6} \Omega_\lambda |\langle 4f^N(\alpha SL)J \| U^{(\lambda)} \| 4f^N(\alpha' S' L)J \rangle|^2 \quad (5)$$

辐射寿命  $\tau_{rad}^e$  与荧光分支比  $\beta_c$  用以下诸式求出:

$$\tau_{rad}^e = \left\{ \sum_{SLJ} A[(\alpha' S' L)J'; (\alpha S J)J] \right\}^{-1} \quad (6)$$

表 2 NdP<sub>5</sub>O<sub>14</sub> 中 Nd<sup>3+</sup> 的辐射跃迁几率  $A_{ed}$ 、辐射寿命  $\tau_{rad}^e$ 、荧光分支比  $\beta_c$ 。

谱项跃迁	$A(s^{-1})$	$\tau_{rad}^e (\mu s)$	$\beta_c$
$^4F_{3/2} \rightarrow ^4I_{9/2}$	808.93	1236.2	0.335
$^4I_{11/2}$	1304.78	766.4	0.541
$^4I_{13/2}$	286.91	3485.4	0.119
$^4I_{15/2}$	13.20	75748.0	0.005
		$\tau_{tot} = 414.28$	

$$\beta_c[(\alpha'S'L')J'; (\bar{\alpha}\bar{S}\bar{L})J] = A[(\alpha'S'L')J'; (\bar{\alpha}\bar{S}\bar{L})\bar{J}] / \sum_{SLJ} A[(\alpha'(S'L')J'; (\bar{\alpha}\bar{S}\bar{L})\bar{J}] \quad (7)$$

(5)式中的约化矩阵元  $|\langle {}^4F_{3/2} \| U^{(\lambda)} \| {}^4I_7 \rangle|^2$  采用了文献[2]中的数据。上面诸式计算的结果列于表 2。

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