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Laser parameters of Er^{+3} doped phosphate glass

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ABSTRACT

Tripositive Erbium ion doped phosphate glass has been prepared by melt-quenching technique. The experimental oscillator strengths were calculated from the areas under the absorption bands. Judd-Ofelt parameters (Ω_λ) evaluated using the observed spectral intensities have been used to compute various laser parameters viz., spontaneous emission probability (A), radiative life time (τ), fluorescence branching ratio (β) and stimulated emission cross-section (σ_p). The bonding environment surrounding the rare earth (RE) ion has also been discussed.

KEYWORDS

Phosphate glass;
Fluorescence spectrum;
Absorption spectrum;
Radiative properties.

INTRODUCTION

Rare earth ions are employed in optical applications due to their metastable excited states over the entire range of optical frequencies[1,2]. For many years, rare-earth doped glasses have been used to make bulk lasers and amplifier devices[3]. The past literature shows that the rare earth ions find more important application in the preparation of the laser materials[4-6]. Rare earth doped crystals like Nd:YAG are considered to be excellent laser materials[7,8], but the rare earth doped glasses have distinctive advantages[9] over doped crystals such as flexibility in size and shape and excellent optical quality. The rapid development of rare earth doped silica fiber amplifiers and lasers have considerably increased the interest in rare earth doped planar waveguide devices. Furthermore, reliable high power CW (Continuous Wave) diode laser pumps provide the possibility of miniaturizing conventional solid-state lasers and amplifiers[10,11]. Such glass based rare earth doped lasers and amplifiers are highly promising for producing small, compact, efficient and reliable communication, signal processing, sensing and medicine applications.

The Ω_λ values obtained from the absorption measurements can be used to calculate the radiative transition probability, radiative lifetime of excited states and branching ratios (which predict the fluorescence intensity of the lasing transition). The radiative properties of lanthanide ions have been theoretically studied by Krupke[12] and others[13-16]. These properties are often called laser parameters like Spontaneous Emission Probability (A), Fluorescence branching ratio (β), Radiative lifetime (τ) and Stimulated emission cross section (σ_p) and have been calculated by using the emission wavelengths for relevant transition, reduced matrix elements and the values of Judd-Ofelt parameter.

Recently, we have carried out fluorescence of Er^{3+} doped phosphate glass with a view to develop suitable glass for laser action in the visible region.

EXPERIMENTAL

Erbium doped Phosphate glass was prepared by melt quenching technique. The composition (by weight) was approximately $Na(PO_3)_6$70%-BaO15%-PbO 10%-Al_2O_3 5%-R Ln (Where R=0.5 % and Ln= Er^{+3}) from reagents of analytical grade in 10 gm batches. The Er_2O_3 ion added to the host glass matrix was 99.99% pure. The glass material was mixed in an agate pestle mortar for two hours and was thermally treated for 4 hours in a platinum crucible at 1200±25^{0}C. Homogeneity of the melt was ensured by stirring the melt with a platinum rod from time to time. The melt was quenched by pouring into rectangular shaped mould placed on a steel plate. The glass specimen was polished using cerium oxide powder and again annealed. The glass specimens contained no crystalline phase as revealed by X-ray diffractogram of the specimen.

The fluorescence spectrum was recorded using a Perkin Elmer Luminescence spectrophotometer model LS50B in the spectral range 200 - 900 nm. The absorption spectrum was recorded at room temperature in the visible region using a double beam spectrophotometer with a resolution of 0.5nm. The length and width of the rectangular glass specimen was measured with the help of vernier calliper, while the path length was measured with a screw gauge. The refractive index of glass specimen was measured on an Abbé refractometer (ATAGO 3T). An ordinary lamp was used as the light source.

RESULTS AND DISCUSSION

In the Er^{+3} doped Phosphate glass specimen eighth absorption bands have been observed which corresponds to the transition from ground level $^4I_{15/2}$ to various excited levels. Their peak position and assignments have been given in TABLE 2. Assignment of the various absorption bands have been made by comparing their band positions with previously reported transitions of these ions on any other glass systems.

The intensities of the observed bands have been measured in terms of line strength S_{exp}, calculated from the observed oscillator strength of the absorption bands, have also been included in TABLE 2. These values serve as a basis for the calculation of the three phenomenological parameters, Ω_λ, (λ= 2, 4, 6), known

TABLE 1 : Fluorescence transitions, their peak values, and radiative properties: spontaneous emission probability (A), radiative life time (), Fluorescence branching ratio (β) and stimulated emission cross- section (σ_p) of Phosphate glass with 0.5 wt % doping concentration of Er^{3+} ion

Transitions	λ_{max} (nm)	A (sec^{-1})	τ (µsec)	β	σ_p (10^{-20}) (cm^2)
$^4F_{7/2} \rightarrow {^4I_{15/2}}$	440	3852.275	259	0.384	0.586
$^2H_{11/2} \rightarrow I_{15/2}$	518	3960.307	252	0.395	1.013
$^4S_{3/2} \rightarrow {^4I_{15/2}}$	559	1034.332	966	0.103	0.287
$^4F_{9/2} \rightarrow {^4I_{15/2}}$	660	1166.782	857	0.116	0.699

TABLE 2 : Experimental oscillator strength (P_{exp}) measured (S_{exp}) calculated (S_{cal}) absorption line strengths and Judd- ofelt intensity parameters for the Er^{3+} doped Phosphate glass

Absorption bands	λ (nm)	$P_{exp.}$(10^{-6})	S_{exp} (10^{-20})	S_{cal}(10^{-20})	ΔS (10^{-20})
$^4I_{15/2}$? $^4F_{9/2}$	652	2.06	1.453	1.445	0.007
$^4S_{3/2}$	543	0.53	0.311	0.311	0.000
$^2H_{11/2}$	520	5.62	3.160	2.843	0.316
$^4F_{7/2}$	488	2.55	1.349	1.130	0.218
$^4F_{3/2}$, $^4F_{5/2}$	451	0.77	0.376	0.513	-0.137
$^2H_{9/2}$	406	0.50	0.219	0.378	-0.159
$^4G_{11/2}$	378	9.60	3.926	4.132	-0.206
$^2G_{9/2}$, $^2K_{15/2}$	365	1.89	0.747	0.741	0.005

Ω_2 = 3.2127, Ω_4 = 1.5445, Ω_6 = 1.4646 as Judd-Ofelt parameters[17,18]. The Judd-Ofelt intensity parameters Ω_2, Ω_4 and Ω_6 found by least squares fit method[19,20] have been presented in TABLE 2 for the Er^{3+} doped Phosphate glass. The calculated line strengths (S_{cal}) have been compared with the experimental measured line strengths (S_{exp}) in TABLE 2.

In Er^{+3} doped Phosphate glass specimen, the most intense band in the Absorption spectrum around 378 nm have been used for the excitation of Er^{+3} ion. As a consequence of which four Fluorescence bands have been observed in the wavelength region 400-700 nm corresponding to the transitions $^4F_{7/2}\rightarrow {}^4I_{15/2}$, $^2H_{11/2}\rightarrow {}^4I_{15/2}$, $^4S_{3/2}\rightarrow {}^4I_{15/2}$ and $^4F_{9/2}\rightarrow {}^4I_{15/2}$ respectively. The values of A, τ, β, σ_p have been collected in 1 for Er^{+3} doped glass specimen.

CONCLUSION

In this case the values of Ω_4 and Ω_6 are almost equal. The Judd-Ofelt theory does not permit an easy calculation of these parameters and it is very difficult to predict the behaviour of the host around the rare earth ion on the basis of their values. In this glass it seems that the rare earth ions gets surrounded by $[AlO_4]^-$. The negative charge of $[AlO_4]^-$ tetrahedra is not properly balanced by the positive charge of alkali ion thereby decreasing the covalent character between the rare earth ions and oxygen atoms provided by $[PO_4]$ tetrahedra. In most of the glasses the Ω_4 parameter seems to follow the trend set by Ω_2 parameter. But the Ω_4 parameter is less sensitive to the environment than the Ω_2 parameter.

It is a general observation that in oxide glasses the Ω_6 values are lower than in fluoride glasses. This indicates that increase in ionicity increases the rigidity of the cage in which the rare earth ion is sitting.

In Er^{+3} doped glass specimen, the laser parameters have been computed and collected in TABLE 1. Transitions having Spontaneous emission probability (A) greater than 500 S^{-1}, Fluorescence branching ratio (β) ~0.5 and 6000 cm^{-1} of energy separation between the energy level under consideration and terminating level are considered to be good radiative transitions[21]. The values of radiative properties indicate that $^2H_{11/2}\rightarrow {}^4I_{15/2}$ transition in Er^{3+} doped glass may be used in applications such as fabrication of electroluminescent devices for use in display technology.

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