Optical Properties of Ho^{3+} Doped in Tellurite Glass

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Abstract:- We visit the standard procedure for analyzing the optical spectrum of Ho^{3+} doped tellurite glass has been studied. The glass was formed using a composition 79% Te O_2 + 20% Li_2 CO_2 + 1% Ho O_2. I density and refractive index were measured and used to calculate various physical properties such as, rare earth concentration, mean atomic volume, electric polarization, ionic radius, molar refractivity, field strength, reflection losses and dielectric constant etc. The absorption spectra of glass have been recoded in the 340 – 2000 nm and fluorescence in the 400 – 710 nm. region.

The spectral lines were used to get the energy levels of Ho^{3+} in tellurite glass. We have also calculated the oscillator strength, Judd-Ofelt intensity parameters, transition probability; branching ration stimulated emission cross section etc. utilizing these special data. It is marked that the line $^5F_4$ ($^5F_2$) - $^5I_8$ is very intense and have very high stimulated emission cross-section and is most suitable for easer emission in Ho^{3+} in tellurite glass.

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I. Introduction

Most of the solid lasers available at the moment involve a trace amount of triply ionized rare earth or transition metal ion doped in a crystal or a glass lattice. Many glass and crystal systems have been investigated in order to develop an understanding of the influence of host material on the laser properties of the active material. In atomic and nuclear technology, special optical glasses have also found applications. Terbium activated. Silicate glasses are used as screens for X-ray imaging (1). Celrium activated barium silicate or lead silicate glasses are utilized as elementary particle detectors in scintillating calorimeter (2) and Cerenkov counters restrictively. Fibre bundles with glasses core activated with cerium and terbium are also used to deted the tracks of high energy particles (3) the composition and impurity dependent nonlinear optical properties of glasses have created the possibility of achieving extremely just modulation of light optical (important for use in telecommunications and optical computers). Homogeneous glasses with high refractive indices and low Abbe numbers have shown significant nonlinear effects (4). However, glasses containing small semi conducting crystals or small metallic colloids show much larger non linear effects in specific wavelength regions (5).

The radiative and non-radiative properties of the rare earth ion in glasses depend strongly on the glass composition. Several studies have appeared in which the variation of the radiative properties has been correlated with the change of network former and network modification (6-8) on the basis of the Judd-Ofelt theory (9-10). Intensity parameters relative to the radiative decay rate depends on two parameters (11).

The advantages with glasses are the case with which large homogeneous pieces can be produced. The non linear refractive indices can be made low and the doping concentration can be large. It has been shown that the fluorescence intensity of rare earth ion are enhanced several fold when glass hosts with low phonon energies e.g. heavy metal fluoride oxide germinate, tellurite etc. [12-14] are used. Recently the spectroscopic properties of Ho^{3+} in oxyfluoroborate glass have been studied by as [15]. It was thought worthwhile to investigate the same ion in a tellurite glass and compare the results.

The Triply ionized holmium is known to case at 2.1 and 0.55 μM [16] and a number of upconversion transitions are known [17]. The absorption and fluorescence spectra of Ho^{3+} ion in different hosts have been studied by several authors [see23) for a good review from these studies it has been concluded that Ho^{sp} has a $^5I_8$ state and ^5I_T, $^5I_6$, $^5I_5$, $^5I_4$, $^5I_3$ etc as low lying excited state. Several of these states are metals strible and are suitable for laser transition. Two hypersensitive transitions involving $^5G_6$ and $^3G_6$ states are also known. The energy levels for this ion are known up tp 50,000/cm but are well assigned up to 40,000/cm.

II. Experimental

Ho^{3+} doped tellurite glass was prepared for a fixed concentration of holmium oxide (1.0mole %). We have used the following composition for glass preparation as:

$$79\%\ Te\ O_2 + 20\%\ Li_2\ Co_3 + 1\%\ Ho_2\ O_3$$

All these chemicals were mixed together and ground to get a homogeneous mixture and then melted in a platinum crucible at about 1200^{o}c in a furnace. The melt was poured in a steel cast kept at 100^{o}c and then pressed with another

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steel disc to feat disc of the glass. The thickness of the glass was .2cm and diameter 0.8 cm. Refractive index of the glass was measured by polarization dependent Brewester's angle measurement at 650 nm. the density measurement was carried out by the gravimetric method using the formula.

$$D(gm/cm^3) = \frac{x}{x-y} \times 0.863$$

Where x is the weight of the glass in air, and y in xylene and 0.863 is the density of xylene.

The absorption spectra were recorded using Cary 2390(Varian associates) UV-VIS.NIR double beam spectrometer for 1mole% of Ho^{+3} doped tellurite glass absorption spectra in the region 340-2000 nm with undoped glass in the reference beam. For recording the fluorescence spectrum of Ho^{3+} doped in tellurite geats we used 306 nm line of XeCl- excimer laser as the exeiting source. The fluorescence spectrum was dispersed using a 0.5m spex monochrometer with a resolution of 0.025 at 500 nm. The signal was processed using a boxcar averager.

III. Result

1. Properties of Ho^{3+} doped Tellurite Glass

Various physical parameters like rare earth concentration mean atomic volume, electronic polarization, ionic radius, molar refractivity, field strength, reflection losses and dielectric containing 1mcle % of Ho^{3+}. These values are given in the table.

Table -1 Physical properties of Ho^{3+} doped tillurite glass

S/N	Physical Parameters	Corresponding Value
1	Density (gm/cm^3)	6055
2	Refractive Index	2.4
3	Av. Mol. Wt. (gm)	141.67
4	Ho^{3+} conc. ($N*10^{22}$ $ions^{-1}$ cm^3)	2.79
5	Mean At. Vol. (cm^3/atom)	.216
6	Dielectric constant	5.76
7	Reflection losses (R%)	41.17
8	Molar Reflection, R_M (cm^3)	13.25
9	Ionic radius (10^{-9})	.617
10	Field strength ($F* 10^{+16}$ cm^2)	4.86
11	Electronic Polarizability ($a_E*10^{24}cm^{-3}$)	

Table -2 Measured and calculated oscillator Strength (fm and fc* 10^6) of Ho^{3+} in tellurite glass matrix.

S/N	Transition from $^5I_8$	Fm	Fc
1	$^5G_5$	2.00	3.15
2	$^5G_6$	10.01	6.26
3	$^3K_8$	.097	.087
4	$^5F_2$	.147	.035
5	$^5F_3$	.241	.209
6	$^5F_4$	2.38	1.47
7	$^5F_5$	2.13	1.24
8	$^5I_5$	.200	.350
9	$^5I_6$	.125	.080
10	$^5I_7$	.250	.430

2. Absorption spectra:

The absorption spectrum of the Ho^{3+} doped tallurite glass in 340-200 nm region is shown in fig. A large number of relatively sharp absorption bands are observed in the spectrum. The absorption spectrum of the Ho^{3+} intellurite glass in similar to that seen in other glasses except a slight shift in peak positions and a small variation in the intensity of the bands. The energy levels of Ho^{3+} is shown in fig. $^5I_8$ forms the ground state of Ho^{3+}. The other low lying excited states arising from this configuration are $^5I_7$, $^5I_6$, $^5I_5$ ----- $^5F_5$, $^5F_4$, $^5F_3$ ---- . the observed bands could be explained on the basis of the energy level diagram. The lines, involving $^5F_7$, $^5G_6$, $^5F_5$ and $^5F_4$ transitions are relatively more intense that the other. They involve ground state $^5I_8$ as the lower state of the transitions. Three broad bands with relatively lower intensity appear at 11253, 9536 and 5144 cm^{-1} and are assigned as $^5I_5 \leftarrow {}^5I_8$, $^5I_6 \leftarrow {}^5I_8$ and $^5I_7 \leftarrow {}^5I_8$ transmissions. An intense and sharp peak observed at 22465 and 20755 cm^{-1} have been assigned as $^5G_6 \leftarrow {}^5I_8$ and $^5F_5 \leftarrow {}^5I_8$ transitions respectively. The weak peaks observed at 21499 and 21346 cm^{-1} are due to transitions $^5K_B \leftarrow {}^5I_8$ and $^5F_2 \leftarrow {}^5I_8$ respectively.

Table -4 electric line strength, Transition probabilities, branching ratios for different transitions and radiative lifetime of different excited stated of Ho^{3+} in tellurite glass.

SLJ	S'L'J'	Energy (cm^{-1})	S_{ed} x 10^{22} (cm^2)	A(s^{-1})	β_R
$^5G_5$					
	$^5G_6$	1721	.514	11.89	.000
	$^5K_8$	2687	.013	1.19	.000
	$^5F_2$	2840	.249	25.90	.000
	$^5F_3$	3431	.298	54.70	.000
	$^5F_4$	5383	.253	179.53	.002
	$^5F_5$	8566	.314	896.57	.014
	$^5I_5$	12932	.122	1204.03	.015
	$^5I_6$	14650	.393	5620.45	.072
	$^5I_7$	19042	.450	14117.67	.181
	$^5I_8$	24200	.868	55889.17	.717

A_T = 77989.85 s^{-1}

I_R = 12.8 µs

SLJ	S'L'J'	Energy (cm^{-1})	S_{ed} x 10^{22} (cm^2)	A(s^{-1})	β_R
$^5F_3$					
	$^5F_4$	1952	.133	7.06	.000
	$^5F_5$	5134	.175	169.33	.003
	$^5I_5$	9502	.364	2230.68	.043
	$^5I_6$	11219	.189	1904.40	.043
	$^5I_7$	15611	.205	5552.57	.106
	$^5I_8$	20769	.664	42410.07	.811

A_T = 52274.13 s^{-1}

I_R = 19.12 µs

SLJ	S'L'J'	Energy (cm^{-1})	S_{ed} x 10^{22} (cm^2)	A(s^{-1})	β_R
$^5F_4$					
	$^5F_5$	3182	.284	2.35	.002
	$^5I_5$	7550	.309	34.30	.027
	$^5I_6$	9267	.459	94.18	.074
	$^5I_7$	13659	.330	216.70	.171
	$^5I_8$	18817	.535	919.78	.725

A_T = 1267.34 s^{-1}

I_R = 78.4 µs

SLJ	S'L'J'	Energy (cm^{-1})	S_{ed} x 10^{22} (cm^2)	A(s^{-1})	β_R
$^5F_5$					
	$^5I_5$	4366	.082	30.936	.001
	$^5I_6$	6084	.307	314.21	.017
	$^5I_7$	10476	.643	3360.59	.189
	$^5I_8$	15634	.810	14049.94	.791

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$A_T = 17755.69\ s^{-1}$
$I_R = 56.31\ \mu s$

SLJ	S'L'J'	Energy (cm^{-1})	S_{ed} x 10^{22} (cm^2)	A(s^{-1})	β_R
$^5I_5$					
	$^5I_6$	5717	.419	356.123	.448
	$^5I_7$	6109	.209	216.739	.272
	$^5I_8$	11268	.034	221.072	.279

$A_T = 7948.35\ s^{-1}$
$I_R = 125.8\ \mu s$

Fluorescence spectra:

The fluorescence spectrum of Ho^{3+} ions doped in tellurite glass at room temperature is shown in fig. there ar two fluorescence lines in the spectrum in between 490-710 nm region. The intensity of one peak is very weak but the other is very intense. The intense peak is due to $^5F_4$ ($^5S_2$) $\rightarrow ^5I_8$ where as the weak peak is due to $^5F_5 \rightarrow$ $^5I_8$ transitions.

We also calculate the stimulated emission cross section for $^5F_5 \rightarrow$ $^5I_8$ and $^5F_4$ ($^5S_2$) $\rightarrow$ $^5I_8$ transitions. The stimulated emission cross section of the transition $^5F_4$ ($^5S_2$) $\rightarrow$ $^5I_8$ is found to be very large compared to $^5F_5 \rightarrow$ $^5I_8$. This is in accordance with observation as the intensity of this line is very high compared to the other.

All the fluorescence transitions, their wave length, corresponding energies, effective band width, stimulated emission cross section and their intensities are in listed.

Table -3 Comparison of Jodd Ofelt Intensity Parameters (Ω_λ * 10^{20} cm^2) of Ho^{3+} in different lost lattices.

S/N	Glass	Ω_2	Ω_4	Ω_6	Ref.
1	Tellurite	.254	.646	.075	Present work
2	Oxyfluoroborate	1.41	12.11	9.96	(ref-18)
3	LiZnBS	18.95	7.25	10.45	(ref-17)
4	LaF_3	1.16	1.38	0.88	(ref-6)
5	$YalO_3$	1.82	2.38	1.53	(ref-6)
6	LiO_2:CaO:B_2O_3	6.83	3.15	2.53	(ref-15)
7	CaF_2	.018	0.57	0.58	(ref-10)

Table-5 Fluorescence peak assignments. Their wavelengths, energy, effective band width, stimulated emission cross section and relative intensities in tellurite glass.

Transition	Wavelength (nm)	Energy (cm^{-1})	$\Delta\lambda$(cm^{-1})	Δ_p^Ex10^{20} (cm^2)
$^5F_4(^5S_2) \rightarrow ^5I_8$	548.00	18803.51	14.38	1.58
$^5F_5 \rightarrow ^5I_8$	654.30	15620.70	13.12	.14

IV. Conclusion

Holmium doped Tellurite glass have been prepared for a fixed concentration (1 mole %) of Holmium. The refractive index and density of the glass have been measured which helped us to determine various optical properties of the glass. The absorption and fluorescence spectrum of the glass have been studied and resulting transmitions were assigned and transition frequencies determined. The oscillator strength. Judd-Ofelt intensity parameter, transition probability, branching ratio stimulated emission cross section have been calculated using these date.

The high intensity, high value of stimulated emission cross section etc. for the $^5F_4 \rightarrow$ $^5I_8$ transition at 5479 A^0 suggest a good probability of laser emission in Ho^{3+} at this wavelength.

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