EMISSION CROSS-SECTION AND UV-VIS-NIR SPECTROSCOPY OF Er^{3+} DOPED TBT GLASS LASER MATERIAL

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A bulk glass consists from the composition $90TeO_2$- $5Bi_2O_3$- $5Ta_2O_5$ in mol% doped with 25000ppm Er^{3+} (TBT doped with Er^{3+}) has prepared by using melt -quenching technique. Spectroscopic and Judd-Ofelt parameters, Ω_t (t= 2, 4, 6) of Er^{3+} were calculated from UV-Vis- NIR absorption spectra. The oscillator strength type transition probabilities, S_{meas}, S_{cal}, branching ratio, β, and radiative lifetimes, τ_R, of different excited states of Er^{3+} have been computed. Moreover, stimulated emission cross-section (σ_e^{peak}) is about $11\times10^{-20}cm^{-20}$of these glass with effective bandwidth full half width maximum (70nm). The spectroscopic characteristics indicate that of present glass may be suitable for use in optical lasers.

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1. Introduction

Oxide glassed based on TeO_2 is candidate material can use in optical device application because of their advantages properties such as; high transmission in visible (Vis), near infrared (NIR), IR region, low melting temperature, high thermal stability and high refractive index [1-3].The character of Te- O bonds leads to UV-Vis cutoff edge spectra in the range of 0.32–0.38 μm extended region multiphonon absorption edge beyond 4 μm. Besides tellurite glass are suitable as promising bulk amorphous materials for hosting lasing ions which possess very low phonon energies [4]. Here Er^{3+}ions are the most widely investigated since the optical properties of Er^{3+} ions are important due to their use in infrared lasers and easy fabrication in the optical amplifiers, up and down-converters. Moreover at 1987 erbium-doped fiber amplifiers (EDFAs), become one of important in the optical communications [1- 5].Also, the Er^{3+-} doped TeO_2- glass has a much higher emission cross section ($\sigma_e \geq 0.75$ pm^2) and a broad fluorescence full width at half-maximum (~65 nm) by comparing with the silicate glass doped with erbium (FWHM 20–30 nm) around 1.55μm which attribute to the third optical fiber communication window.

In the present work Judd-Ofelt theory [6-9] is a useful tool to evaluate 4f transition intensities of rare earth (RE) ions in different hosts. The values of spectroscopic parameter are shown for glasses with related which type the structure of RE ions, these information is important in calculated the emission of RE doped glasses.

The aim of the present paper are to studying host a glass with composition $90TeO_2$- $5Bi_2O_3$- $5Ta_2O_5$ to increase in emission cross section, σ_{em}^{peak} , extend broadband and gain EDFA. It is concluding that oxides like that Bi_2O_3 and Ta_20_5 can be effective at broadening the emission cross section and gain coefficient.

2. Experimental work

The glass with composition $90TeO_2$- $5Bi_2O_3$-$5Ta_2O_5$-25000ppm Er_2O_3 (TBT-25000ppmEr^{3+}) were melted in platinum crucible with batches =50 gm at temperatures 950

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°C.After that the melt was cast in a graphite mould, the samples were transferred to an annealing furnace and kept at 320 °C for 2 h. Then the furnace was switched off and the samples were allowed to cool. From the glassy samples, prisms of the dimension 30x15x15 mm^3 were cut. The prisms were ground and polished using water as liquid component. The prisms were used to measure the linear refractive indices at wavelengths of 643.8, 589.3, 546.1, 479.98 and 435.8 nm.The UV transmittance of the glasses was determined at wavelength from 200 to 2750 nm, using Shimadzu 3101 PC spectrophotometer with optical path lengths of 1 mm and 11 mm.

3. Result and discussion

UV-Vis-NIR absorption spectra of glass90TeO_2-5Ta_2O_5-5Bi_2O_3-25000ppm Er_2O_3in mol% were shown in Fig. (1). The absorption bands of these glass attributed to the ground state of the $^4I_{15/2}$ absorption at 1531, 982, 795, 650, 545, 530 and 490 nm which correspond to the transitions from $^4I_{15/2}$ to $^4I_{13/2}$, $^4I_{11/2}$, $^4I_{9/2}$, $^4F_{9/2}$, $^4S_{3/2}$, $^2H_{11/2}$ and $^4F_{7/2}$, respectively. In the present work the experimental oscillator strength, S_{meas}, and the integrated absorption coefficient for all band evaluated by using Eq. (1);

$$S_{meas} = \frac{mc^2}{\pi\lambda^2 e^2}\int \mu(\lambda)d(\lambda) \qquad (1)$$

Where, μ(λ), is the experimental absorption coefficient, λ, is the mean wavelength of the transition, m is the mass of the electron and c is the speed of light.
Judd- Ofelt theory assumed that an electric dipole transition, S_{calc}, from the ground state (SLJ) to the excited state ($S^/L^/J^/$) can be computed from Eq. (2);

$$S_{cal} = \frac{8\pi^2 mc\cdot[n^2+2]^2}{3h\cdot(2J+1)\lambda\cdot 9n} \times \sum_{t=2,4,6} \Omega(t)\left|\langle (S,L)J\left|U^{(t)}\right|(S^/,L^/)J^/\rangle\right| \qquad (2)$$

Where, n, is the refractive index of the prepared glass, $U^{(t)}$ are doubly reduced matrix elements of the unit tensor operator of the rank, t, where t= 2, 4 and 6. The Judd-Ofelt intensity parameters $\Omega_{(t)}$ values were calculated by using the $U^{(t)}$ values tabulated by Kaminskii [10] and Carnall [11] since they are almost host independent. J-O parameters Ω_t of the $^4I_{13/2}$ metastable level for present glass was shown in Table (1). The values of $\Omega_{(t)}$ are equal in the present work ($\Omega_{(2)}$= 0.647× 10^{-20} cm^2, $\Omega_{(4)}$= 0.772× 10^{-20} cm^2, $\Omega_{(6)}$= 0.4606× 10^{-20} cm^2 and $\Omega_{(4)}$/ $\Omega_{(6)}$ = 1.676). It is conclude that the spectroscopic quality parameter can be used to evaluate the lasing efficiency for convert $^4I_{13/2}\rightarrow$ $^4I_{15/2}$ transition of erbium ions in the host bulk materials. In the present work the spectroscopic parameters are higher than comparing with phosphate, silicate and borate glasses [12, 13]. When the glass has large value of Ω_2 are related to stronger covalent bonds into the host glasses 90TeO_2-5Ta_2O_5- 5Bi_2O_3which increase in Er^{3+}ions concentration. The computed the spontaneous emission probabilities for the $^4I_{13/2}$ state in the compositions 90TeO_2- 5Ta_2O_5- 5Bi_2O-25000ppm Er_2O_3.It know that TeO_2 has structural unit are found in glasses such asTeO_4, TeO_{3+1} and TeO_3 are usually assign as Q_4^4, Q_4^3 and Q_4^2 respectively. Where the TeO_4 trigonal bipyramid (tbp) has free lone pair electron leads to increase in optical properties of host glasses.

Table (1): Measured and calculated oscillator strengths, branching ratio, β, and radiative lifetime, τ_R, of 25000ppm Er^{3+} ions doped TBT glass.

Transition from , $^4I_{15/2}$ to	Wavelength (nm)	Energy (cm^{-1})	Spectroscopic factors			
			S_{meas} (10^6)	S_{meas} (10^6)	β	τ_R in (ms)
$\rightarrow {}^4I_{13/2}$	1531	6532	19.86	16.48	100	2.49
$^4I_{11/2}$	982	10183	2.186	2.113	86.8	1.891
$^4I_{9/2}$	795	12579	1.249	1.742	78.68	0.973
$^4F_{9/2}$	650	15385	5.31	6.312	91.76	0.16
$^4S_{3/2}$	545	18349	0.823	0.879	68.95	0.172
$^4H_{11/2}$	530	18868	11.43	11.2	91.98	0.048
$^4F_{7/2}$	490	20409	2.289	2.132	75.1	0.077

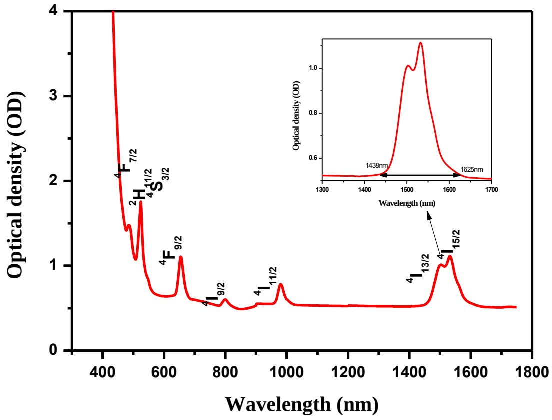

Fig. 1: Optical density of UV-vis-NIR spectra of the TBT glass doped with 25000ppm Er^{3+} ions

The radiative lifetime τ_R for an exited state (J) is calculated by:

$$\tau_R = \frac{1}{\sum A(J \rightarrow J')} \qquad (3)$$

The branching ratio $\beta(J \rightarrow J')$ can be determined from the radiative transition probability by the following expression:

$$\beta(J \rightarrow J') = \frac{A(J \rightarrow J')}{\sum A(J \rightarrow J')} = A(J \rightarrow J')\,\tau_R \qquad (4)$$

The absorption cross-sections of the prepared glass with doped Er^{3+} ion for the $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition can be estimated as follow:

$$\sigma_a(\lambda) = \frac{2.303 \cdot OD(\lambda)}{N\ L} \qquad (5)$$

Where OD (λ) is the optical density of the experimental absorption spectrum, L is the thickness of the sample and N is the concentration of respective rare-earth ions. The concentration of Tm^{3+} ions can be calculated by;

$$N = [RE \ \text{mol\%}] \frac{\rho}{M} 2A_v \tag{6}$$

Where, ρ, is the glass density, [*RE* mol%] is the molar percent concentration of rare-earth oxide based on the glass molar, *M* is the molecular weight of Tm:TZPPN glass and A_v is the Avogadro's number.

The calculation of stimulated emission cross-section $\sigma_e(\lambda)$ of prepared glass with Er^{3+} for the $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition can be estimated from their corresponding ground state absorption cross-section $\sigma_a(\lambda)$ using the follow expression [14]:

$$\sigma_e(\lambda) = \sigma_a(\lambda) \frac{Z_l}{Z_u} \exp\left[\frac{E_{zl} - hc\,\lambda^{-1}}{K_B T}\right] \tag{7}$$

Where K_B is Boltzman constant, Z_l, is partition functions of the lower, Z_u is the partition functions for the upper levels included in the considered optical transition, T is the room temperature, and E_{ZL} is the zero line energy for the transition between the lower Stark sublevels of the emitting multiplets and the lower Stark sublevels of the emitting multiplets.

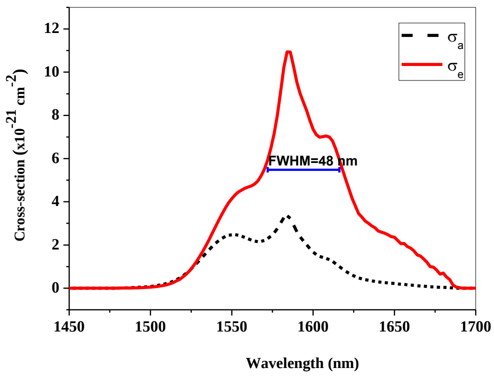

Fig. 2: Absorption cross-sections, $\sigma_a(\lambda)$and stimulated emission cross-section, $\sigma_e(\lambda)$for TBT glass doped with 25000ppm Er^{3+} ions

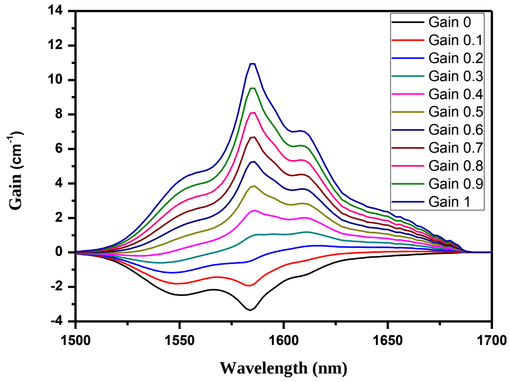

Fig. 3: The gain coefficient for the $^4I_{13/2}\rightarrow{}^4I_{13/2}$transition of the TBT glass doped with 25000ppm Er^{3+} ions.

Fig. (2) obtain that computed absorption and emission cross sections for the present glasses. The peak of the stimulated emission cross-section (σ_e^{peak}) is about $11\times10^{-20}cm^{-20}$for $90TeO_2$- $5Ta_2O_5$- $5Bi_2O_3$-25000ppm Er_2O_3in mol%, where the highest value of σ_e^{peak} for the emission cross-section is refer to the larger value of the line strength of the $^4I_{13/2} \rightarrow {}^4I_{15/2}$. It is note that the full width at half maximum (FWHM) is a critical parameter which it used to attribute the gain characteristic of the optical amplifiers. Herein the present glass has FWHM of the emission peak equal 48 nm due to the overlapping of the emission spectra of erbium ions at 1.59 µm. Moreover the effective line width ($\Delta\lambda$) can be calculate from these expression as; $\Delta\lambda = \int \sigma_e(\lambda) d\lambda / \sigma_e^{peak}$ moreover the optical gain coefficient, G (λ), is an useful important factor for evaluating the performance of laser media. The light field intensity derived from the light field power by the simplified relationship; $E(z) = \frac{Pw(Z)}{A}$, where P_w(Z) is pump power at the position Z and A is an effective cross sectional area of the core. The propagation equation for the pump and signal field powers P (Z) in a given direction are thus:

$$\frac{dPw(Z)}{dz} = [\sigma_e(N_2(Z) - \sigma_a N_1(Z)]Pw(Z) \qquad (8)$$

where$N$ is total population volume-density and defined as $N=N_1+N_2$, N_1 and N_2 represent the population volume-densities of upper and lower levels, respectively. From the absorption and emission cross sections for the transitions between two laser operating levels, the optical gain coefficient $G(\lambda)$ can be calculated using the following formula:

$$G(\lambda) = N(Pw \cdot \sigma_e(\lambda) - (100 - Pw) \cdot \sigma_a(\lambda)) \qquad (9)$$

Where, Pw, is the ratio of $N_2$to N and $0 \leq Pw \leq 100$. In the case of total inversion $(N_2 = N)$ at 1531 nm, we obtained gain coefficients is10.86 $cm^{-1}$with Δλ= 70nm of prepared glass was shown in Fig. 3. This value is very large in comparison to those of some tellurite glasses published in the literature [15].

4. Conclusions

In present work studying in UV- Vis- NIR absorption of oxide glass (TBT doped with Er33+) composition such as; $90TeO_2$- $5Ta_2O_5$- $5Bi_2O_3$-25000ppm Er_2O_3in mol% .The spectroscopic values of $\Omega_{(t)}$ are equal in the present work ($\Omega_{(2)}$= 0.647× 10^{-20} cm^2, $\Omega_{(4)}$= 0.772× 10^{-20} cm^2, $\Omega_{(6)}$= 0.4606× 10^{-20} cm^2 and $\Omega_{(4)}$/ $\Omega_{(6)}$ = 1.676).The luminescence branching ratio(β) = 100% of the$^4I_{13/2}\rightarrow {}^4I_{15/2}$ transition, this attribute to high spontaneous transition probabilities. The optical gain coefficient (G(λ)=10.86 cm^{-1}) of the population inversion of the $^4I_{13/2}$ and emission cross-section (σ_e^{peak} =$11\times10^{-20}cm^{-20}$) of prepared glasses. Hence, these results leads to these glass be can use in optical fibre laser and amplifier gain.

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