

Judd-Ofelt analysis and crystal field calculations of Er³⁺ ions in new oxyfluorogermanotellurite glasses and glass-ceramics

Hayat Zanane^{*,a,c}, Matias Velázquez^b, Dominique Denux^a, Jean-René Duclère^d, Julie Cornette^d, Aïcha Kermaoui^c, Hamid Kellou^c, Michel Lahaye^e, Sonia Buffière^a

^a CNRS, Université de Bordeaux, ICMCB, UMR 5026, 87 avenue du Dr. A. Schweitzer, 33608 Pessac cedex, France

^b Univ. Grenoble Alpes, CNRS, Grenoble INP, SIMAP, 38000 Grenoble, France

^c Faculté de Physique, Laboratoire d'Électronique Quantique, USTHB, BP 32 El alia, 16111 Bab Ezzouar, Alger, Algeria

^d IRCER – Centre Européen de la Céramique – 12 Rue Atlantis – 87068 LIMOGES Cedex Atlantis, Limoges, France

^e PLACAMAT, UMS 3626, CNRS-Université Bordeaux, 87 avenue du Dr. A. Schweitzer, 33600 Pessac, France

* Corresponding author: Hayat Zanane, hzanane@usthb.dz

Samples	30 TeO ₂ -30 GeO ₂ -3 La ₂ O ₃ -15 ZnO-10 Na ₂ CO ₃ -10 CaF ₂ -2 ErF ₃			30 TeO ₂ -30 GeO ₂ -3 La ₂ O ₃ -15 ZnO-10 Na ₂ CO ₃ -10 CaF ₂ -4 ErF ₃		
	Number of atoms	% Weight _{theo}	% Weight _{exp}	Number of atoms	% Weight _{theo}	% Weight _{exp}
Te	30	30.84	32.40	30	29.76	32.12
Ge	30	17.55	17.18	30	16.94	17.02
Zn	10	7.90	9.31	10	7.62	8.77
Na	20	3.70	4.71	20	3.57	5.43
Ca	10	3.23	3.66	10	3.12	3.43
La	3	6.71	6.34	3	6.48	5.93
Yb/Er	2	2.69	3.14	4	5.20	5.98
O	174	22.42	20.71	174	21.64	20.62
F	26	3.98	2.54	32	4.73	0.69
C	10	0.97		10	0.93	

Table 1. Average EPMA/WDS elemental analysis of 2 and 4 % Er³⁺-doped glass samples.

Transition	λ (nm)	A_{Jf}^{DE} (s ⁻¹)	A_{Jf}^{DM} (s ⁻¹)	β_{Jf}^{Rad}	τ_f^{Rad} (ms)
⁴ I _{13/2} → ⁴ I _{15/2}	1518.67	153.98271	68.0428	1	4.504
⁴ I _{11/2} → ⁴ I _{15/2}	977.8	209.34227	0	0.81613	3.899
→ ⁴ I _{13/2}	2745.7	31.35886	15.80412	0.18387	
⁴ I _{9/2} → ⁴ I _{15/2}	801.4	380.75234	0	0.86117	2.262
→ ⁴ I _{13/2}	1696.6	57.7191	0	0.13055	
→ ⁴ I _{11/2}	4442.1	1.64077	2.02268	8.28582*10 ⁻³	
⁴ F _{9/2} → ⁴ I _{15/2}	654.2	3.13497*10 ³	0	0.91605	0.292
→ ⁴ I _{13/2}	1149.4	178.46509	0	0.05215	
→ ⁴ I _{11/2}	1977.1	85.84768	9.8042	0.02795	
→ ⁴ I _{9/2}	3562.5	8.98671	4.19094	3.85057*10 ⁻³	
² S _{3/2} + ² H _{11/2}					0.021
→ ⁴ I _{15/2}	541.4	4.58652*10 ⁴	0	0.94644	
→ ⁴ I _{13/2}	841.3	1.25756*10 ³	256.83136	0.03125	
→ ⁴ I _{11/2}	1213.0	437.00276	29.53878	9.6272*10 ⁻³	
→ ⁴ I _{9/2}	1668.6	513.42648	2.2084	0.01064	
→ ⁴ F _{9/2}	3138.7	98.58376	0.34803	2.04148*10 ⁻³	
⁴ F _{7/2} → ⁴ I _{15/2}	487.1	3.02103*10 ³	0	0.66504	0.220
→ ⁴ I _{13/2}	717.1	968.64386	0	0.21323	
→ ⁴ I _{11/2}	970.6	364.06393	0	0.08014	
→ ⁴ I _{9/2}	1241.9	144.99676	12.87815	0.03475	
→ ⁴ F _{9/2}	1906.6	11.99307	14.18934	5.76368*10 ⁻³	
→ ² S _{3/2} + ² H _{11/2}	4856.7	4.86265	0	1.07044*10 ⁻³	
$\Omega_2=7.275 \times 10^{-20} \text{ cm}^2$, $\Omega_4=2.805 \times 10^{-20} \text{ cm}^2$, $\Omega_6=0.832 \times 10^{-20} \text{ cm}^2$, $\delta_{RMS}=1.033$					

Table 2. Judd-Ofelt parameters and spectroscopic factors of Er³⁺ cations in "2ErF₃"-doped and heat-treated sample at 728 K for 2 h obtained by the standard (unnormalized) procedure with the ⁴I_{15/2} → ⁴G_{11/2} transition included in the Judd-Ofelt analysis.

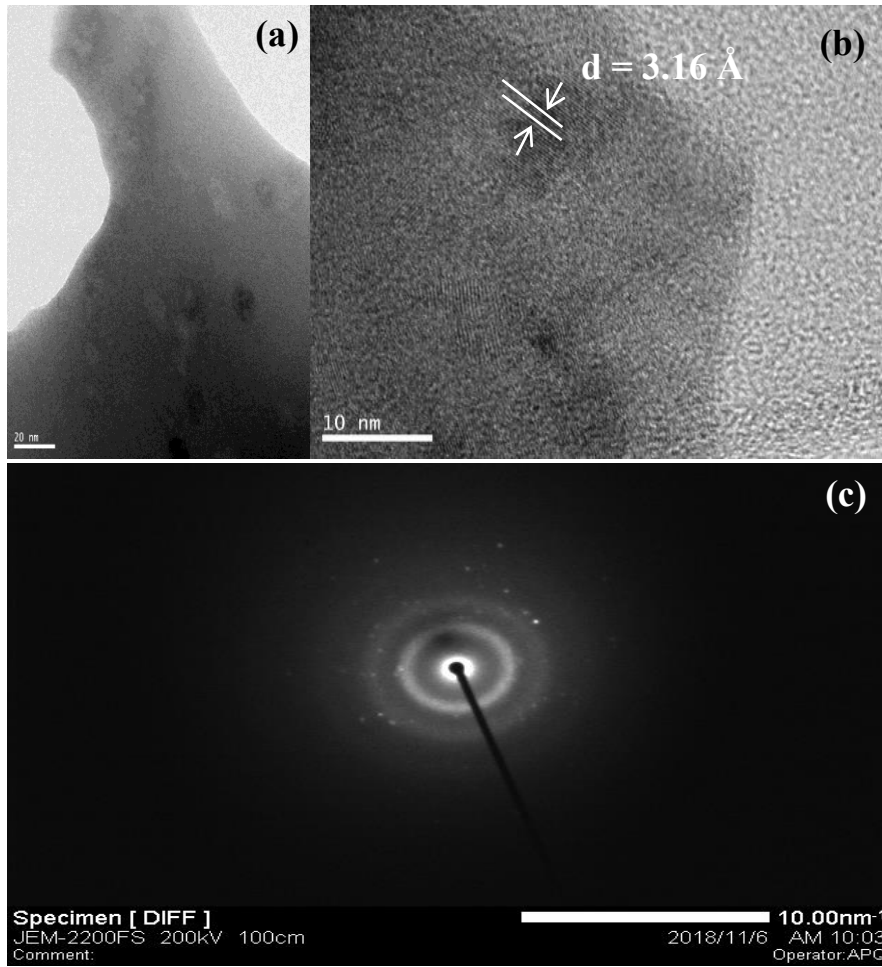


Figure 1. (a) TEM, (b) HRTEM image. (c) SAED pattern of “2ErF₃”-doped and heat-treated sample at 728 K for 2 h.

Transition	Transition number	Calc.S ^{ED} /Exp.S ^{ED}
⁴ I _{15/2} →		
⁴ I _{13/2}	1	0.87
⁴ I _{11/2}	2	0.85
⁴ I _{9/2}	3	0.91
⁴ F _{9/2}	4	1.11
⁴ S _{3/2} , ² H _{11/2}	5	1.21
⁴ F _{7/2}	6	1.04
⁴ F _{5/2} , ⁴ F _{3/2}	7	1.13
² H _{9/2}	8	0.96
⁴ G _{11/2} , ⁴ G _{9/2} , ² K _{15/2}	9	0.72

Table 5. The ratios of calculated electric-dipole transition strengths over measured ones.

Transition	λ (nm)	$A_{J'J}^{DE}$ (s^{-1})	$A_{J'J}^{DM}$ (s^{-1})	$\beta_{J'J}^{Rad}$	τ_J^{Rad} (ms)
$^4I_{13/2} \rightarrow ^4I_{15/2}$	1518.67	156.99537	68.0428	1	4.444
$^4I_{11/2} \rightarrow ^4I_{15/2}$	977.8	209.53961	0	0.82125	3.919
$\rightarrow ^4I_{13/2}$	2745.7	29.80241	15.80412	0.17875	
$^4I_{9/2} \rightarrow ^4I_{15/2}$	801.4	260.62857	0	0.79178	3.038
$\rightarrow ^4I_{13/2}$	1696.6	65.10145	0	0.19778	
$\rightarrow ^4I_{11/2}$	4442.1	1.41548	2.02268	0.01045	
$^4F_{9/2} \rightarrow ^4I_{15/2}$	654.2	2.42251* 10^3	0	0.90973	0.376
$\rightarrow ^4I_{13/2}$	1149.4	132.74652	0	0.04985	
$\rightarrow ^4I_{11/2}$	1977.1	86.84275	9.8042	0.03629	
$\rightarrow ^4I_{9/2}$	3562.5	6.78256	4.19094	4.12092* 10^{-3}	
$^2S_{3/2} + ^2H_{11/2}$					0.027
$\rightarrow ^4I_{15/2}$	541.4	3.41079* 10^4	0	0.93764	
$\rightarrow ^4I_{13/2}$	841.3	1.15812* 10^3	256.83136	0.0389	
$\rightarrow ^4I_{11/2}$	1213.0	332.57986	29.53878	9.95482* 10^{-3}	
$\rightarrow ^4I_{9/2}$	1668.6	415.86498	2.2084	0.01149	
$\rightarrow ^4F_{9/2}$	3138.7	72.84873	0.34803	2.01221* 10^{-3}	
$^4F_{7/2} \rightarrow ^4I_{15/2}$	487.1	2.84137	0	0.72032	0.254
$\rightarrow ^4I_{13/2}$	717.1	657.47074	0	0.16668	
$\rightarrow ^4I_{11/2}$	970.6	272.88015	0	0.06918	
$\rightarrow ^4I_{9/2}$	1241.9	133.01793	12.87815	0.03699	
$\rightarrow ^4F_{9/2}$	1906.6	8.69542	14.18934	5.80156* 10^{-3}	
$\rightarrow ^2S_{3/2} + ^2H_{11/2}$	4856.7	4.08256	0	1.03498* 10^{-3}	
$\Omega_2=5.367 \times 10^{-20}$ cm ² , $\Omega_4=1.904 \times 10^{-20}$ cm ² , $\Omega_6=0.955 \times 10^{-20}$ cm ² , $\delta_{RMS}=6.037$					

Table 3. Judd–Ofelt parameters and spectroscopic factors of Er^{3+} cations in “2 ErF_3 ”-doped and heat-treated sample at 728 K for 2 h obtained by the normalized procedure without the $^4I_{15/2} \rightarrow ^4G_{11/2}$ transition included in the Judd–Ofelt analysis.

Transition	λ (nm)	$A_{J'J}^{DE}$ (s^{-1})	$A_{J'J}^{DM}$ (s^{-1})	$\beta_{J'J}^{Rad}$	τ_J^{Rad} (ms)
$^4I_{13/2} \rightarrow ^4I_{15/2}$	1518.67	175.54898	68.0428	1	4.105
$^4I_{11/2} \rightarrow ^4I_{15/2}$	977.8	235.64476	0	0.83109	3.527
$\rightarrow ^4I_{13/2}$	2745.7	32.08902	15.80412	0.16891	
$^4I_{9/2} \rightarrow ^4I_{15/2}$	801.4	209.12911	0	0.72369	3.460
$\rightarrow ^4I_{13/2}$	1696.6	76.40806	0	0.26441	
$\rightarrow ^4I_{11/2}$	4442.1	1.41534	2.02268	0.0119	
$^4F_{9/2} \rightarrow ^4I_{15/2}$	654.2	2.2049* 10^3	0	0.90313	0.410
$\rightarrow ^4I_{13/2}$	1149.4	117.93287	0	0.04831	
$\rightarrow ^4I_{11/2}$	1977.1	97.98107	9.8042	0.04415	
$\rightarrow ^4I_{9/2}$	3562.5	6.6008	4.19094	4.42029* 10^{-3}	
$^2S_{3/2} + ^2H_{11/2}$					0.029
$\rightarrow ^4I_{15/2}$	541.4	3.23346* 10^4	0	0.93321	
$\rightarrow ^4I_{13/2}$	841.3	1.23111* 10^3	256.83136	0.04294	
$\rightarrow ^4I_{11/2}$	1213.0	308.38139	29.53878	9.75267* 10^{-3}	
$\rightarrow ^4I_{9/2}$	1668.6	416.01528	2.2084	0.01207	
$\rightarrow ^4F_{9/2}$	3138.7	69.89129	0.34803	2.02717* 10^{-3}	
$^4F_{7/2} \rightarrow ^4I_{15/2}$	487.1	3.00999* 10^3	0	0.76137	0.253
$\rightarrow ^4I_{13/2}$	717.1	522.29402	0	0.13211	
$\rightarrow ^4I_{11/2}$	970.6	241.93102	0	0.0612	
$\rightarrow ^4I_{9/2}$	1241.9	140.06415	12.87815	0.03869	
$\rightarrow ^4F_{9/2}$	1906.6	7.80838	14.18934	5.5643* 10^{-3}	
$\rightarrow ^2S_{3/2} + ^2H_{11/2}$	4856.7	4.2135	0	1.0658* 10^{-3}	
$\Omega_2=5.157 \times 10^{-20}$ cm ² , $\Omega_4=1.512 \times 10^{-20}$ cm ² , $\Omega_6=0.129 \times 10^{-20}$ cm ² , $\delta_{RMS}=0.081$					

Table 4. Judd–Ofelt parameters and spectroscopic factors of Er^{3+} cations in “2 ErF_3 ”-doped and heat-treated sample at 728 K for 2 h obtained by the standard (unnormalized) procedure without the $^4I_{15/2} \rightarrow ^4G_{11/2}$ transition included in the Judd–Ofelt analysis.

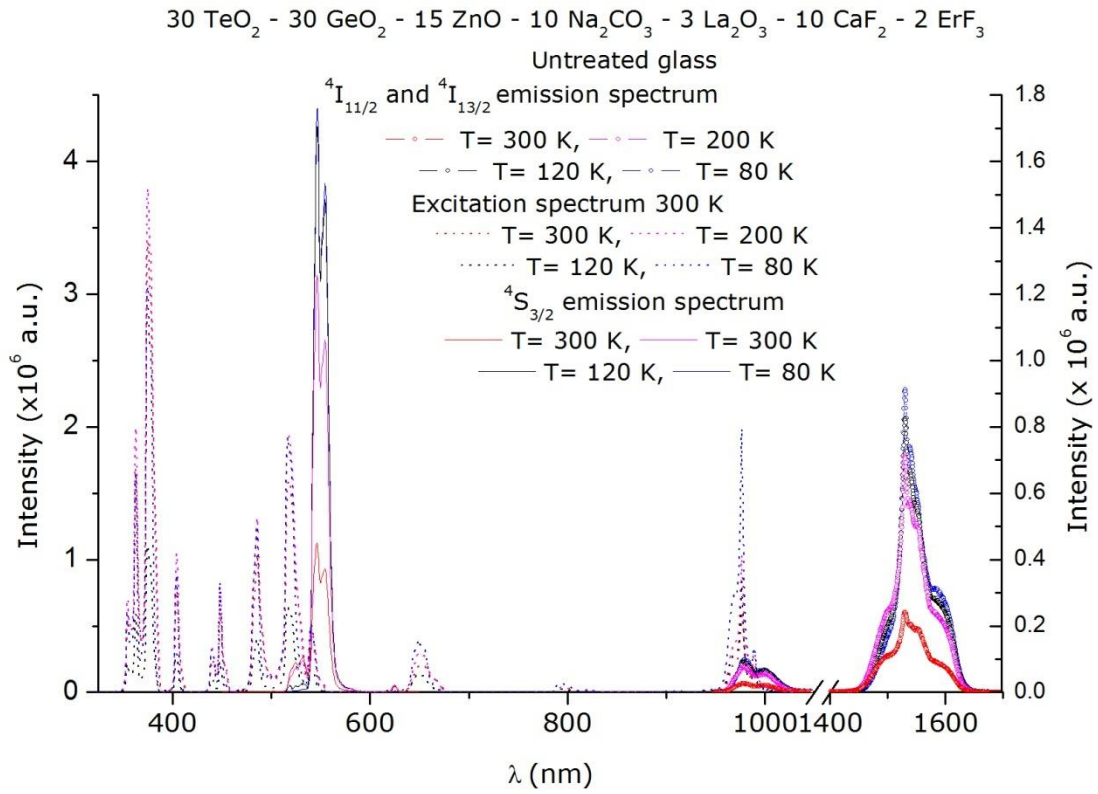


Figure 2. “2 ErF₃”-doped and untreated glass excitation and emission spectra recorded at 80, 120, 200 and 300 K. The peak positions remain unchanged from 300 to 80 K.

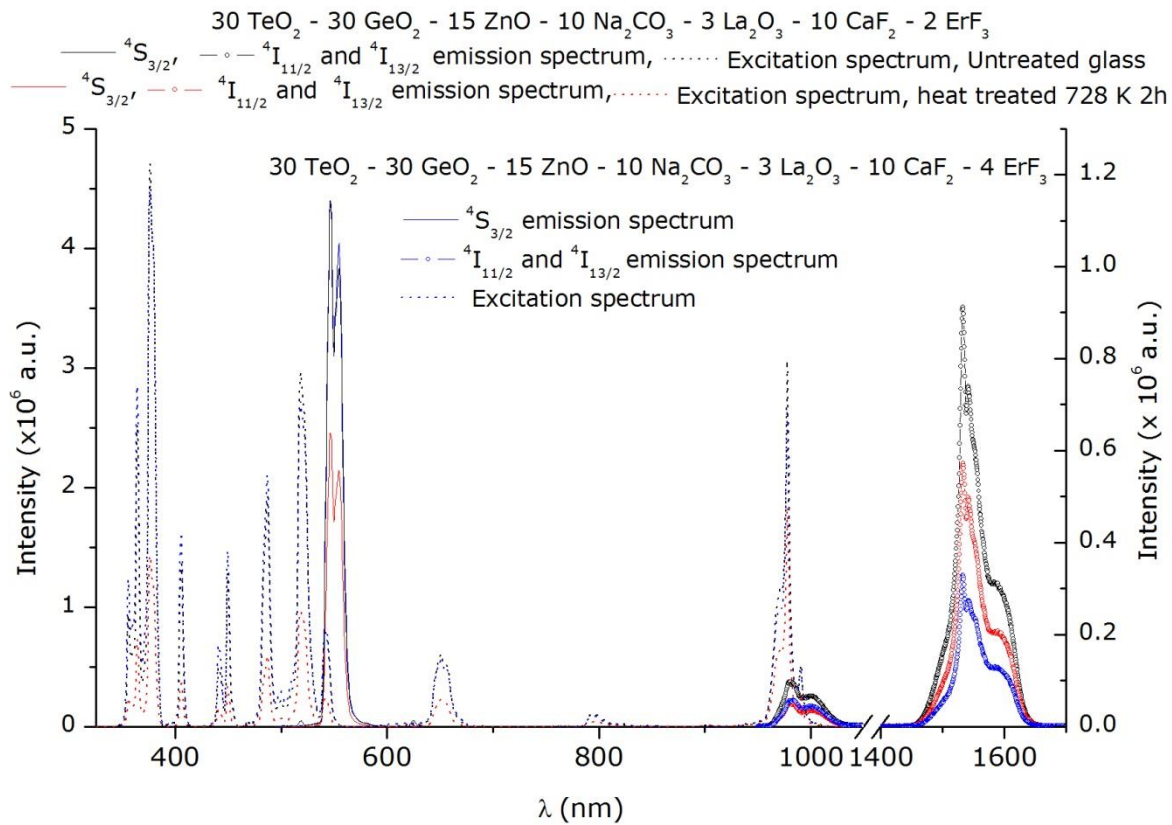
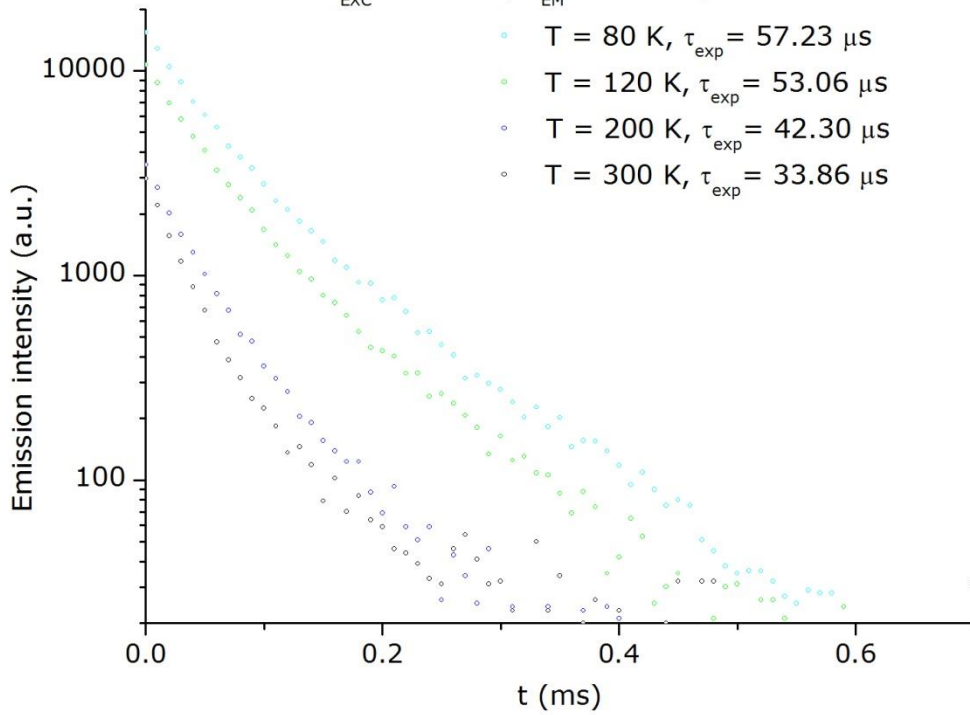


Figure 3. “2 ErF₃”-doped glass annealed at 728 K for 2 h excitation and emission spectra recorded at 300 K. Same spectra for the “4 ErF₃”-doped and thermally untreated glass. The peak positions remain unchanged by the thermal annealing or the Er³⁺-concentration increase.

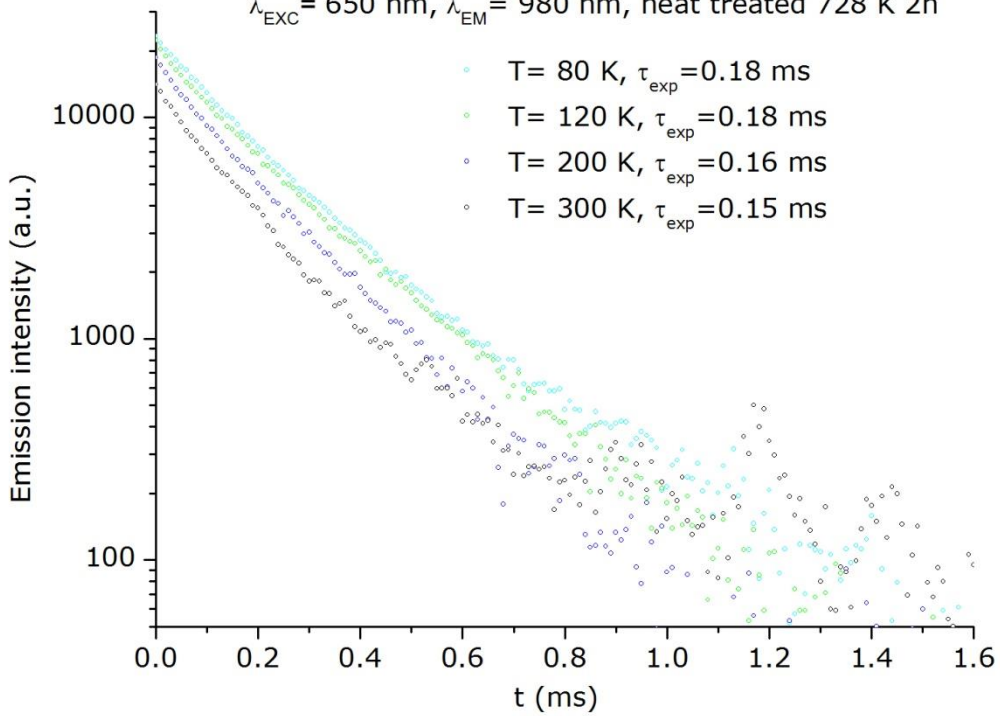
30 TeO₂ - 30 GeO₂ - 15 ZnO - 10 Na₂CO₃ - 10 CaF₂ - 3 La₂O₃ - 2 ErF₃

$\lambda_{\text{EXC}} = 380 \text{ nm}$, $\lambda_{\text{EM}} = 546 \text{ nm}$, heat treated 728K 2h



30 TeO₂ - 30 GeO₂ - 15 ZnO - 10 Na₂CO₃ - 10 CaF₂ - 3 La₂O₃ - 2 ErF₃

$\lambda_{\text{EXC}} = 650 \text{ nm}$, $\lambda_{\text{EM}} = 980 \text{ nm}$, heat treated 728 K 2h



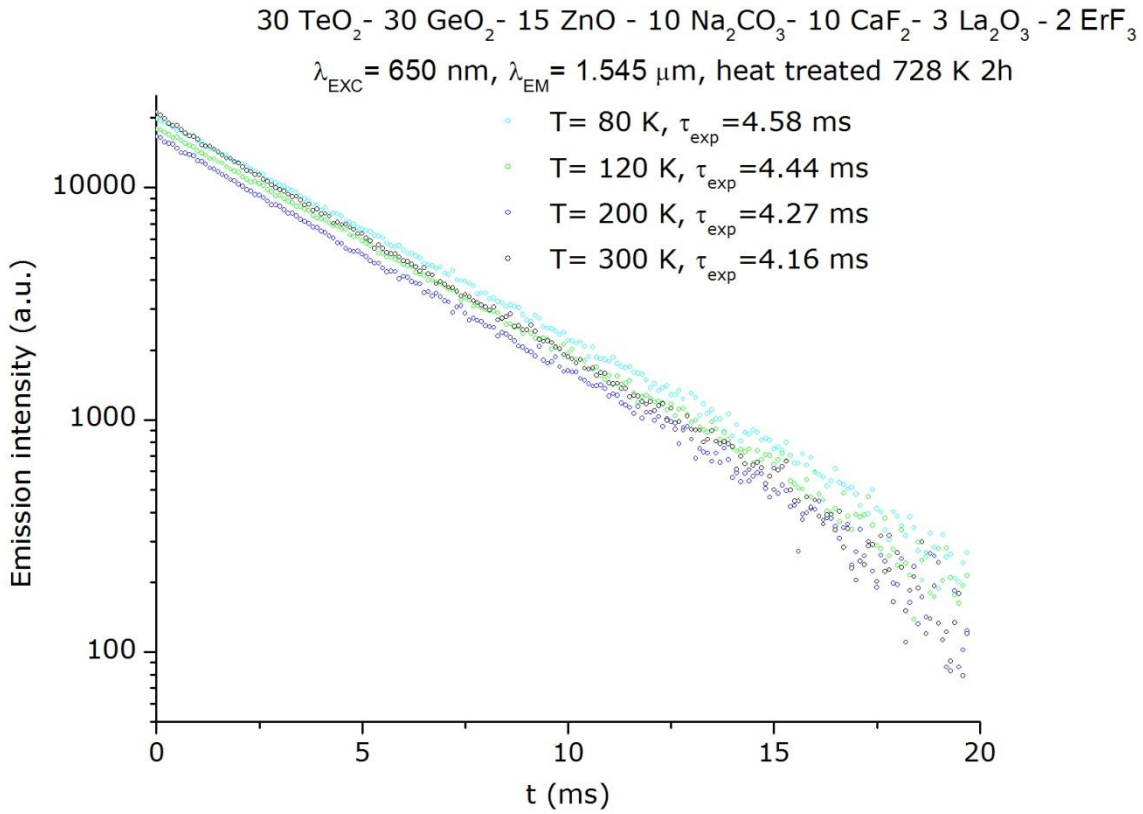
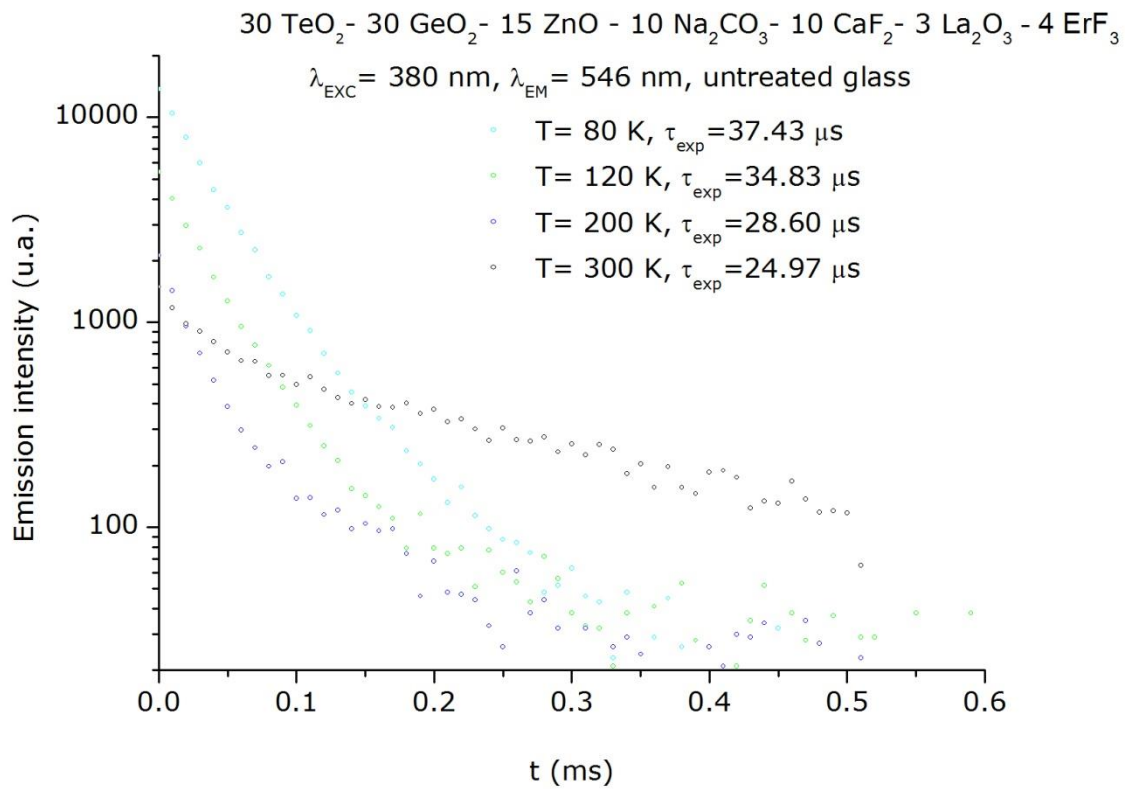


Figure 4. *Er³⁺ ions fluorescence decays at $\lambda_{em}=456$ (⁴S_{3/2}), 980 (⁴I_{11/2}) and 1545 (⁴I_{13/2}) nm in “2 ErF₃”-doped and annealed at 728 K for 2h sample as a function of temperature.*



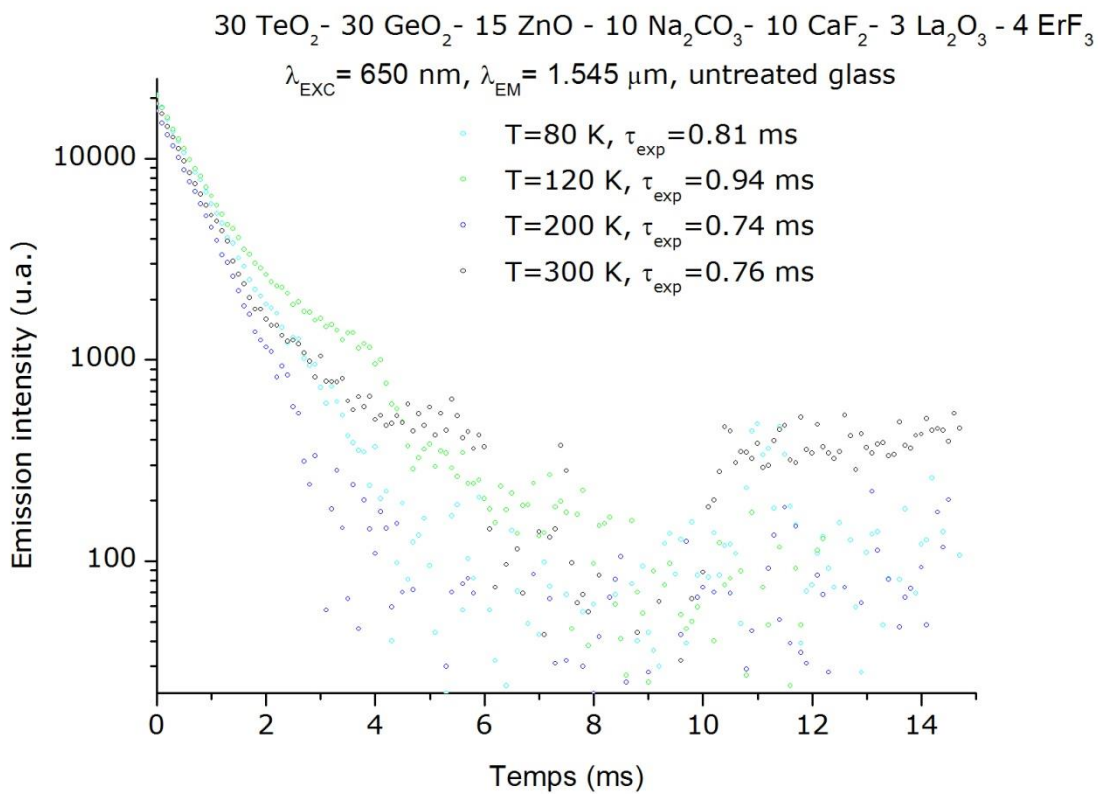
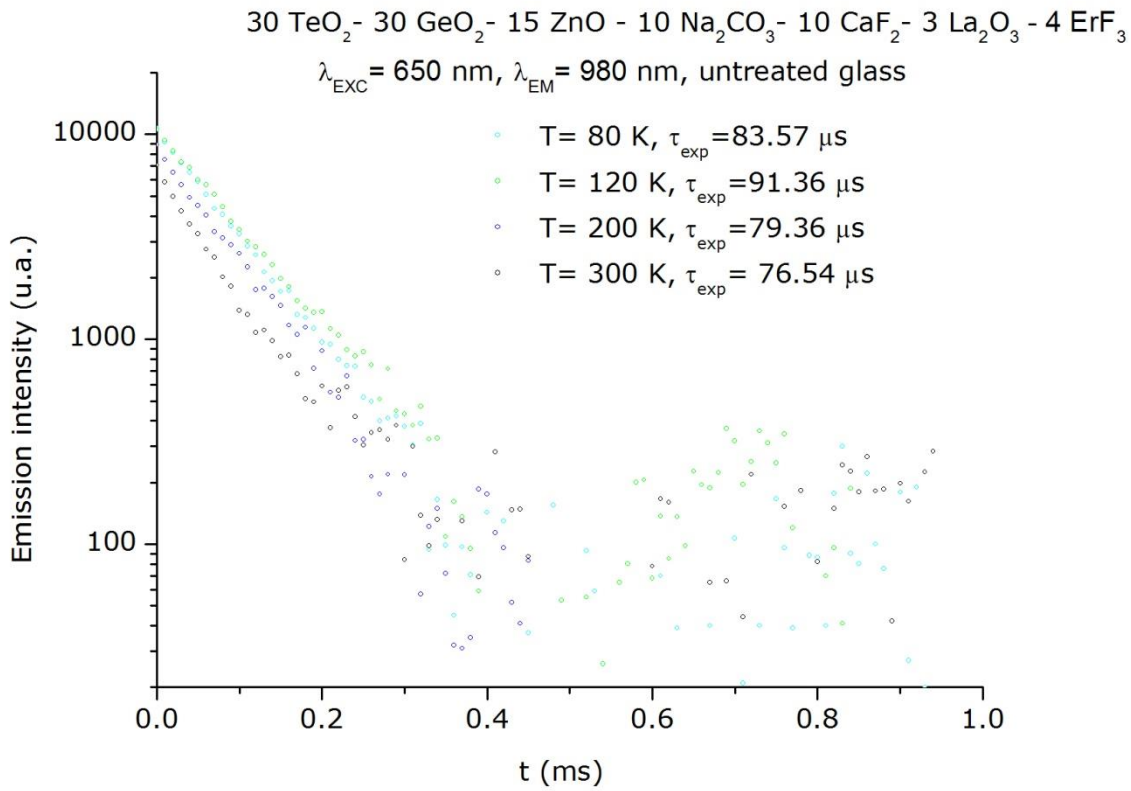


Figure 5. *Er³⁺ ions fluorescence decays at $\lambda_{em}=456$ (⁴S_{3/2}), 980 (⁴I_{1/2}) and 1545 (⁴I_{13/2}) nm in the “4 ErF₃”-doped and untreated glass as a function of temperature.*

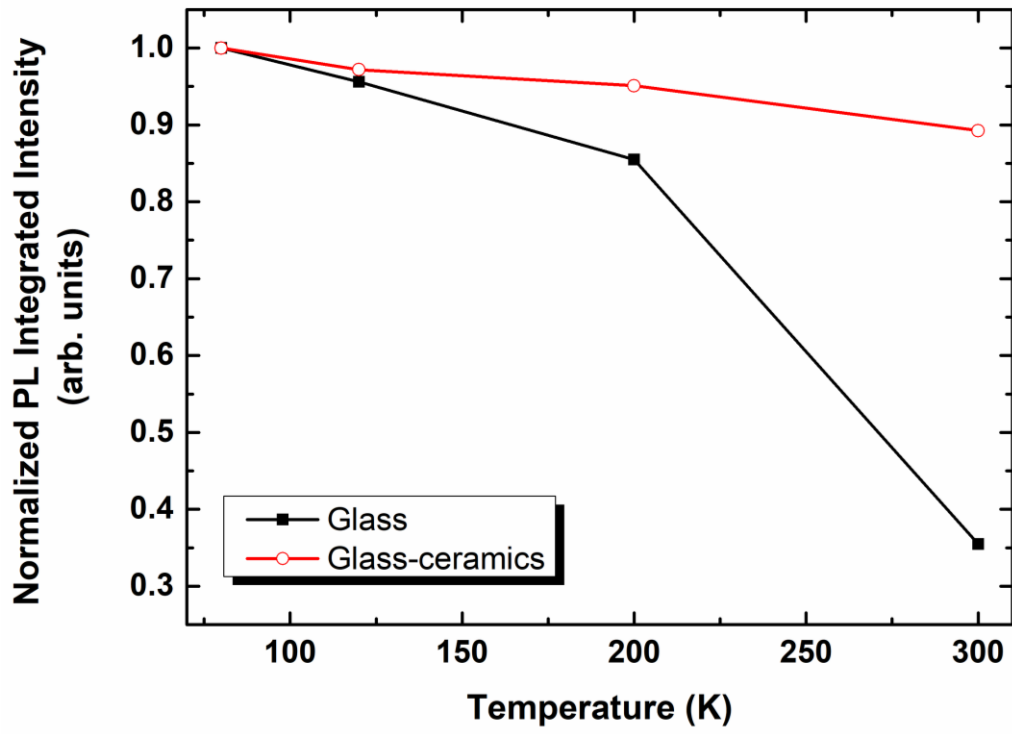


Figure 6. Integrated emission intensity of the Er^{3+} cations ${}^4I_{13/2}$ level (1533 nm) as a function of temperature in the untreated and heat-treated (728 K, 2 h) “2 ErF_3 ”-doped glass materials. The integrated intensity is normalized to the 80 K-value.