

Energy transfer from Ag species to Nd³⁺ in Ga-fluoride-phosphate glasses: Near-infrared emission enhancement via controlled heat treatment and femtosecond laser inscription

Vinicius D. Jesus^{1*}, Leonnam G. Merizio^{1,2}, Gustavo Galleani¹, Guillaume Raffy³, Mathis Carpentier⁴, Yannick Petit^{4*}, Thierry Cardinal⁴, Andrea S. S. de Camargo^{5,6*}

¹São Carlos Institute of Physics, University of São Paulo, São Carlos, SP, 13566-590, Brazil

²São Carlos Institute of Chemistry, University of São Paulo, São Carlos, SP, 13566-590, Brazil

³Université de Bordeaux, CNRS, ISM, UMR 5255, F-33400 Talence, France

⁴Université de Bordeaux, CNRS, Bordeaux INP, ICMCB, UMR 5026, F-33600 Pessac, France

⁵Federal Institute for Materials Research and Testing (BAM), Berlin, 12489, Germany

⁶Otto-Schott Institute of Materials Research, Friedrich-Schiller University, Jena, 07743, Germany

Supplementary Material

Figure S.1. Photoluminescence emission spectra of the Ga0Ag sample before and after annealing

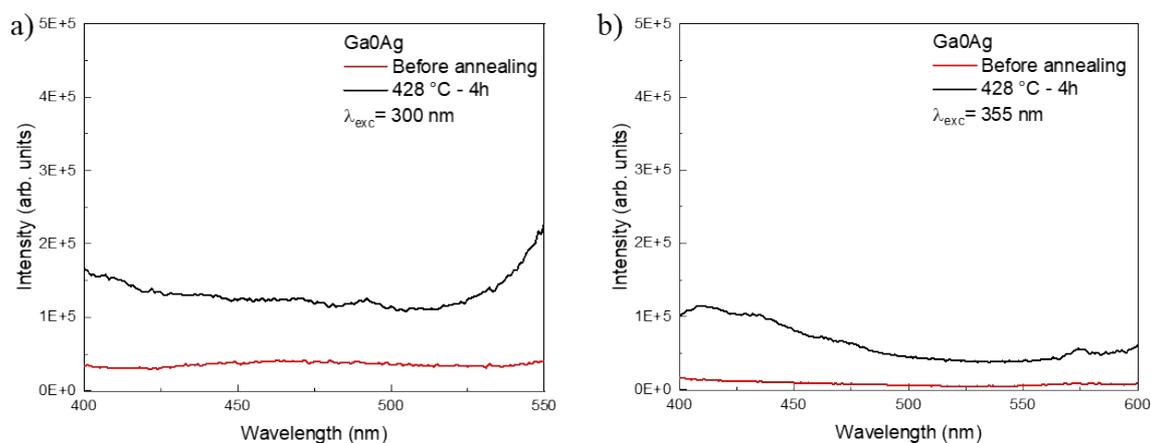


Figure S.2. Photoluminescence spectra of the samples after annealing and polishing doped with different concentrations of silver: a) 1 mol%, b) 3 mol%, c) 5 mol% d) 10 mol%.

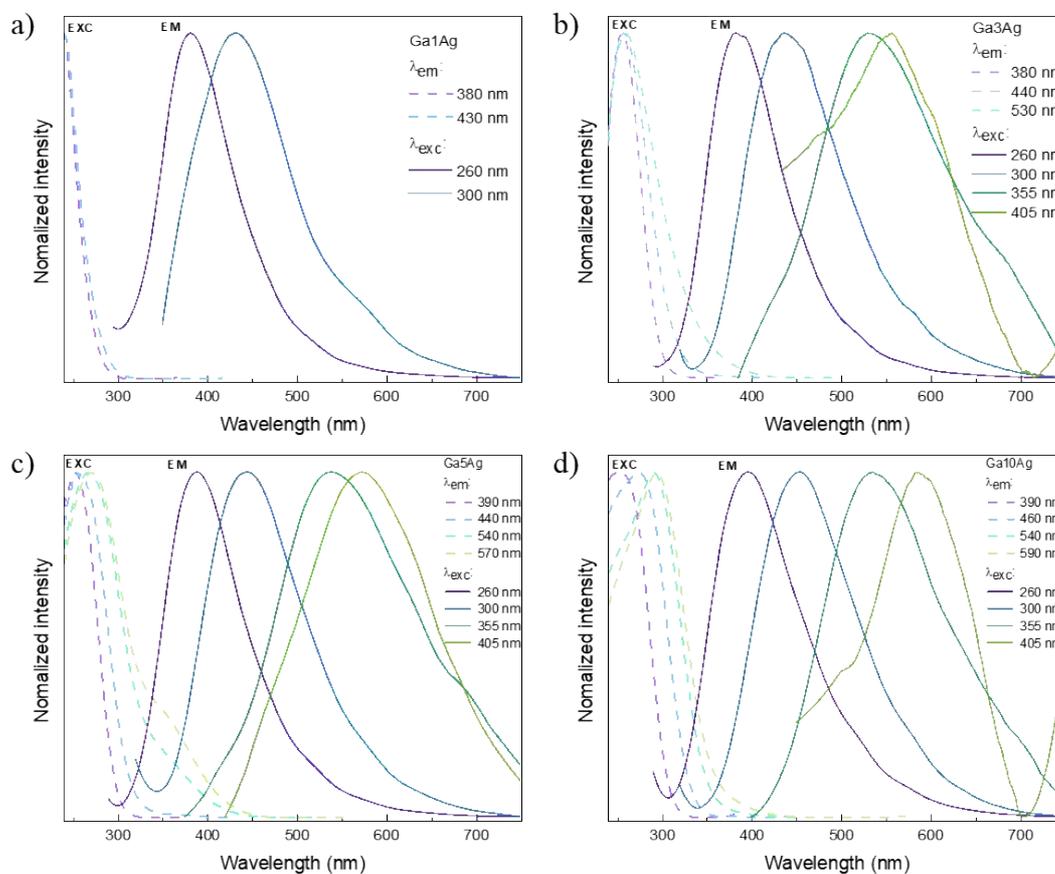


Figure S.3. Time-resolved emission decay curves of FP glass samples singly Ag-doped, under 300 nm excitation and monitoring the emission at 500 nm, with different concentrations of silver: 1, 3, 5 and 10 mol%.

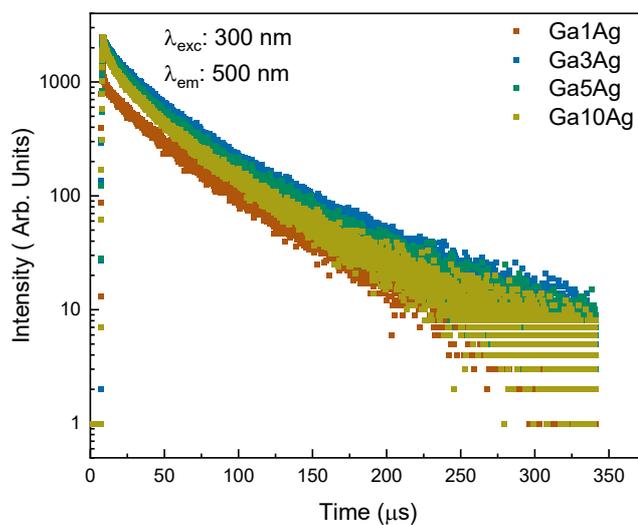


Figure S.4. Time-resolved emission decay curves of FP glass samples singly Ag/Nd co-doped, under a) 300 and b) 355 nm excitations and monitoring the emission at 1051 nm, with 1 mol% of Nd³⁺ and different concentrations of silver 3 and 5 mol%.

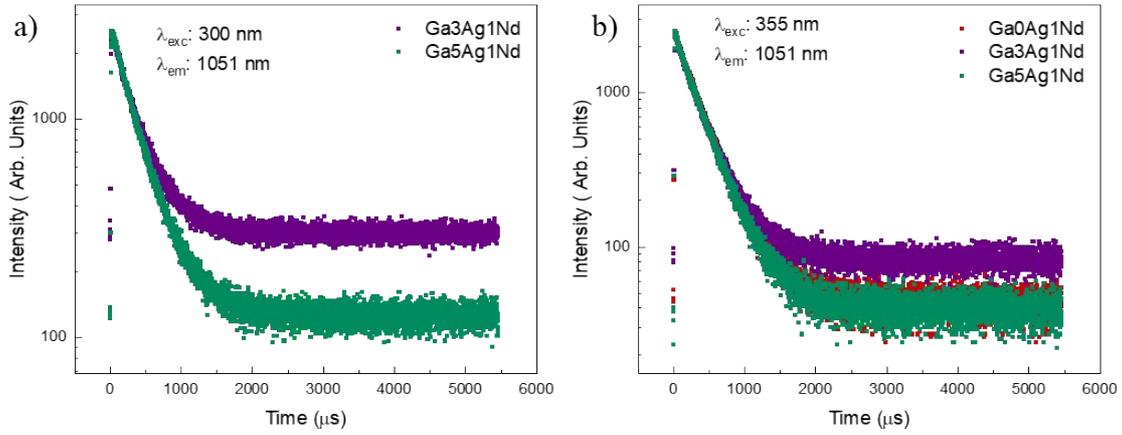


Figure S.5. Microluminescence spectra of laser written lines under 405 nm excitation for a) Ga3Ag and b) Ga3Ag1Nd; Peak intensity of Ag-NC visible emission versus laser irradiance for c) Ga5Ag and d) Ga5Ag1Nd; e) Peak intensity of Nd³⁺ emission at 880 nm in Ga5Ag1Nd; f) Correlation between Ag-NC visible emission and Nd³⁺ emission (NIR) in Ga5Ag1Nd by combining d) and e).

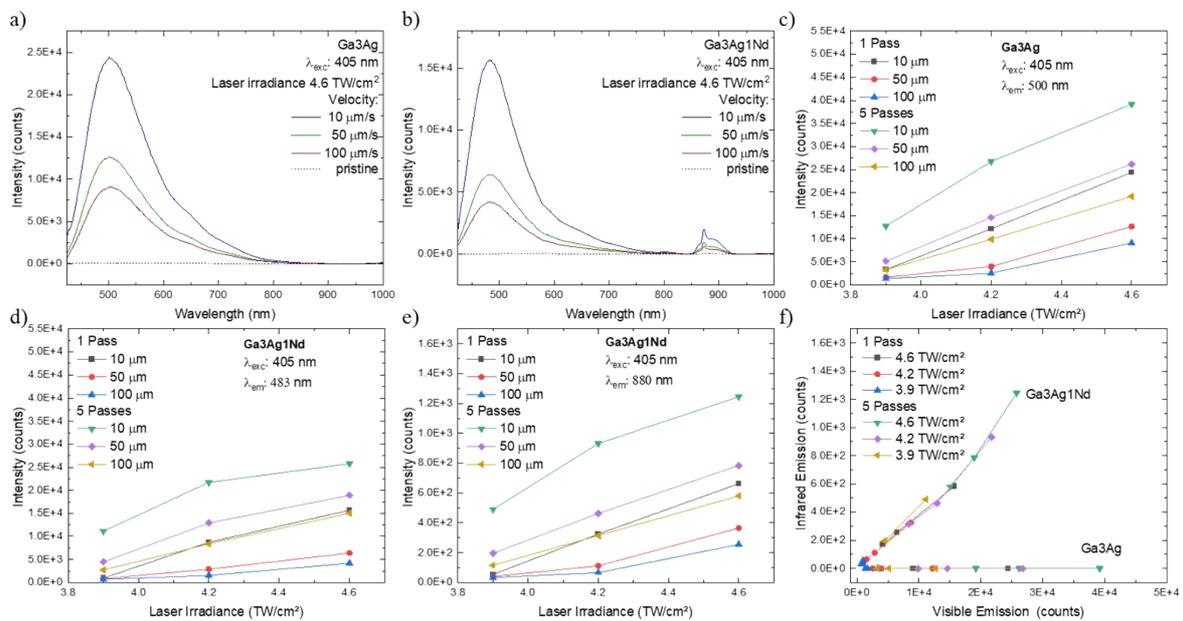


Table S.1. Fitted parameters of the bi-exponential decay model applied to temporal decays from Fig. 10 for the samples singly Ag-doped and Ag/Nd co-doped.

Glass	A_1	τ_1 (μs)	A_2	τ_2 (μs)	τ^{av} (μs)
Ga1Ag	1E8 \pm 1E7	0.7	1068 \pm 3	38.4	0.7
Ga3Ag	2026 \pm 18	9.6	1804 \pm 12	45.1	26.4
Ga3Ag1Nd	5477 \pm 81	5.2	1641 \pm 9	30.9	11.1
Ga5Ag	3050 \pm 40	7.3	1709 \pm 10	41.9	19.7
Ga5Ag1Nd	7817 \pm 141	4.3	1642 \pm 8	29.4	8.7
Ga10Ag	5519 \pm 100	5.0	1624 \pm 7	38.0	12.5
Ga10Ag1Nd	530134 \pm 289	1.4	1291 \pm 7	22.0	1.4

Table S.2. Fitted parameters of the exponential decay model applied to temporal decays from Fig. S.4 for the samples Ag/Nd co-doped.

Glass	Excitation (nm)	A_1	τ_1 (μs)
Ga0Ag1Nd	355	2477 \pm 2	328.1
Ga3Ag1Nd	300	2348 \pm 3	315.5
	355	2446 \pm 2	308.9
Ga5Ag1Nd	300	2611 \pm 2	328.2
	355	2473 \pm 2	321.5

Table S.3. Fitted parameters of the three-exponential decay model applied to the fluorescence temporal decays from Fig. 13d for the samples Ga5Ag and Ga5Ag (overall image analysis that includes all the patterns obtained with the distinct irradiation parameters during femtosecond laser inscription.)

Glass	A_1 (%)	τ_1 (ns)	A_2 (%)	τ_2 (ns)	A_3 (%)	τ_3 (ns)	τ^{av} (ns)	$Q(\tau_{5Ag1Nd}^{av}/\tau_{5Ag}^{av})$ (%)
Ga5Ag	6880	7.43	15800	1.00	1720	3.50	3.19	44.8%
Ga5Ag1Nd	719	5.14	3840	0.72	2740	2.32	1.76	

Table S.4. Amplitude-weighted average lifetimes for the four considered samples and associated fluorescence quenching ratios. Calculated from the all fitted parameters of the three-exponential decay model applied to the fluorescence temporal decay corresponding to each pattern obtained with the distinct irradiation parameters during femtosecond laser inscription.

Laser irradiation parameters			τ^{av} (ns) $Q(\tau_{3Ag1Nd}^{av}/\tau_{3Ag}^{av})$			τ^{av} (ns) $Q(\tau_{5Ag1Nd}^{av}/\tau_{5Ag}^{av})$		
N_{pass}	I (TW/cm ²)	v (μ m/s)	<i>Ga3Ag</i>	<i>Ga3Ag1Nd</i>	(%)	<i>Ga5Ag</i>	<i>Ga5Ag1Nd</i>	(%)
1	4.57	100	5.08	2.25	55.7	3.47	1.77	49
1	4.57	50	4.99	2.13	57.3	3.16	1.72	45.6
1	4.57	10	4.5	1.88	58.2	2.64	1.57	40.5
1	4.22	100	5.07	2.39	52.9	3.8	2.01	47.1
1	4.22	50	5.1	2.31	54.7	3.46	1.9	45.1
1	4.22	10	4.84	2.1	56.6	2.91	1.7	41.6
1	3.86	100	5.2	2.31	55.6	4.39	2.09	52.4
1	3.86	50	5.11	2.29	55.2	4.25	2.09	50.8
1	3.86	10	5.02	2.34	53.4	3.63	1.98	45.5
5	4.57	100	5.2	2.58	50.4	4.51	2.24	50.3
5	4.57	50	4.97	2.46	50.5	4.17	2.15	48.4
5	4.57	10	4.63	2.21	52.3	3.36	1.85	44.9
5	4.22	100	4.99	2.58	48.3	4.69	2.29	51.2
5	4.22	50	5.21	2.53	51.4	4.5	2.14	52.4
5	4.22	10	5.06	2.31	54.3	3.84	2.05	46.6
5	3.86	100	5.02	2.46	51	4.85	2.09	56.9
5	3.86	50	5.03	2.48	50.7	4.82	2.08	56.8
5	3.86	10	5.08	2.52	50.4	4.67	2.12	54.6