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Color-tunable luminescence and temperature sensing properties of Bi^{3+}/Sm^{3+} or Bi^{3+}/Eu^{3+} codoped $Ba_2Gd_2Ge_4O_{13}$phosphors

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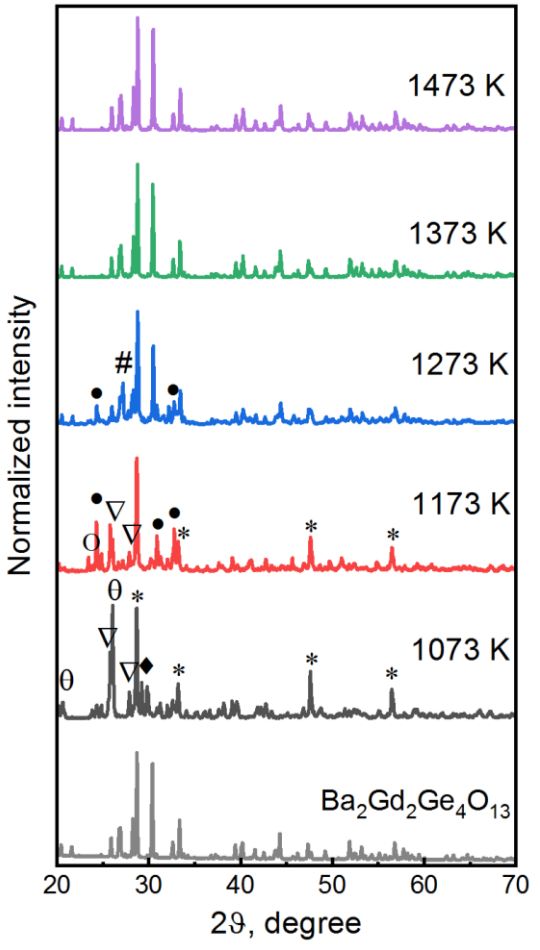
a)



b)

T, K	Content of the main phase, mass.%	Impurities
1073	0.0	$BaGeO_3$,Ba_2GeO_4, GeO_2, Gd_2O_3, $Gd_2Ge_2O_7$, $BaGe_4O_9$
1173	6.8	$Ba_3(GeO_3)_3$, $BaGe_4O_9$, $BaGeO_3$, $BaGd_2Ge_3O_{10}$, Gd_2O_3
1273	65.2	$BaGe_4O_9$, $BaGeO_3$, $BaGd_2Ge_3O_{10}$, Gd_2O_3, Gd_2GeO_5
1373	97.7	$BaGd_2Ge_3O_{10}$
1473	100.0	-

c)

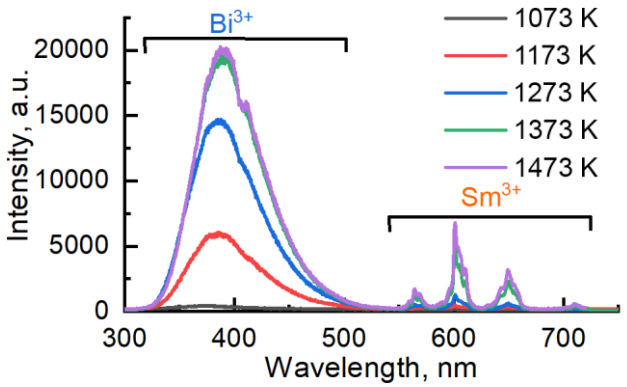


Fig. S1 Influence of the annealing temperature on the XRPD patterns and the phase composition of the $Ba_2Gd_{1.94}Bi_{0.01}Sm_{0.05}Ge_4O_{13}$ precursor, ∇ - $BaGeO_3$, ● - $BaGe_4O_9$, * - Gd_2O_3, o - $Ba_3(GeO_3)_3$, # - $BaGd_2Ge_3O_{10}$, *θ* - GeO_2, ♦ - Ba_2GeO_4 (a and b), the PL spectra of the $Ba_2Gd_{1.94}Bi_{0.01}Sm_{0.05}Ge_4O_{13}$ precursor annealed at T = 1073, 1173, 1273, 1373 and 1473 K (c).

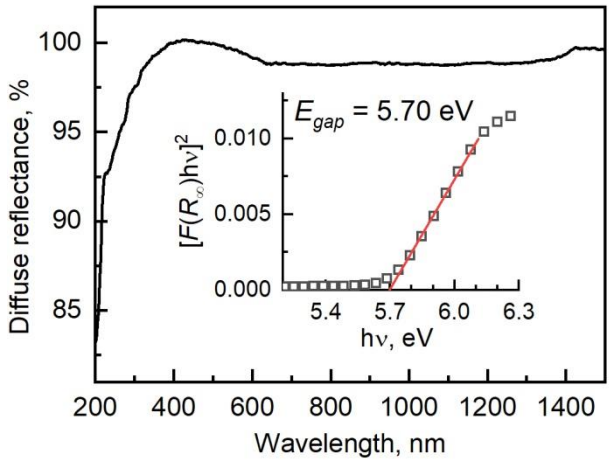


Fig. S2 Diffuse reflectance spectrum of the $Ba_2Gd_2Ge_4O_{13}$ host. The insets show the determination of the band gap energy.

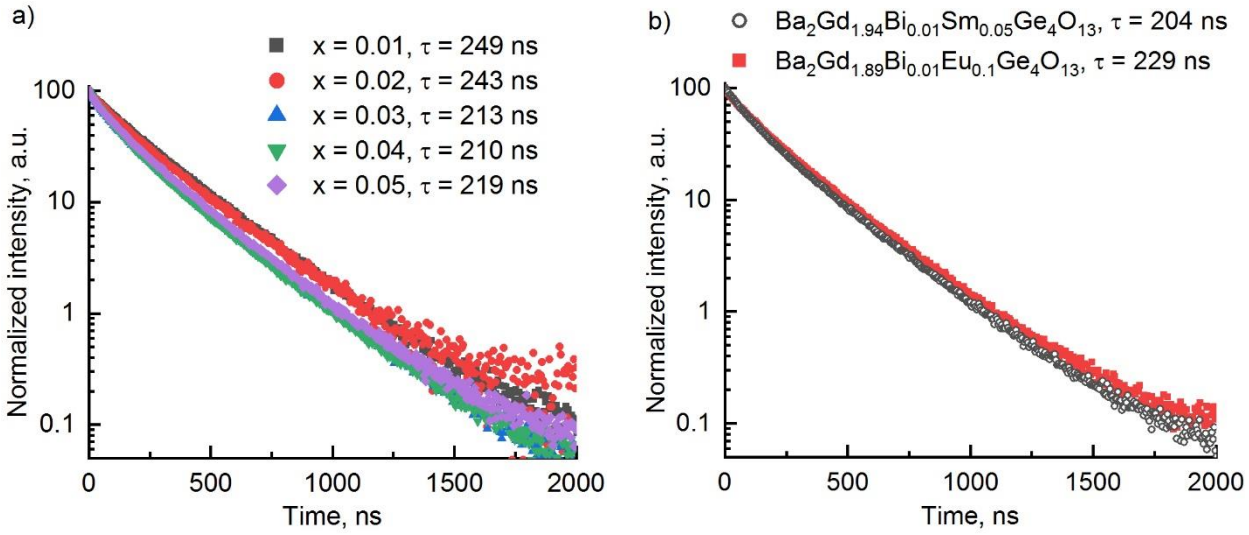


Fig. S3 Luminescence decay curves of $Ba_2Gd_{2-x}Bi_xGe_4O_{13}$ (a), $Ba_2Gd_{1.94}Bi_{0.01}Sm_{0.05}Ge_4O_{13}$ and $Ba_2Gd_{1.89}Bi_{0.01}Eu_{0.1}Ge_4O_{13}$ (b) phosphors monitored at 386 nm under 280 nm excitation.

Table S1 Crystallographic data for $Ba_2Gd_{2-x}Bi_xGe_4O_{13}$, $Ba_2Gd_{1.99-x}Bi_{0.01}Sm_xGe_4O_{13}$ and $Ba_2Gd_{1.99-x}Bi_{0.01}Eu_xGe_4O_{13}$

x	*a*, Å	*b*, Å	*c*, Å	*β*, °	*V*, Å^3
			$Ba_2Gd_{2-x}Bi_xGe_4O_{13}$		
0.01	13.0763(2)	5.36930(10)	17.9936(4)	105.120(1)	1219.61(4)
0.02	13.0758(2)	5.36936(10)	17.9937(4)	105.132(1)	1219.52(4)
0.03	13.0760(2)	5.36997(10)	17.9939(4)	105.135(1)	1219.67(4)
0.04	13.0770(3)	5.37075(12)	17.9928(4)	105.135(2)	1219.86(5)
0.05	13.0771(2)	5.37081(10)	17.9934(4)	105.136(1)	1219.92(4)
			$Ba_2Gd_{2-x}Bi_{0.01}Sm_xGe_4O_{13}$		
0.05	13.0782(2)	5.36950(11)	17.9948(4)	105.123(1)	1219.89(4)
0.1	13.0793(3)	5.37000(11)	17.9944(4)	105.129(1)	1220.06(5)
0.15	13.0795(3)	5.37040(11)	17.9946(4)	105.139(1)	1220.11(5)
0.2	13.0815(2)	5.37067(9)	17.9947(3)	105.142(1)	1220.36(4)
0.25	13.0825(2)	5.37109(10)	17.9949(4)	105.134(1)	1220.60(4)
0.3	13.0843(4)	5.37214(16)	17.9961(6)	105.154(2)	1220.97(6)
0.35	13.0877(3)	5.37242(13)	17.9964(5)	105.142(2)	1221.44(5)
0.4	13.0897(3)	5.37230(12)	17.9978(4)	105.148(2)	1221.66(5)
0.45	13.0906(4)	5.37318(15)	17.9962(5)	105.155(2)	1221.80(6)
0.5	13.0916(3)	5.37443(12)	17.9982(4)	105.170(1)	1222.22(5)
			$Ba_2Gd_{2-x}Bi_{0.01}Eu_xGe_4O_{13}$		
0.1	13.0760(2)	5.36944(9)	17.9926(3)	105.1326(10)	1219.47(4)
0.2	13.0764(2)	5.37023(8)	17.9929(3)	105.1447(9)	1219.63(3)
0.3	13.0787(2)	5.37050(7)	17.9937(3)	105.1427(8)	1219.98(3)
0.4	13.0818(2)	5.37132(8)	17.9950(3)	105.1472(10)	1220.52(3)
0.5	13.0838(2)	5.37133(7)	17.9967(2)	105.1338(8)	1220.90(3)
0.6	13.0838(2)	5.37259(7)	17.9950(3)	105.1589(9)	1220.92(3)
0.7	13.0867(2)	5.37303(8)	17.9962(3)	105.1447(10)	1221.46(3)
0.8	13.0883(2)	5.37308(9)	17.9971(3)	105.1500(11)	1221.65(4)

Table S2 The CIE chromaticity coordinates for $Ba_2Gd_{1.99-x}Bi_{0.01}Sm_xGe_4O_{13}$ and $Ba_2Gd_{1.99-x}Bi_{0.01}Eu_xGe_4O_{13}$ series measured under 291 nm excitation radiation.

$Ba_2Gd_{1.99-x}Bi_{0.01}Sm_xGe_4O_{13}$				**$Ba_2Gd_{1.99-x}Bi_{0.01}Eu_xGe_4O_{13}$**			
Dopant content	CIE chromaticity coordinates		Color[a]	Dopant content	CIE chromaticity coordinates		Color[a]
	x	**y**			**x**	**y**	
0.05	0.244	0.113	purple	0.1	0.360	0.188	reddish-purple
0.1	0.260	0.128	purple	0.2	0.435	0.228	purplish-pink
0.15	0.277	0.142	purple	0.3	0.480	0.253	purplish-red
0.2	0.288	0.152	purple	0.4	0.523	0.279	purplish-red
0.25	0.292	0.157	purple	0.5	0.530	0.278	purplish-red
0.3	0.307	0.172	reddish-purple	0.6	0.536	0.278	purplish-red
0.35	0.306	0.176	reddish-purple	0.7	0.573	0.299	red
0.4	0.320	0.189	reddish-purple	0.8	0.563	0.300	red
0.45	0.327	0.204	reddish-purple				
0.5	0.348	0.229	purplish-pink				

[a]According to the CIE chromaticity diagram proposed in [K. L. Kelly, Color designations for lights, *J. Opt. Soc. Am.*,1943, **33**, 627–632]

Table S3 The CIE chromaticity coordinates for $Ba_2Gd_{1.94}Bi_{0.01}Sm_{0.05}Ge_4O_{13}$ and $Ba_2Gd_{1.89}Bi_{0.01}Eu_{0.1}Ge_4O_{13}$ phosphors measured at different temperatures, λ_{ex} = 280 nm.

$Ba_2Gd_{1.94}Bi_{0.01}Sm_{0.05}Ge_4O_{13}$				**$Ba_2Gd_{1.89}Bi_{0.01}Eu_{0.1}Ge_4O_{13}$**			
T, K	CIE chromaticity coordinates		Color[a]	T, K	CIE chromaticity coordinates		Color[a]
	x	**y**			**x**	**y**	
298	0.245	0.109	purple	298	0.358	0.163	reddish-purple
323	0.241	0.110	purple	323	0.331	0.152	reddish-purple
348	0.243	0.117	purple	348	0.320	0.147	reddish-purple
373	0.244	0.121	purple	373	0.309	0.143	reddish-purple
398	0.250	0.129	purple	398	0.301	0.141	purple
423	0.254	0.137	purple	423	0.298	0.142	purple
448	0.267	0.154	purple	448	0.300	0.149	purple
473	0.279	0.166	purple	473	0.311	0.160	reddish-purple

[a]According to the CIE chromaticity diagram proposed in [K. L. Kelly, Color designations for lights, *J. Opt. Soc. Am.*,1943, **33**, 627–632]

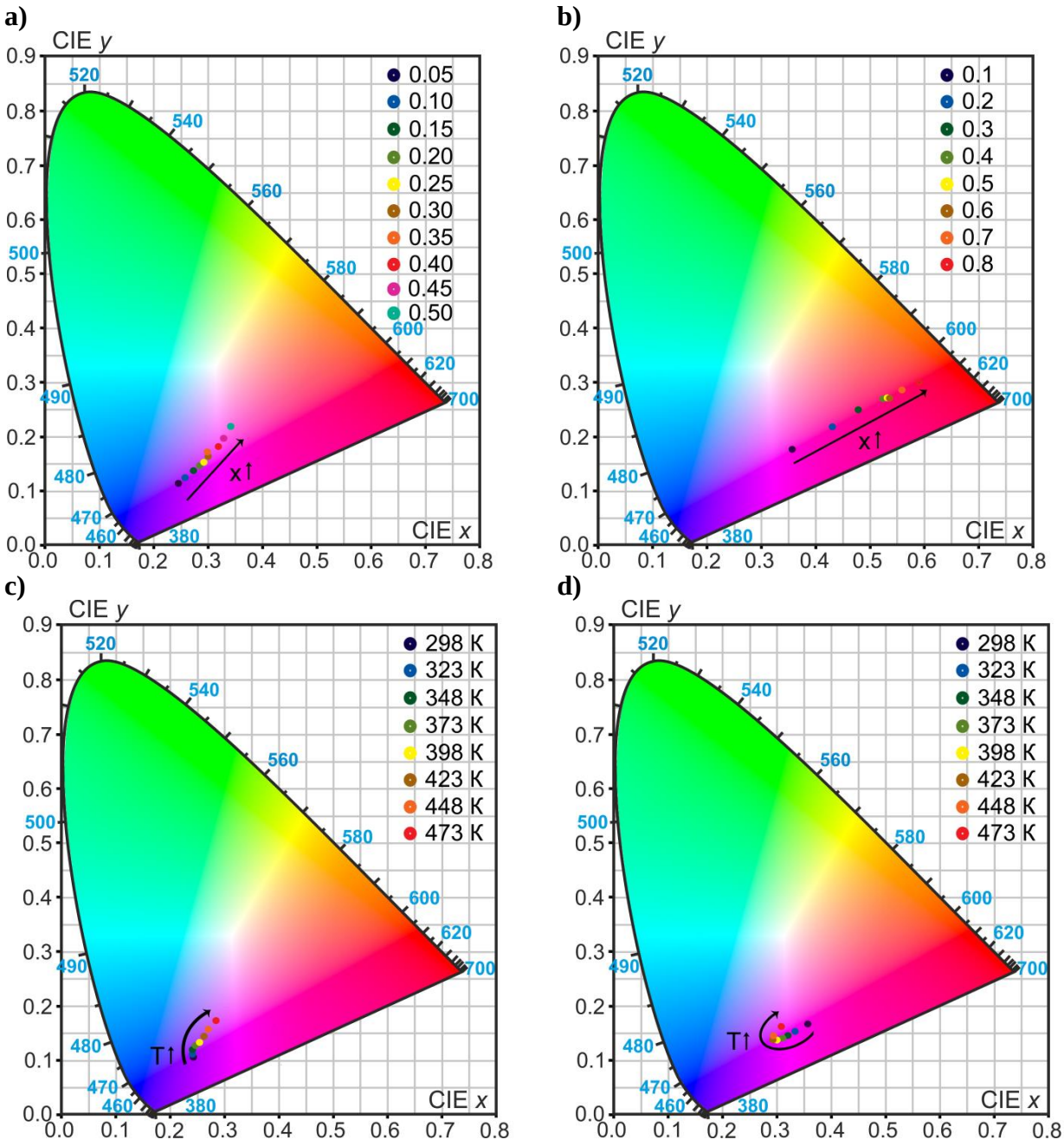


Fig. S4 The changes of CIE chromaticity coordinates of $Ba_2Gd_{1.99-x}Bi_{0.01}Sm_xGe_4O_{13}$ and $Ba_2Gd_{1.99-x}Bi_{0.01}Eu_xGe_4O_{13}$ series with codopant concentration (a and b), the changes of CIE chromaticity coordinates of $Ba_2Gd_{1.94}Bi_{0.01}Sm_{0.05}Ge_4O_{13}$ (c) and $Ba_2Gd_{1.89}Bi_{0.01}Eu_{0.1}Ge_4O_{13}$ (d) with temperature.

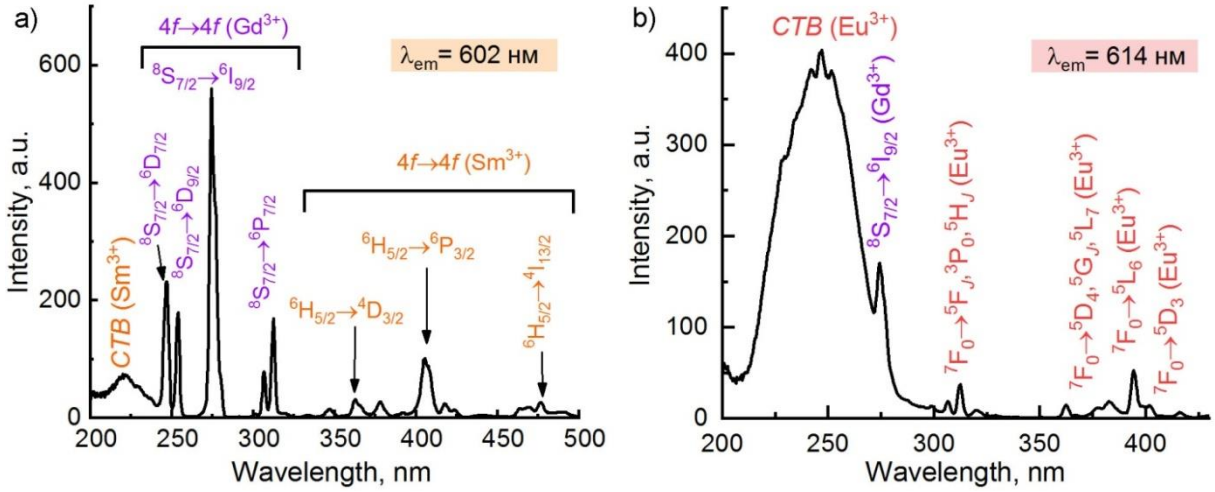


Fig. S5 Excitation spectra of single doped germanates: $Ba_2Gd_{1.95}Sm_{0.05}Ge_4O_{13}$, λ_{em} = 602 nm (a); and $Ba_2Gd_{1.9}Eu_{0.1}Ge_4O_{13}$, λ_{em}= 614 nm (b).

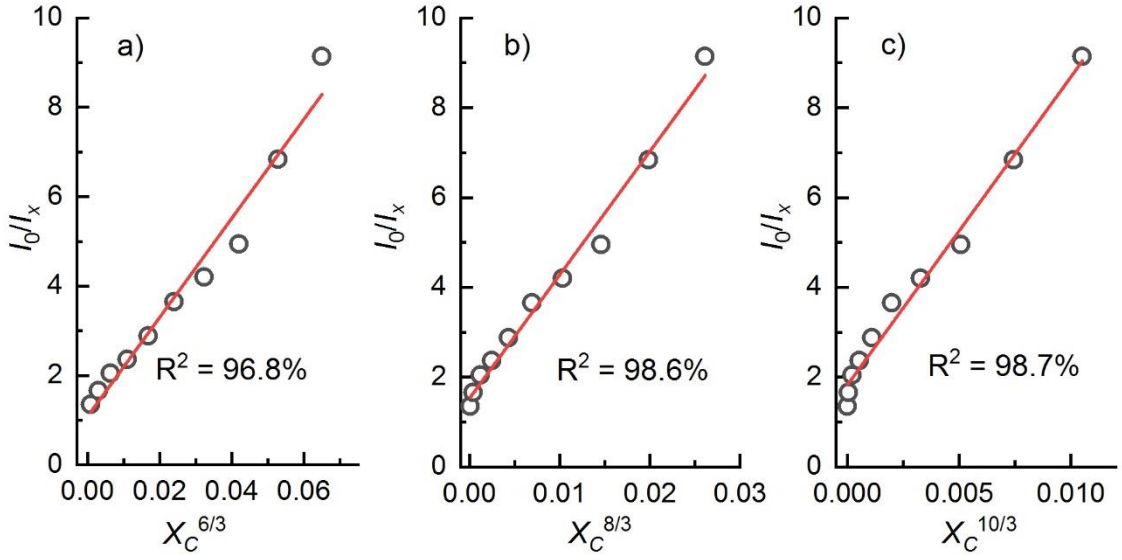


Fig. S6 Dependences of I_0/I_x on $X_c^{6/3}$ (a), $X_c^{8/3}$ (b) and $X_c^{10/3}$ (c) for $Ba_2Gd_{1.99-x}Bi_{0.01}Sm_xGe_4O_{13}$.

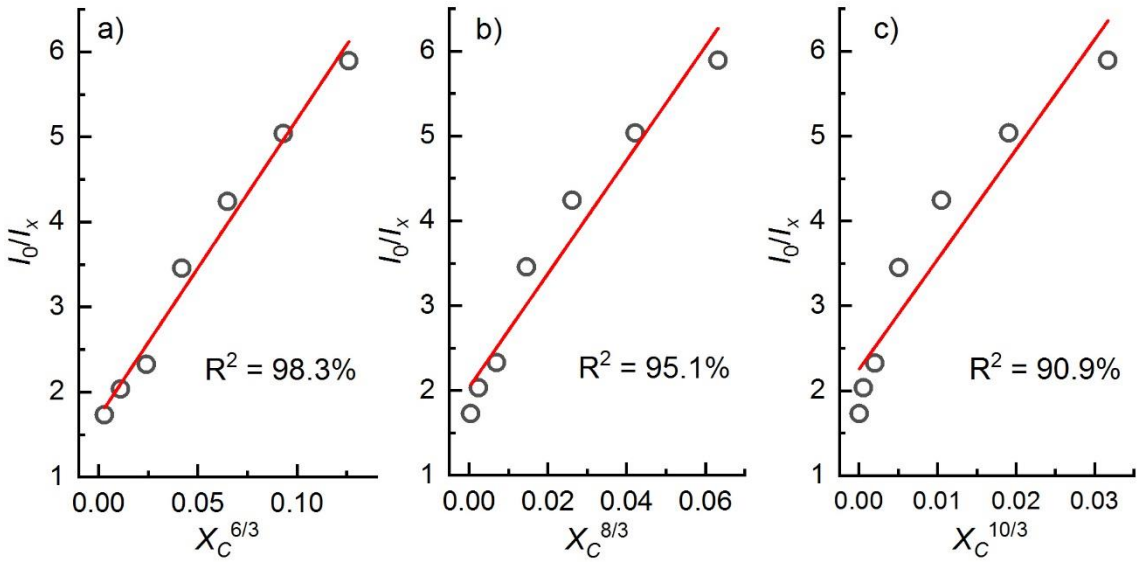


Fig. S7 Dependences of I_0/I_x on $X_c^{6/3}$ (a), $X_c^{8/3}$ (b) and $X_c^{10/3}$ (c) for $Ba_2Gd_{1.99-x}Bi_{0.01}Eu_xGe_4O_{13}$.