Supporting Information (SI)

A novel red phosphor $Cs_2NaGaF_6:Mn^{4+}$ with ultra-strong zero-phonon lines and long wavelength phonon sidebands for high-quality WLEDs

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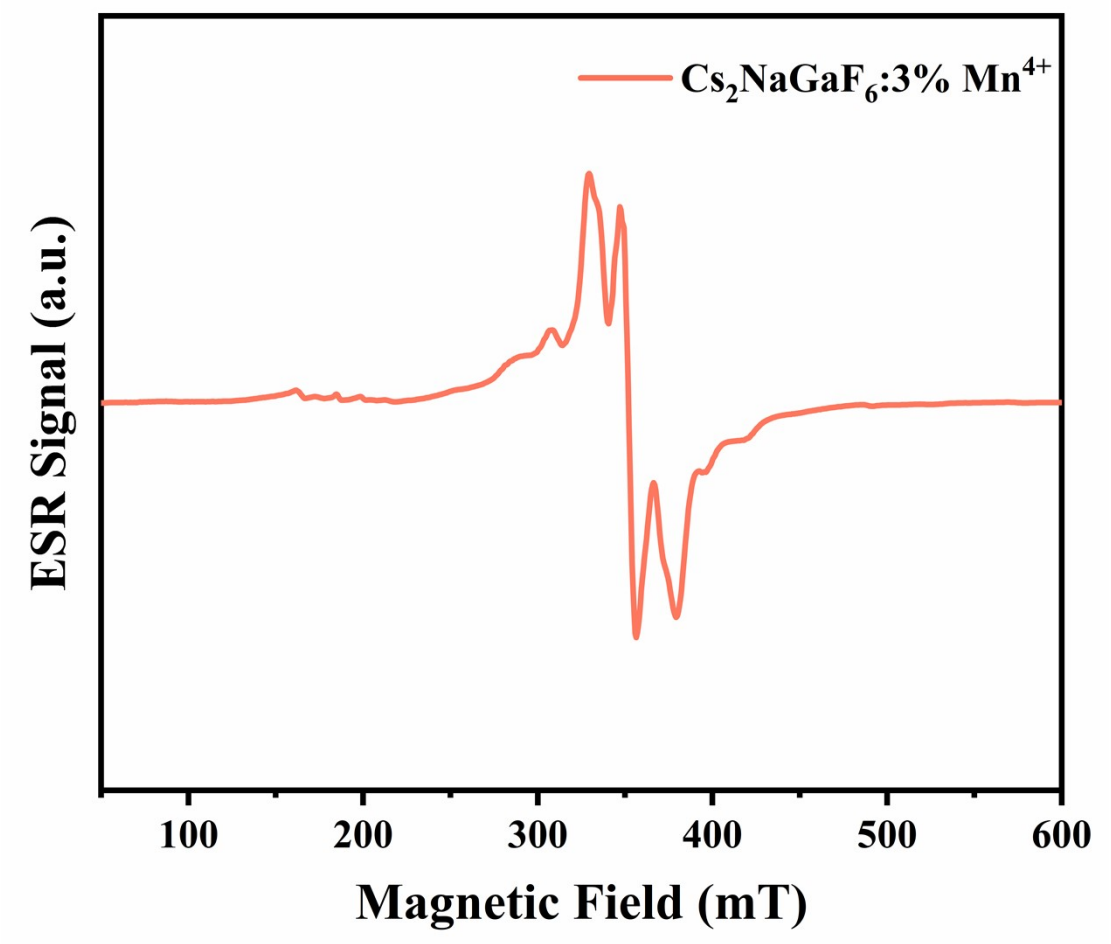

Fig. S1 EPR spectra of Cs_2NaGaF_6:3%Mn^{4+}

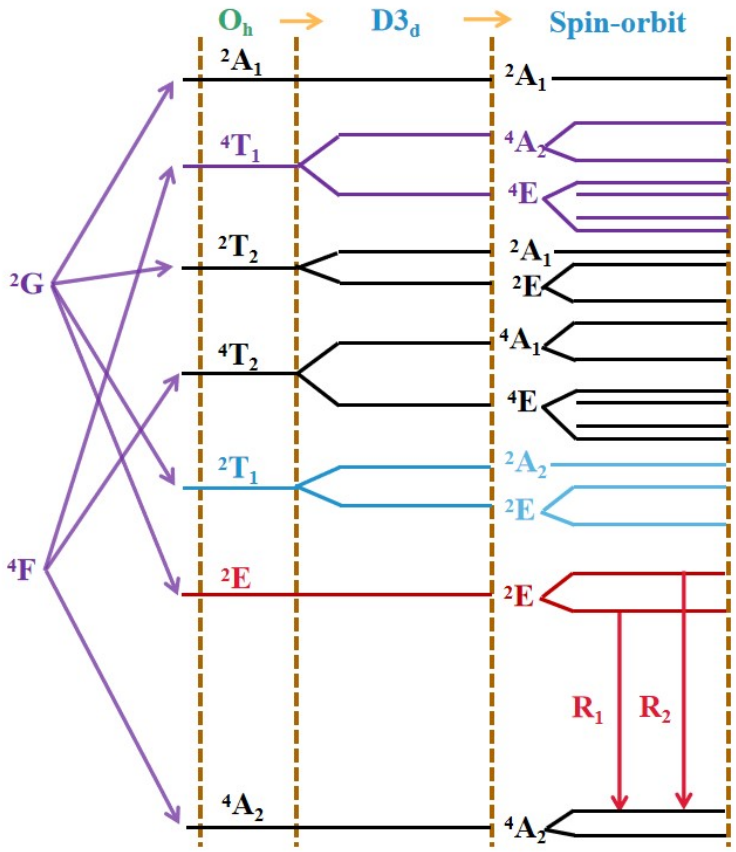

Fig. S2 Energy level splitting of the Mn^{4+} ions

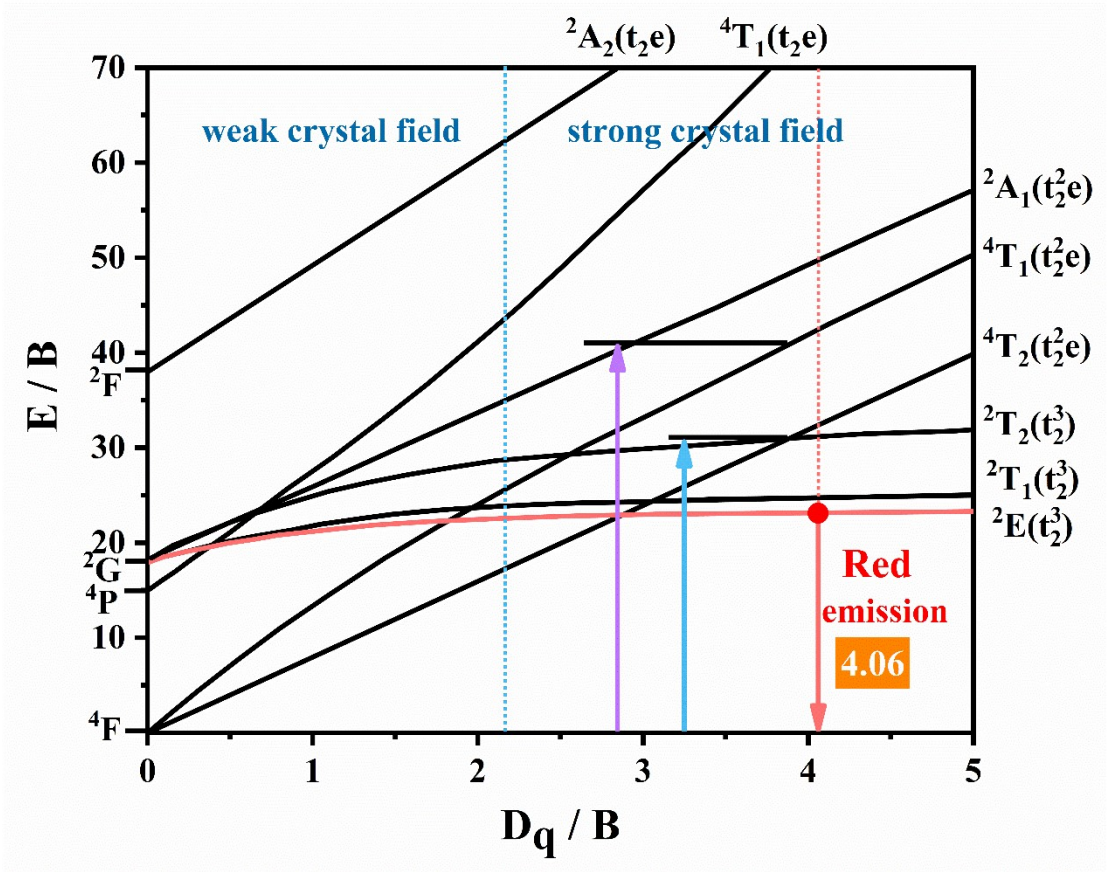

Fig. S3 Tanabe−Sugano diagram of $Cs_2NaGaF_6:Mn^{4+}$

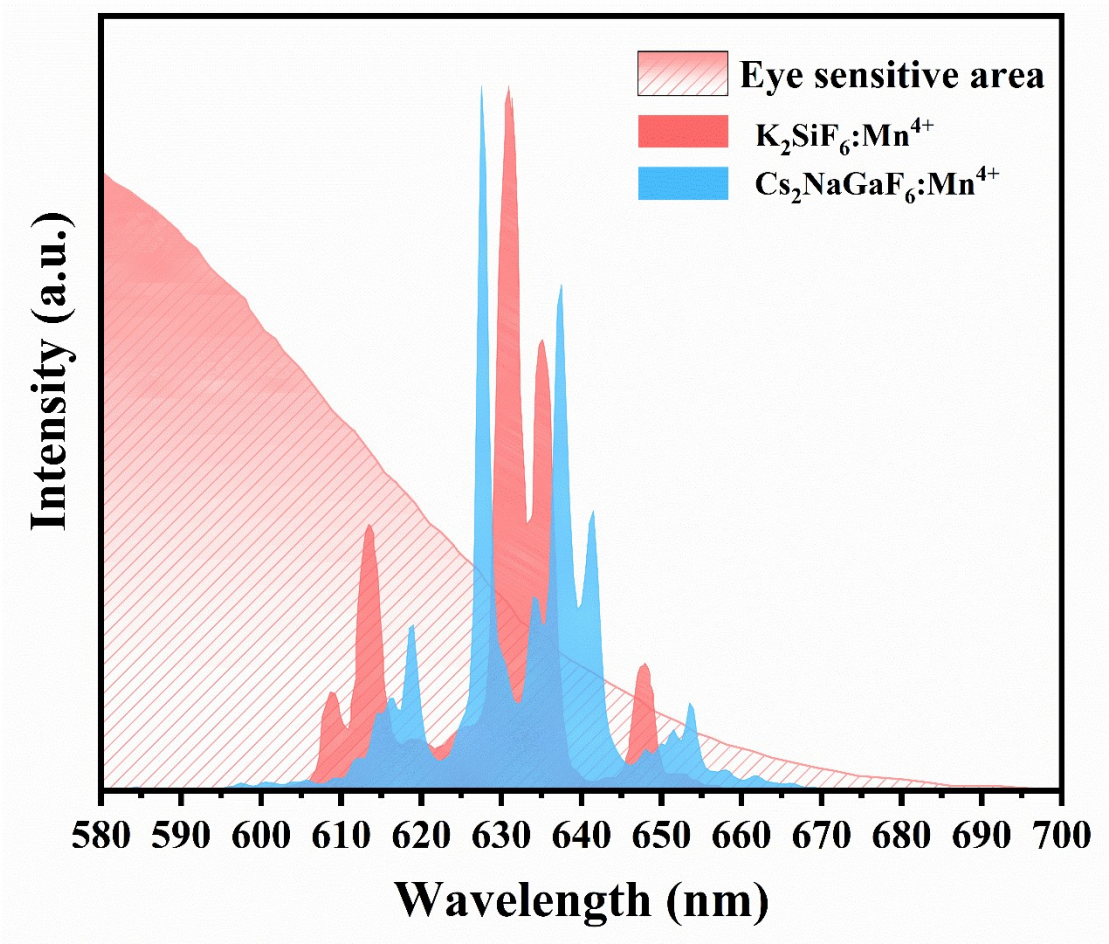

Fig. S4 Comparison of matching degree between KSFM and CNGFM and sensitive areas of human eyes

Table S1. Refined structural parameters of Cs_2NaGaF_6:3%Mn^{4+} sample

Atom	x	y	z	Occ.	Uiso (Å^2)	site
Cs(I)	0	0	0.1277(14)	1	0.0292(26)	6c
Cs(II)	0	0	0.2822(12)	1	0.0262(24)	6c
Na	0	0	0.3924(8)	1	0.0576(30)	6c
Ga(I)	0	0	0	0.985	0.0016(5)	3a
Ga(II)	0	0	0.5000	0.984	0.0139(6)	3b
F(I)	0.1397(13)	-0.1397(13)	0.4584(5)	1	0.0179(13)	18h
F(II)	0.1993(17)	-0.1993(17)	0.6284(4)	1	0.0220(7)	18h
Mn(I)	0	0	0	0.014	0.0065	3a
Mn(II)	0	0	0.5000	0.016	0.0100	3b

Table S2. Rietveld refinement results of $Cs_2NaGaF_6:Mn^{4+}$and Cs_2NaGaF_6.

Formula	Cs_2NaGaF_6:3%Mn^{4+}	Cs_2NaGaF_6
Crystal system	Trigonal	Trigonal
Space group	*R*-3*m*	*R*-3*m*
a, Å	6.24052(8)	6.24029(7)
b, Å	6.24052(8)	6.24029(7)
c, Å	30.26000(7)	30.25880(7)
α=β(°)	90	90
γ(°)	120	120
V_{cell}(Å^3)	1020.450(29)	1020.5661(27)
Z	6	6
R_{WP}	7.08%	6.94%
R_P	5.51%	5.38%
χ^2	1.574	1.513

Table S3. Vibronic modes and frequencies (cm^{-1}) in $Cs_2NaGaF_6:Mn^{4+}$ crystal.

Mode	Cs_2NaGaF_6(ref.24)	$Cs_2NaGaF_6:Mn^{4+}$ (This work)
TL[1]	56	61
RL[2]	133	139
ν_6^+	237	238
ν_6^-	223	212
ν_5^+	277	-
ν_5^-	268	-
ν_4^+	359	335
ν_3^+	-	646
ν_3^-	-	588
ν_2	519	-
ν_1	533	-

[1]TL denotes translatory lattice mode.

[2] RL denotes rotatory lattice mode.

Table S4 Luminous properties of WLEDs and color gamut after filtration

Green	Red	CCT(K)	LE(lm/W)	CIE(x, y)	NTSC(%)	Ref.
CCFL					75.0	39
RGB LED					105.0	39
β-SiALON	$CaAlSiN_3:Eu^{2+}$	8620	38	(0.2883, 02.996)	82.1	9
β-SiALON	$K_2NaScF_6:Mn^{4+}$	8841	73.7	(0.2852, 0.3159)	105.6	43
β-SiALON	$Cs_2MoO_2F_4:Mn^{4+}$	7896	114.7	(0.2948, 0.3104)	109.1	39
β-SiALON	$Rb_2NaScF_6:Mn^{4+}$	8458	80.7	(0.2891, 0.3056)	108.4	43
β-SiALON	$Cs_2NaScF_6:Mn^{4+}$	8470	77.0	(0.2852, 0.3159)	105.6	43
β-SiALON	$Cs_2NaGaF_6:Mn^{4+}$	8302	81.66	(0.3149,0.3262)	118.4%	This work