# Cyan-Emitting $Ti^{4+}$- and $Mn^{2+}$-Coactivated $Mg_2SnO_4$ as a Potential Phosphor to Enlarge Color Gamut for Field Emission Display

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## Experimental Section:

**Preparation.** The $Mg_2SnO_4$: x mol% $Ti^{4+}$, y mol% $Mn^{2+}$ powder samples were prepared by conventional solid state reaction. The doping concentrations of $Ti^{4+}$ and $Mn^{2+}$ were chosen as 0.1–5 mol% of $Sn^{4+}$ and 0.01–1 mol% of $Mn^{2+}$ in $Mg_2SnO_4$, respectively. Typically, stoichiometric amounts of MgO, $SnO_2$, $TiO_2$, and $MnCO_3$ were thoroughly mixed with an appropriate amount of ethanol in an agate mortar and then dried at 90 $^oC$ for 2 h. The powder mixtures were sintered at 1200 °C for 4 h in air to produce the final samples. All chemicals are of analytical degree.

**Characterization.** The X-ray diffraction (XRD) measurements were carried out on a D8 Focus diffractometer using Cu Kα radiation (λ = 0.15405 nm). The PL measurements were performed on a Hitachi F-4500 spectrophotometer equipped with a 150 W xenon lamp as the excitation source. The CL measurements were carried out in an ultra-highvacuum chamber ($<10^{-8}$ Torr), where the phosphors were excited by an electron beam in the voltage range of 0.5–5.0 kV and different anode current density, and the emission spectra were recorded using an F-7000 spectrophotometer. Photoluminescence quantum yield (QY) was measured by absolute PL quantum yield measurement system C9920-02. The PL lifetimes of the samples were measured with a Lecroy Wave Runner 6100 Digital Oscilloscope (1GHz) using a tunable laser (pulse width 4 ns) as the excitation source (Continuum Sunlite OPO). All the measurements were performed at room temperature (RT).

**Table 1.** Ionic radii (Å) and their coordination number (CN) of $Mg^{2+}$, $Mn^{2+}$, $Sn^{4+}$ and $Ti^{4+}$.

| Ion | CN = 4 | | CN = 6 | |
|---|---|---|---|---|
| | Crystal radius (CR) (Å) | Effective ionic radius (IR) (Å) | Crystal radius (CR) (Å) | Effective ionic radius (IR) (Å) |
| $Mg^{2+}$ | 0.71 | 0.57 | 0.86 | 0.72 |
| $Mn^{2+}$ | 0.80 | 0.66 | 0.81 | 0.67 |
| $Sn^{4+}$ | — | — | 0.83 | 0.69 |
| $Ti^{4+}$ | — | — | 0.745 | 0.605 |

**Table 2.** The CIE chromaticity coordinates, emission colors of $Mg_{2(1-y)}Sn_{(1-x)}O_4$: x mol% $Ti^{4+}$, y mol% $Mn^{2+}$ (x = 0-3, y = 0-0.1 ) samples under the $V_a$ = 3.0 kV, $J_a$ = 50 μA/cm$^2$ electron beam excitation, and their quantum yields under $\lambda_{ex}$ = 244 nm UV light excitation.

| Sample | $Mg_{2(1-y)}Sn_{(1-x)}O_4$: x mol% $Ti^{4+}$, y mol% $Mn^{2+}$ | Quantum yield (%) | CIE chromaticity coordinates (X, Y) | Color |
|---|---|---|---|---|
| S1 | x = 0, y = 0 | — | (0.1780, 0.2449) | blue |
| S2 | x = 2.0, y = 0 | 35 | (0.1773, 0.2186) | blue |
| S3 | x = 0, y = 0.1 | 4 | (0.0908, 0.5668) | green |
| S4 | x = 0.5, y = 0.01 | 17 | (0.1512, 0.2717) | cyan |
| S5 | x = 0.5, y = 0.025 | 18 | (0.1464, 0.2871) | cyan |
| S6 | x = 0.5, y = 0.05 | 13 | (0.1409, 0.3185) | cyan |
| S7 | x = 2.0, y = 0.01 | 23 | (0.1637, 0.2574) | cyan |
| S8 | x = 2.0, y = 0.025 | 22 | (0.1647, 0.2819) | cyan |
| S9 | x = 3.0, y = 0.01 | 19 | (0.1676, 0.2397) | cyan |

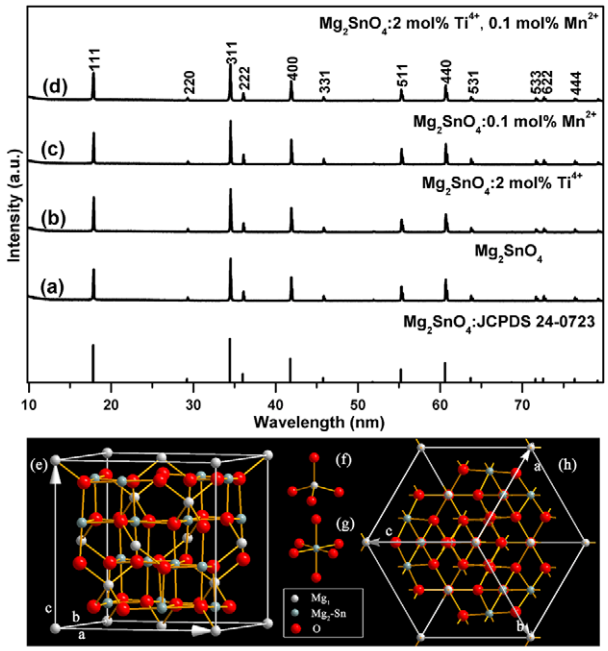


**Fig. S1** The XRD patterns of (a) $Mg_2SnO_4$, (b) $Mg_2SnO_4$:2 mol% $Ti^{4+}$, (c) $Mg_2SnO_4$:0.1 mol% $Mn^{2+}$, (d) $Mg_2SnO_4$:2 mol% $Ti^{4+}$, 0.1 mol% $Mn^{2+}$ samples calcined at 1200 $^oC$ for 4 h and the standard data for $Mg_2SnO_4$ (JCPDS No. 24-0723) as reference. (e)-(h) are the schematic drawing of the crystal structure of $Mg_2SnO_4$.

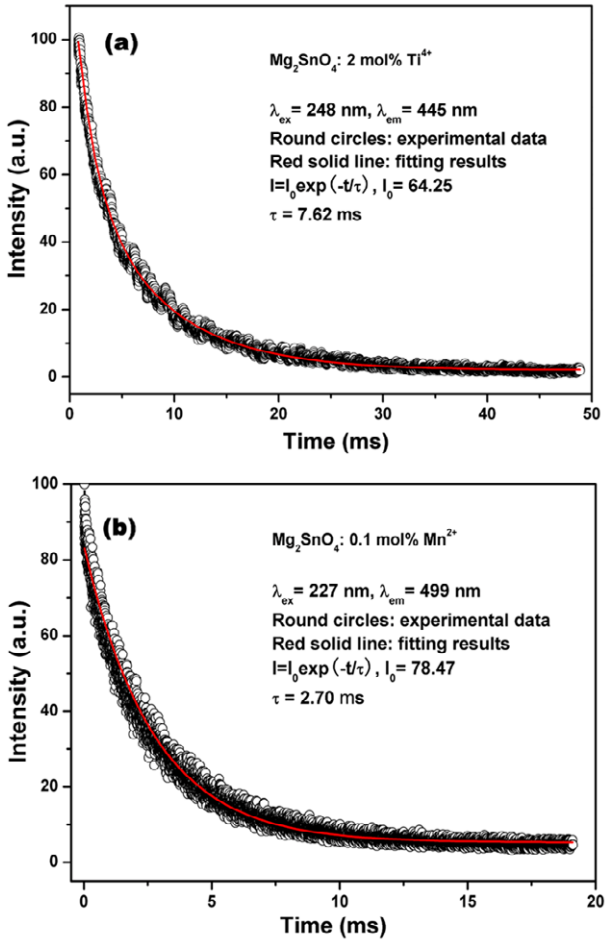


**Fig. S2** The photoluminescence lifetime of $Ti^{4+}$ and $Mn^{2+}$ ions in the $Mg_2SnO_4$:2 mol% $Ti^{4+}$ and $Mg_2SnO_4$:0.1 mol% $Mn^{2+}$ samples, respectively.

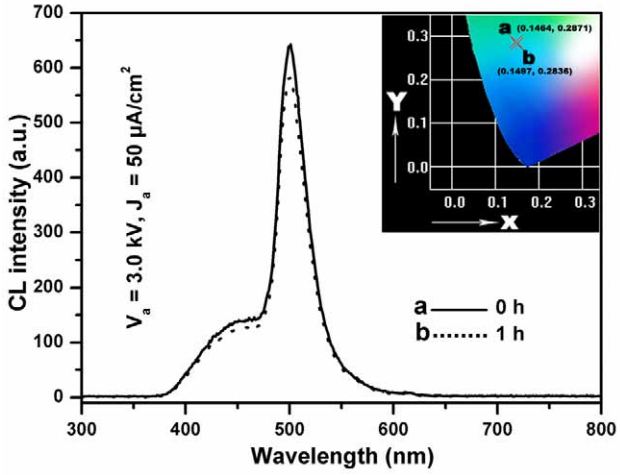


**Figure S3**. The CL spectra of $Mg_2SnO_4$: 0.5 mol% $Ti^{4+}$, 0.025 mol% $Mn^{2+}$ sample ($V_a$ = 3.0 kV, $J_a$ = 50 μA/cm$^2$), and $I_a$ denotes the initial intensity for 0 h, and $I_b$ denotes the intensity after continuous electron beam excitation for 1 h and the inset are their corresponding CIE chromaticity coordinates. $I_b/I_a$ = 0.92.

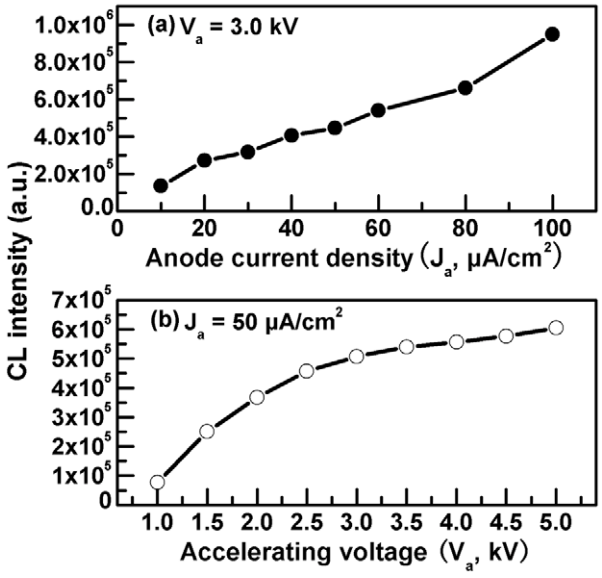


**Fig. S4** The CL intensity of the representative $Mg_2SnO_4$: 5 mol% $Ti^{4+}$, 0.025 mol% $Mn^{2+}$ sample as a function of (a) anode current density ($J_a$) and (b) accelerating voltage ($V_a$).