Electronic Supplementary Information (ESI)

A new red phosphor BaGeF$_6$:Mn$^{4+}$: hydrothermal synthesis, photo-luminescent properties, and its application in warm white LED devices

Qiang Zhou,$^{a}$ Yayun Zhou,$^{a}$ Yong Liu,$^{a}$ Lijun Luo,$^{a}$ Zhengliang Wang,$^{*,a}$ Jinhui Peng,$^{a}$

Jing Yan,$^{b}$ and Mingmei Wu$^{*b}$

a) Key Laboratory of Comprehensive Utilization of Mineral Resources in Ethnic
Regions, Key Laboratory of Resource Clean Conversion in Ethnic Regions,
Education Department of Yunnan, School of Chemistry and Biotechnology, Yunnan
Minzu University, Kunming, Yunnan 650031, P. R. China

b) MOE Key Laboratory of Bioinorganic and Synthetic Chemistry, School of
Chemistry and Chemical Engineering, Sun Yat-Sen (Zhongshan) University,
Guangzhou, 510275, P. R. China, E-mail: ceswmm@mail.sysu.edu.cn

Email: wangzhengliang@foxmail.com

ceswmm@mail.sysu.edu.cn
Fig. S1: SEM images of BaGeF$_6$:Mn$^{4+}$ products obtained with 10.0 mmol·L$^{-1}$ KMnO$_4$ and (a) 10 %, (b) 20 % and (c) 30 % HF solution at 180 °C for 8.0 h.
Fig. S2 XPS spectrum of red phosphor BaGeF₆: Mn⁴⁺.

Fig. S3 Diffuse reflection spectrum of red phosphor BaGeF₆: Mn⁴⁺.
**Fig. S4** CIE chromaticity diagram for (a) BaGeF$_6$:Mn$^{4+}$ and (b) NTSC “ideal red”.

**Fig. S5** Emission spectra of BaGeF$_6$:Mn$^{4+}$ red phosphors obtained from 40% HF and 10.0 mmol·L$^{-1}$ KMnO$_4$ at 180 °C for (a) 2.0 h, (b) 4.0 h, (c) 8.0 h, (d) 12.0 h and (e) 24.0 h. The inserted curve is the effect of reaction time on the relative emission intensity of BGFM.
**Fig. S6** Thermogravimetrics (TG) as synthesized BaGeF$_6$:Mn$^{4+}$ under N$_2$ atmosphere. The thermal stability the red phosphor behavior of BaGeF$_6$:Mn$^{4+}$ is investigated by thermogravimetrics analysis (TG: PerkinElmer STA 8000, at a heating rate of 10 K/min).
**Fig. S7** Decay curve of the BGFM red phosphors examined at room temperature. The monitoring wavelength is at 634 nm with a 460 nm light excitation.

**Tab. S1:** Performance of the GaN-based WLEDs coated with: (1) YAG:Ce, (2) YAG:Ce and BGFM mixture at 20 mA forward current and 5 V reverse voltage.

<table>
<thead>
<tr>
<th>No. of LEDs</th>
<th>Samples</th>
<th>CT(K)</th>
<th>CRI</th>
<th>Luminous Efficiency (lm/W)</th>
<th>CIE (x, y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6283</td>
<td>76.0</td>
<td></td>
<td>45.21</td>
<td>(0.3129, 0.3660)</td>
</tr>
<tr>
<td>2</td>
<td>4210</td>
<td>84</td>
<td></td>
<td>52.21</td>
<td>(0.3693, 0.3608)</td>
</tr>
</tbody>
</table>

Note: The luminous efficiency has also been enhanced with the use of BGFM.