Electronic Supplementary Material (ESI) for Journal of Materials Chemistry C.

Water stability analysis

CSS is the most water-sensitive among three phosphors. Thus, the water resistance of CSS can represent the water stability of the luminescent 3D code. A normal environment (25 °C, relative humidity=65%) was selected for analysis. Fluorescence intensity indicates the extent of hydrolysis given that increasing the extent of hydrolysis leads to decrease in the fluorescence intensity (Fig. S1).

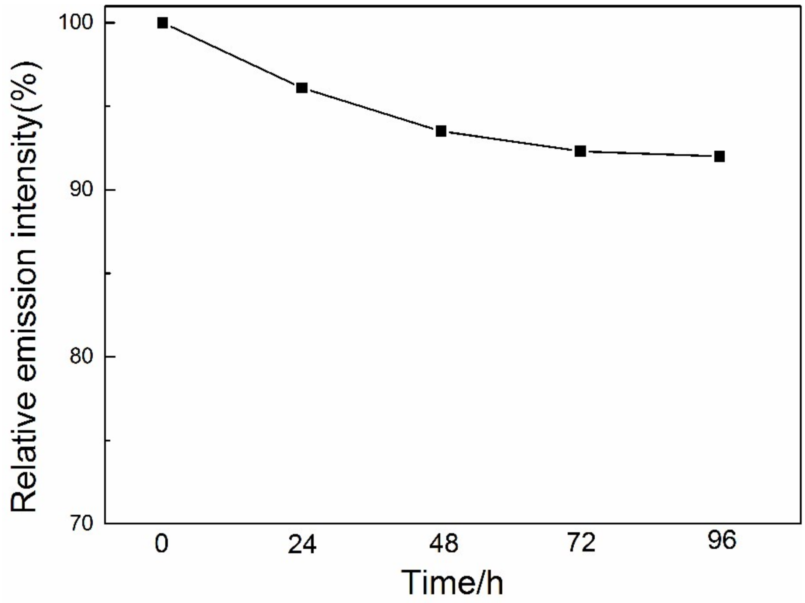


Fig.S1 Changes of relative emission intensity as a function of time

The fluorescence intensity decreased rapidly first and then slowly. After 96 h, the intensity decreased by 8% because of the rapid degradation of the surface of CSS phosphors after its exposure to humidity, which are difficult to come close to the inner layer. Thus, the intensity declined slowly. These results indicate that the sample can remain at a normal environment for more than 96 h.

Energy transfer efficiency analysis

To further quantify the presence of energy transfer one may calculate the transfer efficiency by relating the donor fluorescence intensities with (*F*D′) and without an acceptor (*F*D) according to the equation *E*=1 - *F*D’/*F*D. This approach is not suitable in our case due to that inhibition effect by acceptor could not be ignored. The energy transfer efficiency may be alternatively quantified by comparison of the emission peak (I_D) of the acceptor and the emission peak of donor without the acceptor. The results are listed in the Tab.S1

Tab.S1 The energy transfer efficiency values of the samples

Sample	*E* (%)	Sample	*E* (%)	Sample	*E* (%)
B/G 1：0.5	3.4	B/R 1:0.5	4.5	B/R 1:0.5	5.8
B/G 1：1	3.6	B/R 1:1	4.8	B/R 1:1	6.4
B/G 1：1.5	3.9	B/R 1:1.5	4.9	B/R 1:1.5	6.7

The results indicated that, for the same type mixtures, the energy transfer efficiency is positively related to the content of acceptor. For the same ratio, the G/R mixture show the higher efficiency than the B/R mixtures and B/G mixtures (more detail analysis are in the Supporting information).

Color coordinate calculation

When the color coordinates of red, green, and blue lights are (x_R,y_R), (x_B,y_B), and (x_G,y_G) and the brightness values are L_R, L_B, and L_G, respectively, the tristimulus values can be obtained from the following equation:

$$\begin{cases} X = \frac{x}{y} L \\ Y = L \\ Z = \frac{z}{y} L = \frac{1 - x - y}{y} L \end{cases} \tag{1}$$

Furthermore, the tristimulus values of the mixed color can be written as follows:

$$\begin{aligned} X &= X_R + X_G + X_B \\ Y &= Y_R + Y_G + Y_B \\ Z &= Z_R + Z_G + Z_B \end{aligned} \tag{2}$$

Substituting Equation (2) to Equation (1) leads to:

$$\begin{aligned} X &= \frac{x_R}{y_R} L_R + \frac{x_G}{y_G} L_G + \frac{x_B}{y_B} L_B \\ Y &= L_R + L_G + L_B \\ Z &= \frac{1 - x_R - y_R}{y_R} L_R + \frac{1 - x_G - y_G}{y_G} L_G + \frac{1 - x_B - y_B}{y_B} L_B \end{aligned} \tag{3}$$

The color coordinate of the mixture is described by the following equation:

$$\begin{aligned} x &= \frac{X}{X + Y + Z} \\ y &= \frac{Y}{X + Y + Z} \\ z &= \frac{Z}{X + Y + Z} \end{aligned} \tag{4}$$

Given that $x + y + z = 1$, Equation (3) is substituted into Equation (4); the desired target color coordinate is as follows:

$$
\begin{aligned}
x &= \frac{\frac{x_R}{y_R}L_R + \frac{x_G}{y_G}L_G + \frac{x_B}{y_B}L_B}{\frac{1}{y_R}L_R + \frac{1}{y_G}L_G + \frac{1}{y_B}L_B} \\
y &= \frac{L_R + L_G + L_B}{\frac{1}{y_R}L_R + \frac{1}{y_G}L_G + \frac{1}{y_B}L_B}
\end{aligned}
\tag{5}
$$

Rearranging Equation (5) to obtain Equation (6),

$$
\begin{aligned}
L_R &= \frac{y_R[(y-y_G)(x_B-x)+(x-x_G)(y-y_B)]}{y_B[(y-y_g)(x-x_R)+(x-x_G)(y_R-y)]}L_B \\
L_G &= \frac{y_G(y_R-y)[(y-y_G)+(x-x_G)(y-y_B)]+(y_B-y)[(y-y_G)(x-x_R)+(x-x_G)(y_R-y)]}{y_B(y-y_G)[(y-y_G)(x-x_R)+(x-x_G)(y_R-y)]}L_B
\end{aligned}
$$

(6)

For example, if we want to obtain the target color coordinate (x=0.333, y=0.333), the color coordinates of the three primary phosphors were measured (Table 1).

Table 1 Color coordinates of the primary phosphors

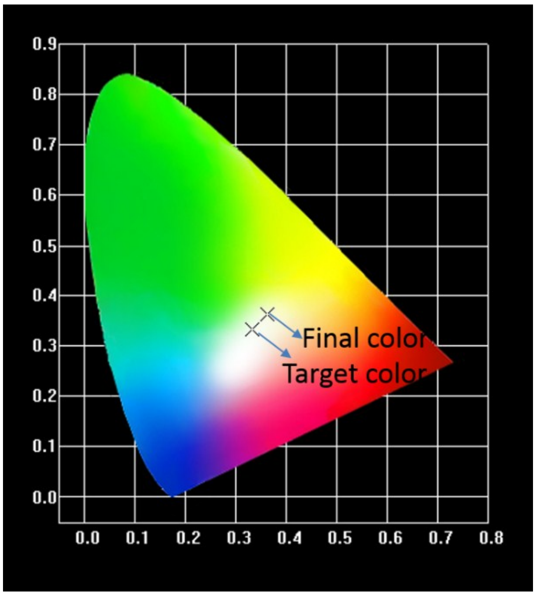
Item	Color coordinates	
	X	y
CAO(B)	0.1548	0.0356
SAO(G)	0.2522	0.5710
CSS(R)	0.6592	0.3406

Therefore, Equation (6) can be simplified as follows:

$$
\begin{aligned}
L_R &= 8.12L_B \\
L_G &= 36.5L_B
\end{aligned}
$$

The intensity of the target color is presumed to be 100%; the ratios of the intensities of the three phosphors are: R=17.8%, B=2.2%, and G=80%. According to the initial intensity of the primary phosphors (R:B:G= 0.34:0.5:5), the intensity can be converted into weight ratio R:B:G=11.89:1:3.64.

According to the above analysis, a mixture sample with the final weight ratio was prepared to verify the result. The results are show in the Fig.S2.



Despite differences between the final results and the target color, the final color is located in the white region. The color difference may have resulted from the interaction effect among the components.

Therefore, energy transfer efficiency *E* and intensity decay need to be considered. Before blending the phosphors at t moment, the emission intensities L_{Rt}, L_{Gt}, and L_{Bt} follow the formula:

$$L_{Rt} = L_{R0}e^{-k_1 t}$$

$$L_{Bt} = L_{B0}e^{-k_2 t}$$

$$L_{Gt} = L_{G0}e^{-k_3 t}$$

where L_{R0}, L_{B0}, and L_{G0} are the initial intensities of the trichromic phosphors; and k_1, k_2, and k_3 are constants.

After blending the phosphors, the following expression is obtained

$$\begin{aligned} L_{Rt} &= L_{R0}e^{-k_1 t}\left(1 + E_{B-R} + E_{G-R}\right) \\ L_{Bt} &= L_{B0}e^{-k_1 t}\left(1 - E_{B-R} - E_{B-G}\right) \\ L_{Gt} &= L_{G0}e^{-k_1 t}\left(1 - E_{G-R} + E_{B-G}\right) \end{aligned} \qquad (7)$$

If we know the target color coordinate, then the RGB ratio of the trichromic mixture is defined as

$$R{:}G{:}B = \frac{L_R}{L_{R0}e^{-k_1 t}\left(1 + E_{B-R} + E_{G-R}\right)} : \frac{L_G}{L_{R0}e^{-k_1 t}\left(1 - E_{G-R} + E_{B-G}\right)} : \frac{L_B}{L_{G0}e^{-k_1 t}\left(1 - E_{G-R} + E_{B-G}\right)}$$