Electronic Supplementary Information

Efficient and Stable fluorescent Graphene Quantum Dot/Agar Composite as Converting Material in White Light Emitting Diodes

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Experimental process

Preparation of water-soluble GQDs: The water-soluble GQDs were prepared by microwave-assisted hydrothermal pyrolysis method. The glucose (Sigma-Aldrich, > 99.5%) was dissolved in deionized water with the concentration of ~11 wt%. The solutions were tapped to the glass bottle with tightened cover. The glass bottle was heated with a conventional microwave oven (Galanz P70B17L-T1) at a power of 595 W for a specific time (1, 3, 5, 7 and 9 min). Followed by the microwave irradiation, the GQD solutions were cooled down to room temperature under air ambient without further purification.

Preparation of GQD/agar composite: 10 mg of agar flakes (Chancevon Agar) was inserted into 2 mL of the GQD solution at 85°C under vortex mixing. The mixture was well stirred and heated until it became homogeneous with the solution. Subsequently the mixture was poured into a 0.8 cm diameter glass tube mound and was cooled down to room temperature under ambient atmosphere.

Preparation of the GQD/agar composite LEDs: For the fabrication of the GQD/agar coated LEDs, the GQD solution prepared under the microwave irradiation time of 5 minutes without dilution was used. The agar was mixed with the GQD solution as described above. Then the GQD/agar mixture (ca. 0.5 mL) was slowly dispersed onto a commerical blue LED chips at 85 ℃, followed by cooling down to room temperature.

Characterizations: Transmission electron microscopy (TEM) was measured by JEOL, JEM-2100F electron microscopy at operating voltage of 200 kV. The PL measurement was carried out by a Q-switched 355 nm Nd:YAG laser at pulsed operation (~ 6 ns, 10 Hz). For the excitation-dependent PL, the excitation wavelength was adjusted from 300 to 430 nm using an optical parameter oscillator with beta barium borate (BBO). The quantum yield (QY) of the GQD solutions and composites were measured using an FLS920P Edinburgh fluorescence spectrometer with a barium sulfate coated integrating sphere. The time-resolved PL of the GQD/agar composite was measured by using a laser diode (pulse width: 48 ps) with excitation wavelength of 375 nm. Fourier Transform Infrared (FTIR) spectra of the samples were obtained by Nicolet Magna-IR 760 spectrometer. Samples were dispersed in pure KBr which was pressed to a flake for the measurement. XPS measurement was performed using Al Kα source, having 1486.6 eV of energy with the VG ESCAlab MKII at room temperature. The electroluminescence of the GQD/agar LED was measured by Ocean Optics USB4000 fiber optic spectrometer at room temperature. An integrated sphere was used in the assessment of luminous efficiency, colour rendering index and correlated colour temperature. To determine the light conversion efficiency of the white LED, the wavelength was firstly converted to photon energy, and followed by the integration of the emission spectra to obtain the peak areas of blue and GQD emission. As a result, the conversion efficiency can be calculated by the ratio of the GQD emission area to total area of the blue and GQD emission.

Figure S1

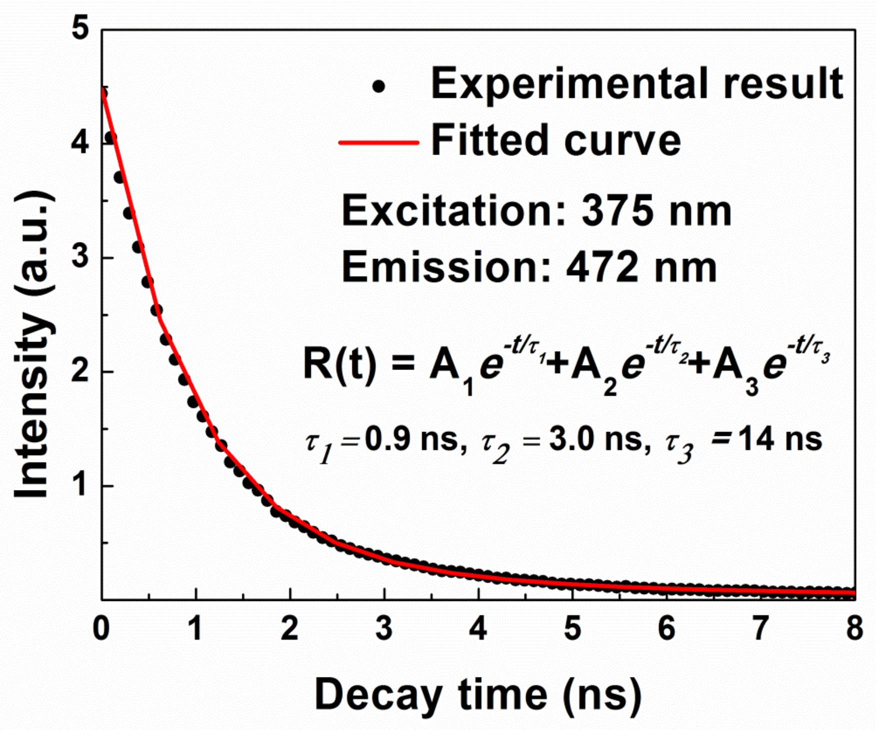

Figure S1. Time-resolved PL spectra of the GQD/agar composite. The GQDs were prepared under microwave irradiation time of 5 minutes.

Table S1. Summary of the average lifetimes $<\tau>$ of the GQD/agar composite at different emissions (excitation: 375 nm Xe lamp).

Emission	τ_1 (ns)	τ_2 (ns)	τ_3 (ns)	$<\tau>$ (ns)
440 nm	0.83	2.30	15.86	3.52
444 nm	0.88	2.56	19.38	3.25
472 nm	0.89	2.90	14.15	3.47
507 nm	1.02	3.56	13.39	3.99
513 nm	1.02	3.39	11.82	3.96
527 nm	0.98	3.42	12.21	4.35

Remark: The PL decay curves were fitted at triple exponential function:

$$R(t) = \sum_{i=1}^{3} A_i e^{\frac{-t}{\tau_i}}$$

where A_i is constant.

The average lifetime $<\tau>$ can be calculated according to

$$< \tau >= \frac{A_1\tau_1^2 + A_2\tau_2^2 + A_3\tau_3^2}{A_1\tau_1 + A_2\tau_2 + A_3\tau_3}.$$

Table S2. Summary of the device performance under 20 mA.

Luminous efficiency	CRI	Colour temperature	Light conversion efficiency	CIE
42.2 lmW^{-1}	72.0	5532 K	61.1 %	(0.33, 0.38)