

Supporting Information

# **Ru Single Atoms on One-Dimensional CF@g-C<sub>3</sub>N<sub>4</sub> Hierarchy as Highly Stable Catalysts for Aqueous Levulinic Acid Hydrogenation**

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**Table S1** The atom percentage and elemental analysis for different Ru-containing catalysts

Catalyst	Percentage of different elements <sup>a</sup> (at. %)				Ru loading <sup>b</sup> (wt%)	Ru loss <sup>b</sup> (ppm)
	C	N	O	Ru		
CF@g-C <sub>3</sub> N <sub>4</sub> -Ru SAs	55	18	20	7	3.0	0.004
CF@g-C <sub>3</sub> N <sub>4</sub> -Ru NPs	51	28	10	11	1.3	0.016
g-C <sub>3</sub> N <sub>4</sub> -Ru	-	-	-	-	4.5	-
CF-Ru	-	-	-	-	4.1	-

<sup>a</sup>Estimated by XPS.

<sup>b</sup>Detected by ICP-OES analysis.

**Table S2** Textural properties of various Ru-containing catalysts

Catalyst	$S_{\text{BET}}^{\text{a}}$	$V_{\text{p}}^{\text{b}}$	$d_{\text{meso}}^{\text{c}}$	$V_{\text{micro}}^{\text{d}}$	$d_{\text{micro}}^{\text{e}}$	$X_{\text{mesoporosity}}^{\text{f}}$
	( $\text{m}^2 \text{g}^{-1}$ )	( $\text{cm}^3 \text{g}^{-1}$ )	(nm)	( $\text{cm}^3 \text{g}^{-1}$ )	(nm)	(%)
CF@g-C <sub>3</sub> N <sub>4</sub> -Ru SAs	380	0.57	3.7	0.161	0.52	71.9
CF@g-C <sub>3</sub> N <sub>4</sub> -Ru NPs	266	0.25	3.5	0.103	0.60,0.65	60.0
g-C <sub>3</sub> N <sub>4</sub> -Ru	16	0.09	-	0.007	-	-
CF-Ru	587	0.30	3.4	0.227	0.51,0.62	23.3
spent CF@g-C <sub>3</sub> N <sub>4</sub> -Ru SAs	267	0.219	2.4	-	-	
spent CF@g-C <sub>3</sub> N <sub>4</sub> -Ru NPs	195	0.159	2.1	-	-	

<sup>a</sup>The BET surface area was obtained from the adsorption branches in the relative pressure range of 0.05~0.29.

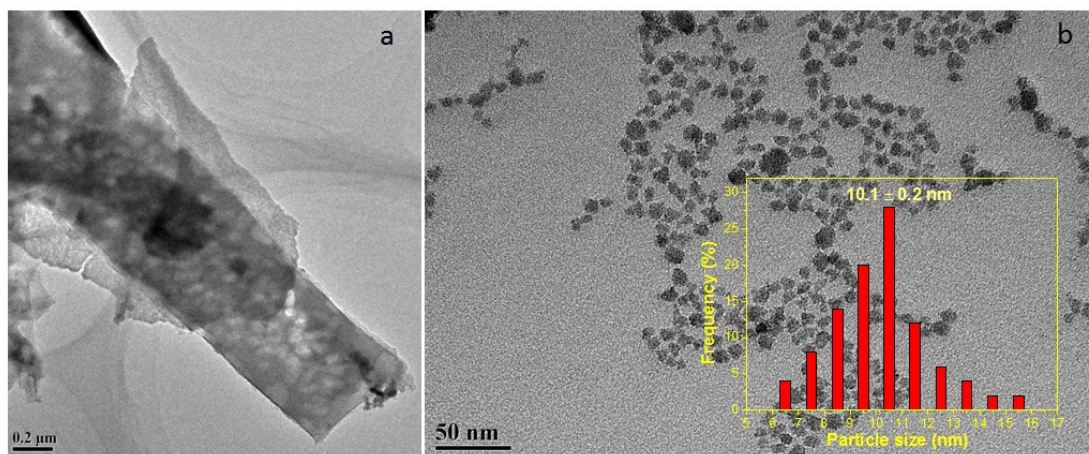
<sup>b</sup>The single point adsorption total pore volume was taken at the relative pressure of 0.99.

<sup>c</sup>The mesopore size distribution was calculated from the desorption branches by the Barret-Joyner-Halenda (BJH) method.

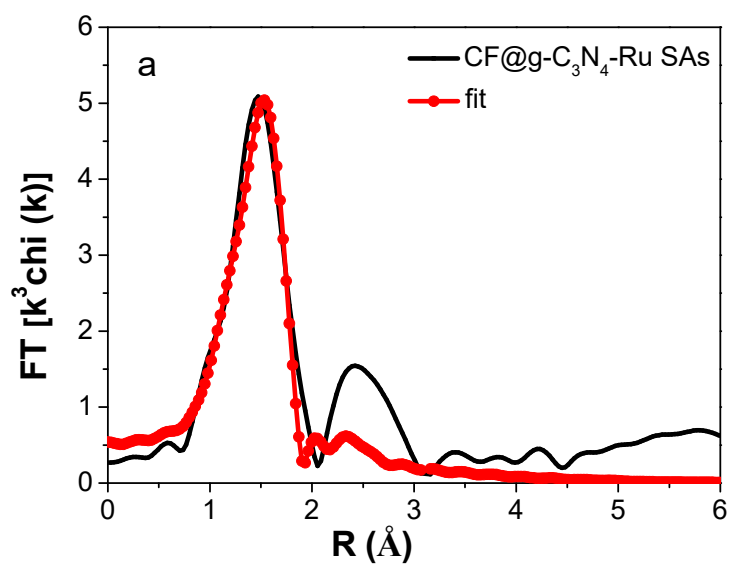
<sup>d</sup>The single point adsorption micropore volume was taken at the diameter less than 2 nm.

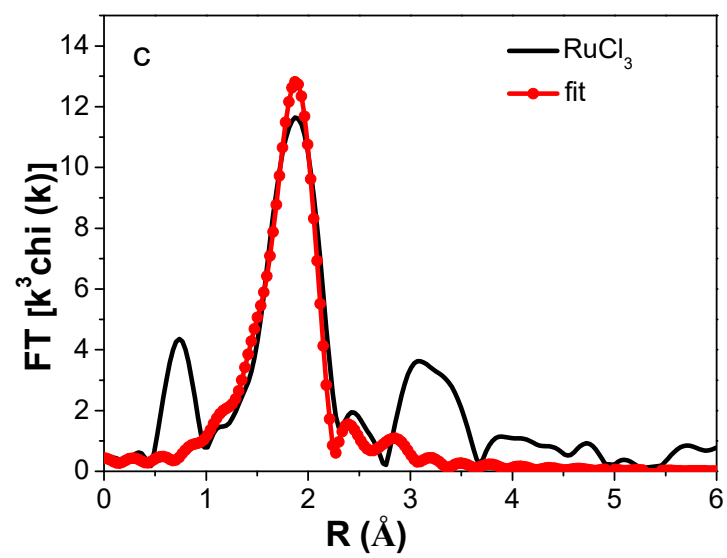
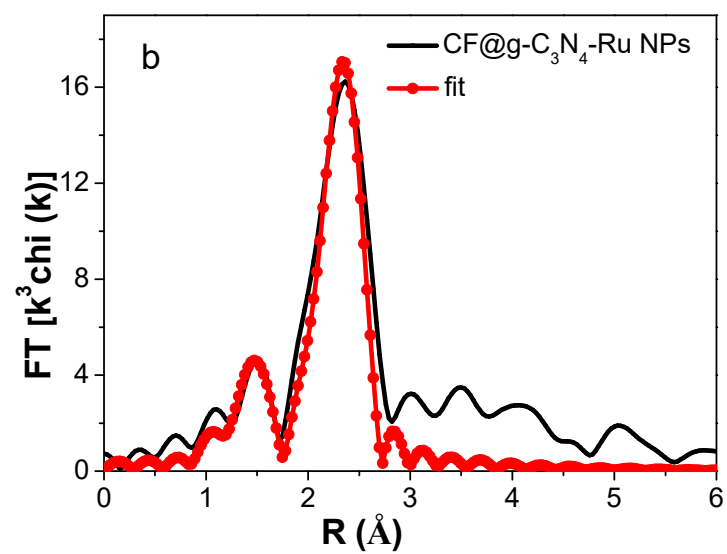
<sup>e</sup>The micropore size distribution was estimated by the Horvath-Kawazoe (H-K) method.

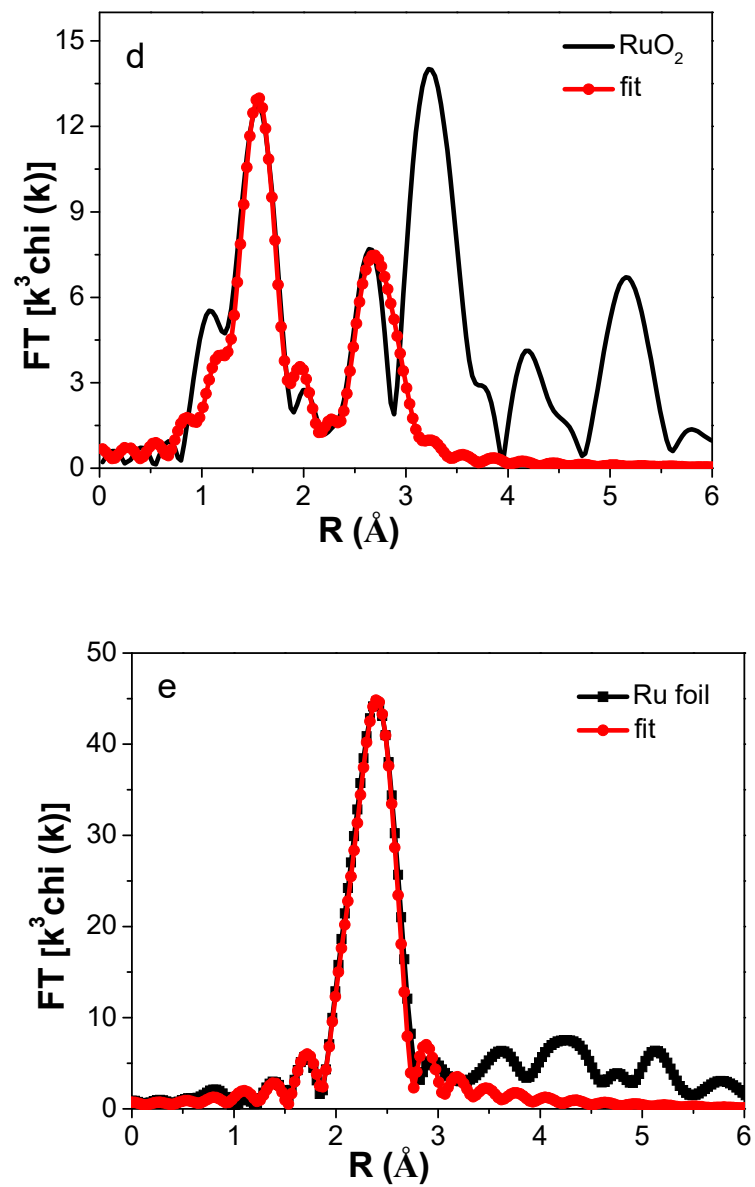
<sup>f</sup>The mesoporosity is defined as the ratio of  $V_{\text{meso}}/V_{\text{p}}$ , and was calculated according to the equation,  $X_{\text{mesoporosity}} = (1 - V_{\text{micro}}/V_{\text{p}}) \times 100\%$ .



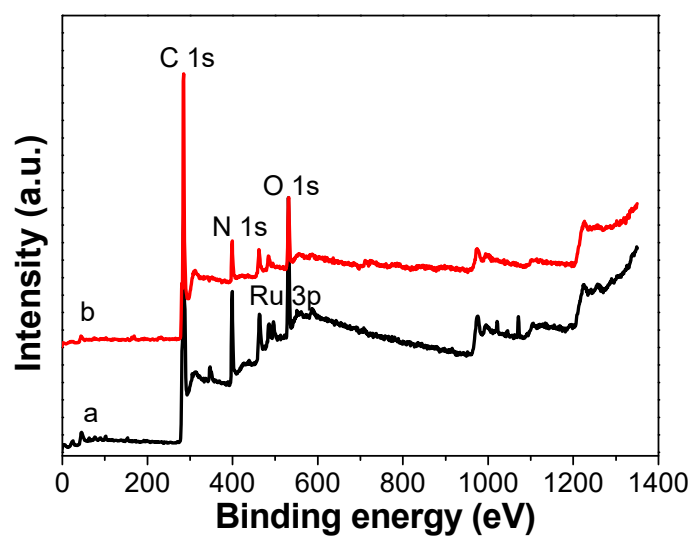
**Figure S1.** TEM images for (a) CF@g-C<sub>3</sub>N<sub>4</sub>-Ru NPs and (b) filtrate obtained by ultrasonic treatment of CF@g-C<sub>3</sub>N<sub>4</sub>-Ru NPs in ethanol, with the corresponding particle size distribution histogram (inset).



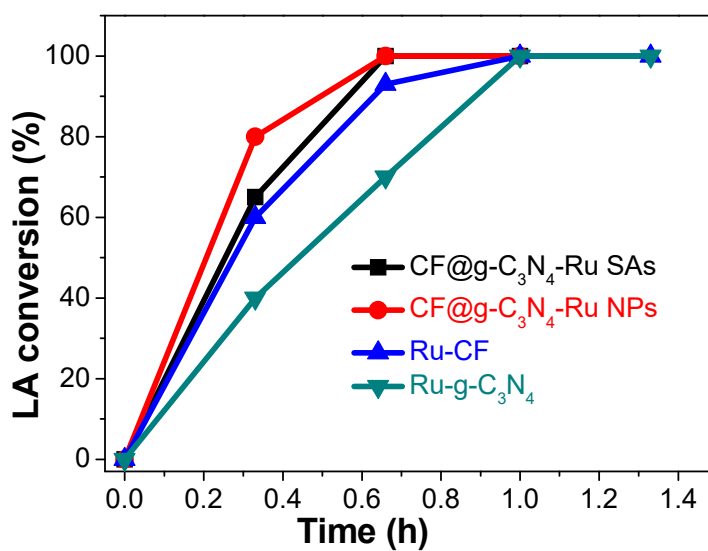




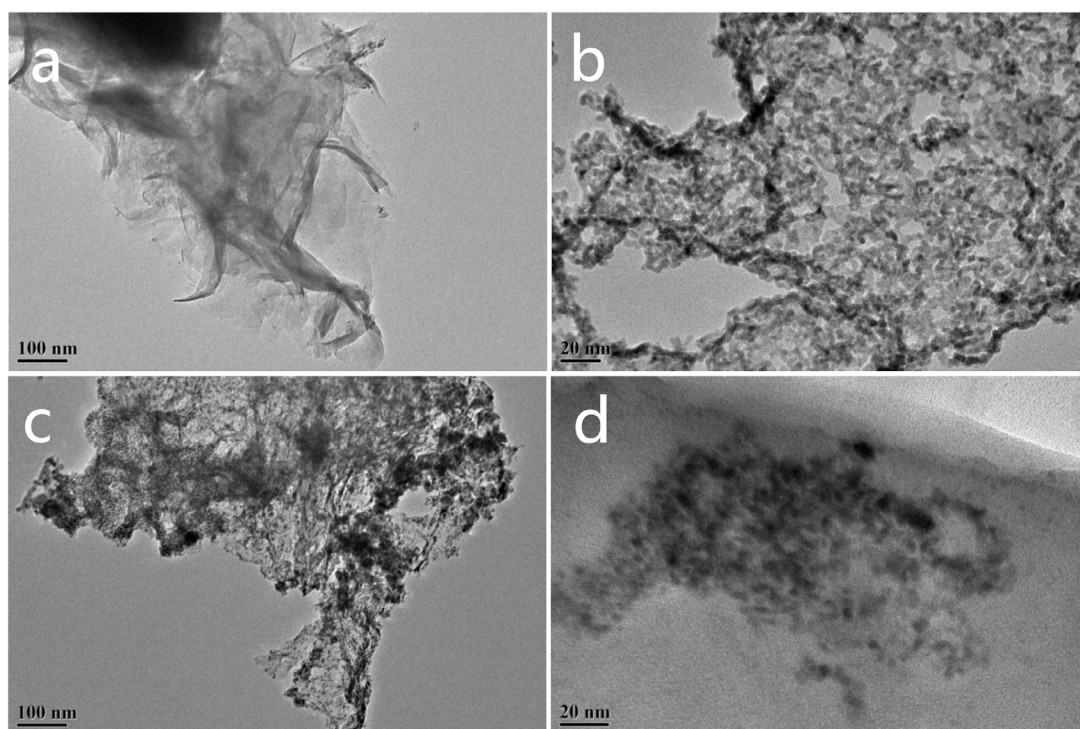
**Figure S2.** Curve fitting for (a) CF@g-C<sub>3</sub>N<sub>4</sub>-Ru SAs, (b) CF@g-C<sub>3</sub>N<sub>4</sub>-Ru NPs, (c) RuCl<sub>3</sub>, (d) RuO<sub>2</sub> and (e) Ru foil.



**Figure S3.** XPS survey scan for (a) CF@g-C<sub>3</sub>N<sub>4</sub>-Ru SAs and (b) CF@g-C<sub>3</sub>N<sub>4</sub>-Ru NPs.

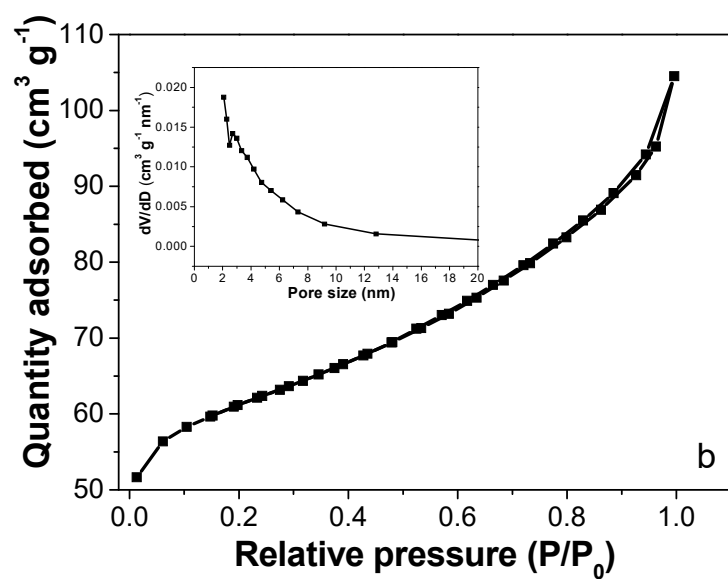
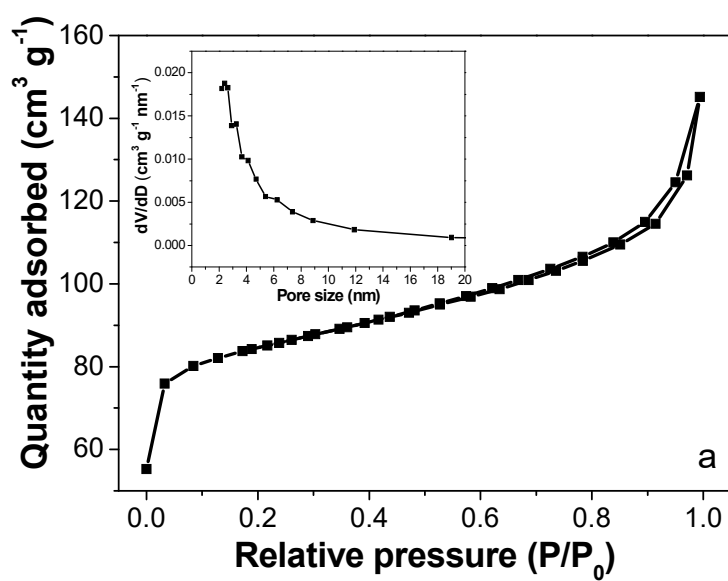


**Figure S4.** Time profiles for catalytic conversion of LA in water using different Ru-containing catalysts.

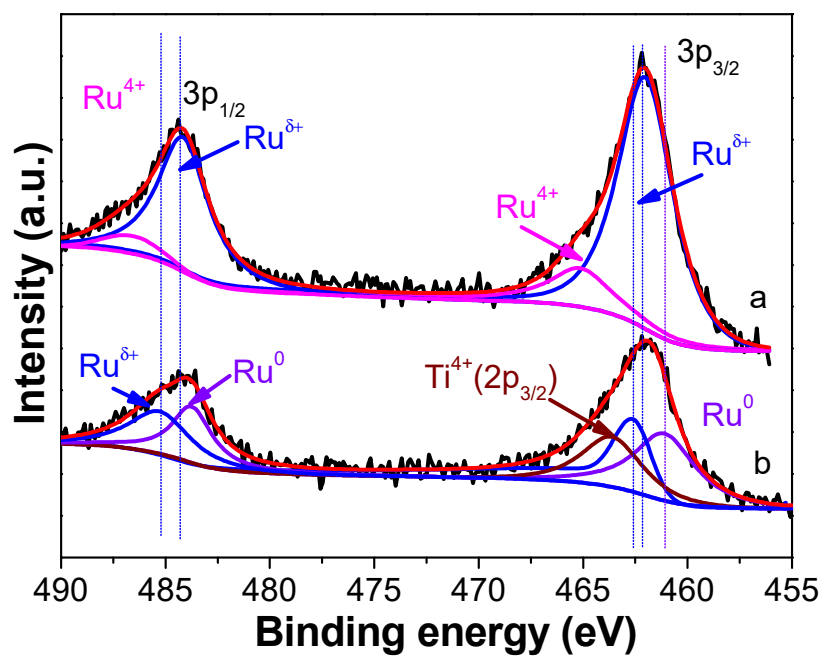


**Figure S5.** TEM images of (a,b) spent CF@g-C<sub>3</sub>N<sub>4</sub>-Ru SAs and (c,d) spent CF@g-C<sub>3</sub>N<sub>4</sub>-Ru NPs.





**Figure S6.**  $N_2$  adsorption/desorption isotherm and the corresponding pore size distribution curve (inset) for (a) spent  $CF@g-C_3N_4-Ru$  SAs and (b)  $CF@g-C_3N_4-Ru$  NPs.



**Figure S7.** High-resolution Ru 3p spectra for (a) spent CF@g-C<sub>3</sub>N<sub>4</sub>-Ru SAs and (b) spent CF@g-C<sub>3</sub>N<sub>4</sub>-Ru NPs.