Electronic Supplementary Material (ESI) for Sustainable Energy & Fuels.

Supporting information

Transparent supercapacitors of 2-nm ruthenium oxide nanoparticles decorated on 3D nitrogen-doped graphene aerogel

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Calculation method

Based on the XRD result, the interlayer distance ($d_{spacing}$) of both samples can be calculated by using the Bragg's law in equation (1)[1];

$$2d\sin\theta = n\lambda \tag{1}$$

where d is the interlayer distance, θ is the scattering angle, λ is the incident X-ray wavelength (1.5418 Å).

Based on the CV result, the specific (C_{sp}) and areal (C_{ae}) capacitances of the electrode can be calculated by the following equation (2) and (3):

$$C_{sp} = 4\frac{\int IdV}{(2vm\Delta V)} \tag{2}$$

$$C_{ae} = 4\frac{\int IdV}{(2vA\Delta V)} \tag{3}$$

where I is the current, V is the cell voltage, v is the scan rate, m is the total mass of active material, A is the total effective area of the device (8 cm^2), and ΔV is the working cell voltage window.

Based on the GCD result, the specific (C_{sp}) and areal (C_{ae}) capacitances from GCD curves were calculated by the following equation (4)[2] and (5)[3]:

$$C_{sp} = 4\frac{I\Delta t}{m\Delta V} \tag{4}$$

$$C_{ae} = 4\frac{I\Delta t}{A\Delta V} \tag{5}$$

where I is the applied current, Δt is the discharge time, ΔV is the cell voltage window excluding the *iR* drop, m is the total mass of active material, and A is the total effective area of the device (8 cm^2).

Based on the EIS result, the complex power can be calculated by using equation (6)-(9):

$$P(\omega) = \omega C''(\omega)\left|\Delta V_{rms}\right|^2 \tag{6}$$

$$Q(\omega) = -\omega C'(\omega)\left|\Delta V_{rms}\right|^2 \tag{7}$$

$$S(\omega) = P(\omega) + jQ(\omega) \tag{8}$$

$$\left|\Delta V_{rms}\right|^2 = \frac{\Delta V_{max}}{\sqrt{2}} \tag{9}$$

where V_{max} is the maximum amplitude of applied ac perturbation (5 mV), j is an imaginary number, ω is an angular frequency (ω=2πf). The C' and C" are the real and imaginary parts of the complex capacitance which can be calculated by (10) and (11):

$$C'(\omega) = -Z''(\omega)/\{\omega|Z(\omega)|^2\} \tag{10}$$

$$C''(\omega) = Z'(\omega)/\{\omega|Z(\omega)|^2\} \tag{11}$$

where Z' and Z" are the real and imaginary parts of the complex impedance Z, respectively.

The relaxation time constant (τ_0) can be calculated by equation (12):

$$\tau_0 = \frac{1}{2\pi f_0} \tag{12}$$

where f_0 is a relaxation frequency.

For the Ragone plot, the areal energy (E) and areal power (P) can be calculated by using the following equation (13) and (14):

$$E = \frac{1}{2}C_{cell}\Delta V^2 \quad (13)$$

$$P = \frac{E}{t} \quad (14)$$

where C_{cell} is the areal capacitance of a cell, ΔV is the cell voltage window excluding the *iR* drop, and t is the discharge time[4].

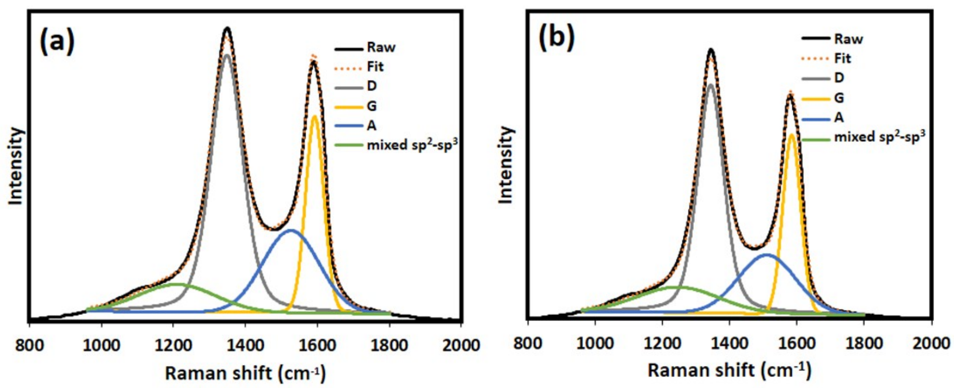

Fig. S1. Deconvoluted Raman spectra of (a) bare NGA and (b) RuO_2/NGA.

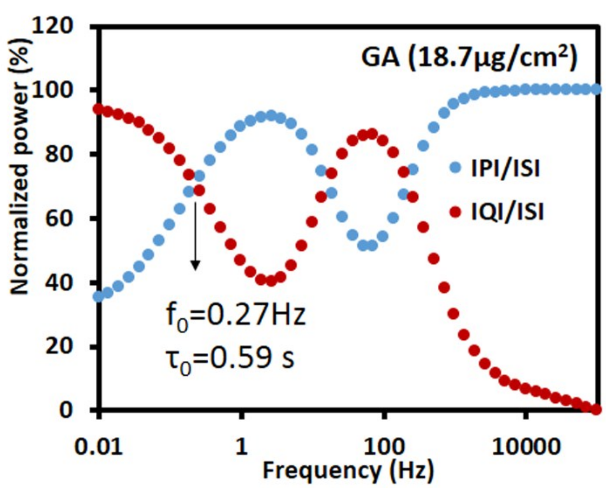

Fig. S2. Complex power analysis of the as-fabricated bare NGA supercapacitor at a mass loading of 18.7 μg cm^{-2}.

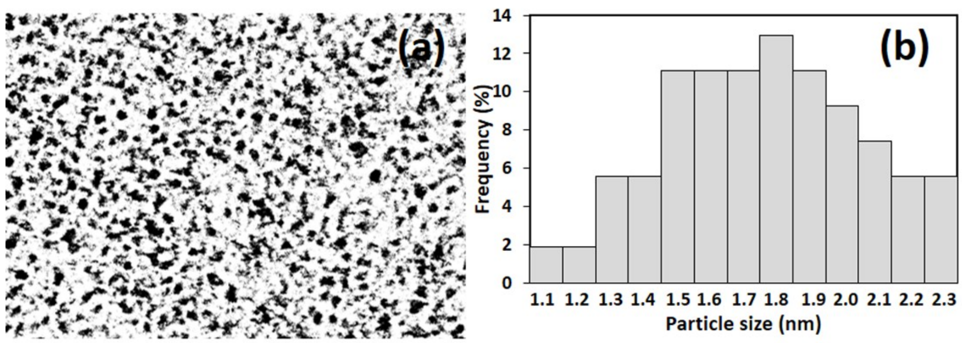

Fig. S3. (a) TEM image after processed using the ImageJ program and (b) the particle size distribution of RuO_2 nanoparticles on NGA.

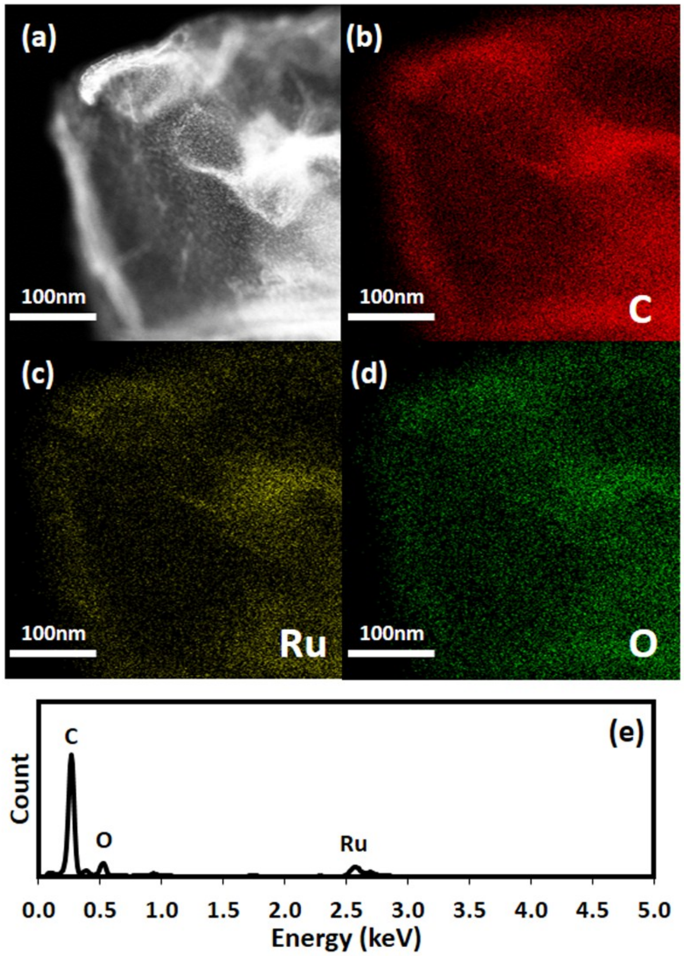

Fig. S4. (a) STEM image, EDS elemental mapping data for (b) C, (c) Ru, (d) O, and (e) EDS spectrum of RuO_2/NGA.

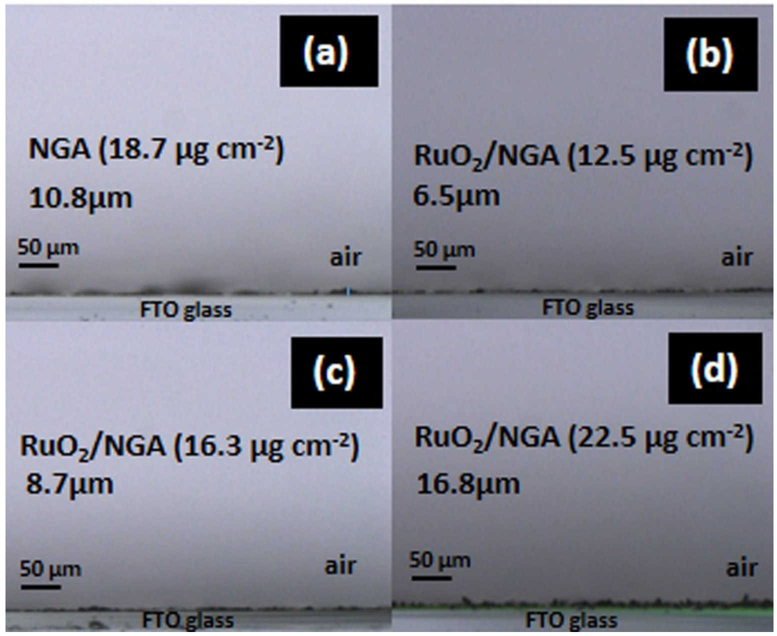

Fig. S5. Cross-section optical micrographs of (a) NGA (18.7 μg cm^{-2}) and RuO_2/NGA with different mass loadings, (b) 12.5, (c) 16.3, and (d) 22.5 μg cm^{-2}

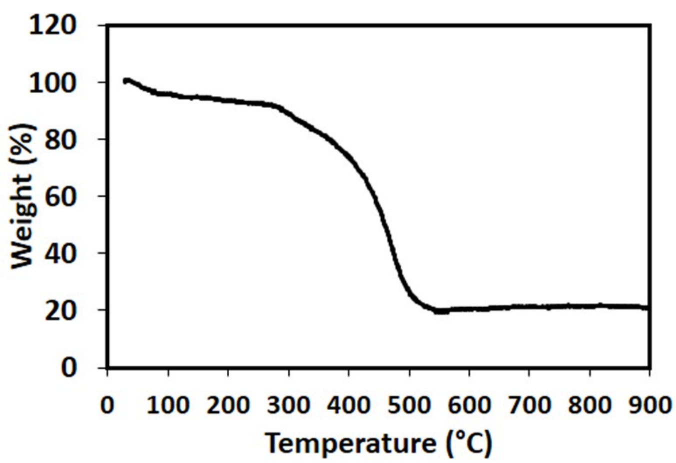

Fig. S6. TGA thermogram of RuO_2/NGA under O_2 atmosphere at a heating rate of 10°C min^{-1}.

Literature reviews on transparent supercapacitors

Electrode	%T of the device	Areal Capacitance of electrode (mF cm^{-2})	Condition	Electrolyte	Reference
Cellulose nanofiber-RGO10	56	0.66	5 mV s^{-1}	H_2SO_4–PVA	5
Cellulose nanofiber-RGO20	30	0.78	5 mV s^{-1}	H_2SO_4–PVA	5
PANI/SWCNT	55	0.55	26 µA cm^{-2}	H_2SO_4	6
Wrinkled graphene	57	0.0058	0.8 µA	H_3PO_4–PVA	7
Aligned CNTs	75	0.0038	100 mV s^{-1}	H_3PO_4–PVA	8
Graphene network	84	0.0042	0.1 µA	H_3PO_4–PVA	9
CVD graphene	-	0.080	630 mA cm^{-2}	H_3PO_4–PVA	10
Reduced multilayer graphene oxide (RMGO)	-	0.394	281 nA cm^{-2}	H_3PO_4–PVA	10
Few-layer graphene film	-	0.060	100 mV s^{-1}	H_3PO_4–PVA	11
RuO_2/PEDOT:PSS	80	0.84	10 mV s^{-1}	H_2SO_4–PVA	12
NGA	53.6	0.77	9.35 µA cm^{-2} (0.5A g^{-1})	H_2SO_4–PVA	This work
RuO_2/NGA	34.1	1.57	8.15 µA cm^{-2} (0.5A g^{-1})	H_2SO_4–PVA	This work

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