Electronic Supplementary Information (ESI) for

Magnetic catalysts as nanoactuator achieve simultaneously momentum-transfer and continuous-flow hydrogen production

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Experimental section

The morphology of the as-prepared product was studied by using transmission electron microscope (TEM, Hitachi H-7560). Fourier transform infrared (FT-IR) spectra measurement was carried out on a NICOLET 380 Fourier transform infrared spectrophotometer. X-ray photoelectron spectrum (XPS) was recorded on a PHI quantera SXM spectrometer with an Al K_{α} = 280.00 eV excitation source, where binding energies were calibrated by referencing the C1s peak (284.8 eV) to reduce the sample charge effect. The N₂ sorption isotherms were measured on NOVA 1000e surface area and poresize analyzer (Quantachrome Instrument, USA) at 77 K. From the adsorption branch of isotherm curves in the P/P₀ range between 0.05 and 0.35, the specific surface areas of the CCGC are calculated by the multi-point Brunauer–Emmett–Teller (BET) method. The pore size distribution was evaluated by the Barrett-Joyner-Halenda (BJH) model. The total pore volume was determined from the amount adsorbed at the relative pressure of about 0.99.

Graphite oxide was prepared from natural graphite according to a modified Hummers method.^[27] First, an aqueous solution (200 mL) of graphite oxide (200 mg) was stirred and ultrasonicated for 2 h to form aqueous suspension of graphene oxide (GO). An aqueous solution (20 mL) of Co nitrate (13.842 g for CRGC-I and 13.703 g for CRGC-II) and ruthenium trichloride (0.0645 g for CRGC-I and 0.1295 g for CRGC-II) an aqueous solution (15 mL) of polyvinyl

pyrrolidone (PVP, MW: 58000, 150 mg) were added to the aqueous suspension of GO under stirring and then the mixture was stirred for further 4 h. Then an aqueous solution (20 mL) of sodium hydroxide (3.844 g) was added into the mixture followed by a further stirring for 0.5 h. An aqueous solution of glucose (4.504 g) was then added and the mixture was stirred for another 0.5 h. The mixture was transferred into a Teflon-lined stainless steel autoclave (500 mL) and heated to 180 °C for 24 h. After cooling to room temperature naturally, the resulting solid was washed with water and dried at 80 °C in air for 12 h. After being heated to 550 °C with a heating rate of 10 °C·min⁻¹ and kept for 1 h under N₂ flow, the solid powder was cooled and added into an ethanol solution (15 mL) (*Caution! The sample is easy to combust when exposed to air.*). After dried in air at room temperature, black powder was obtained and noted as CRGC-I (1 *mol*% of Ru) and CRGC-II (2 *mol*% of Ru).



Scheme S1. The synthesis route and structure of CCGC.



Figure S1. The thermal analysis curves of (a) the CCGC-I, (b) the CCGC-II, (c) the CCGC-III and (d) Co-C in air atmosphere.



Figure S2. TEM images of (a, b) CCGC-I, (c, d) CCGC-II, (e, f) CCGC-III and (g, h) Co-C.



Figure S3. FT-IR spectra of Co-C, CCGC, rGO and GO.

In FT-IR spectrum (Figure S3), the bands at 1726 and 1053 cm⁻¹can be assigned to GO. No stretching vibration of carboxyl groups 1726 cm⁻¹ can be observed for the CCGC and rGO, suggesting the complete reduction of GO to rGO.^[S1] The peak at 1580-1680 cm⁻¹ can be assigned to the stretching vibration of C=C of rGO.^[S2] Another peak at 990-1150 cm⁻¹ can be assigned to the stretching vibration of O-C-O of rGO.^[S2]



Figure S4. (a-c) XPS spectra of the CCGC-I.



Figure S5. (a) N₂-sorption isotherms and (b) pore width distribution of the CCGC-I.



Figure S6. The photograph of the catalytic hydrogen generation in (a) batch and (b) slurry-bed reactor, the magnetic performance of catalysts (c) with magneton or external magnetic field, and (d) the catalyst was separated from reaction mixture by a magnet to stop reaction.



Figure S7. The catalytic performances of the CCGC-I in hydrogen generation at 303 K (a, c) under various stirring rates from 0.1 M of NaBH₄ and (b, d) from various concentration of NaBH₄ under stirring rate of 500 *rpm*. (a, b) Magneton-stirring mode and (c, d) self-stirring mode.



Figure S8. The catalytic performances of (a) the CCGC-II, (b) the CCGC-III, and (c) Co-C in hydrogen generation from $NaBH_4$ at 303 K under stirring rate of 500 r/min.



Figure S9. The XRD patterns of CRGC.



Figure S10. (a) N₂-sorption isotherms and (b) pore width distribution of of the CRGC (1%).



Figure S11. (a) N₂-sorption isotherms and (b) pore width distribution of the CRGC (2%).

Table S1. The hydrogenation generation rates and activation energies with various catalysts from literatures.

Catalyst	Catalyst	Hydride	Maximun H ₂	Activation	Reference
	Weight		Generation	Energy	
	(mg)		specific rate	$(kJ \cdot mol^{-1})$	
			$(mL \cdot min^{-1} \cdot g^{-1})$		
Pt/C	100	NaBH ₄	23,000 (298 K)	_	S3
Pt/CoO	3.8	NaBH ₄	350 (293 K)	_	S4
Pt/LiCoO ₂	20	NaBH ₄	3680 (303 K)	70.4	S5
Co@Pt core-shell	7	NH ₃ BH ₃	5869 (303 K)	_	S6
Raney Co	500	NaBH ₄	267.5 (293 K)	53.7	S 7
Raney Ni ₅₀ Co ₅₀	500	NaBH ₄	648.2 (293 K)	52.5	S 7
Cu/Co ₃ O ₄	12	NH ₃ BH ₃	1411 (298 K)	-	S 8
Со-Р-В	15	$NaBH_4$	2120 (298 K)	32	S9
Octahedral CoO	20	$NaBH_4$	8333 (303 K)	_	S10
CoO	10	$NaBH_4$	6130 (303 K)	45.94	S11
CCS/Co	20	$NaBH_4$	10400 (293 K)	21.51	S12
Co/IR-120	200	NaBH ₄	200 (298 K)	66.67	S13
Ni–Fe–B	200	NaBH ₄	2910 (298 K)	57.0	S14
Со-Мо-В	10	NaBH ₄	4200 (303 K)	43.7	S15
Co-Ni-P/Pd-TiO ₂	25	NaBH ₄	460 (298 K)	57.0	S16
Со-W-Р	-	NaBH ₄	5000 (303 K)	22.8	S17
Со-В	250	NaBH ₄	_	44.1	S18

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