

Electronic Supplementary Information for :

RuTe/M (M=Pt, Pd) nanoparticle nanotubes with enhanced electrocatalytic activity

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1. Experimental Section

Synthesis of RuTe/Pd nanotubes. 2 mL of the above prepared RuTe nanotubes and 30 mg of PVP were mixed into 10 mL of water and stirred for 10 min. Then, 0.2 mL of H₂PdCl₄ (56.4 mmol L⁻¹) was added to the mixture. Sequentially, 1 mL of AA (0.1 mol L⁻¹) were added into the above reaction and react for 30 min. After that, the product was collected by centrifugation and washed several times with water for further characterization and electrochemical measurements.

Synthesis of RuTe/PdPt nanotubes. 2 mL of the above prepared RuTe nanotubes and 30 mg PVP were mixed into 15 mL of ethylene glycol and stirred for 10 min. Then, 0.1 mL of H₂PdCl₄ (56.4 mmol L⁻¹) and 0.3 mL of H₂PtCl₆ (19.3 mmol L⁻¹) was added to the mixture. Sequentially, 1 mL of AA (0.1 mol L⁻¹) were added into the above mixture and react for 20 min in a water bath which maintained at 60 °C. After that, the product was collected by centrifugation, and washed several times with water for further characterization and electrochemical measurements.

Synthesis of RuTe/PdAu nanotubes. 2 mL of the above prepared RuTe nanotubes and 30 mg of PVP were mixed into 15 mL of ethylene glycol and stirred for 10 min. Then, a mixture containing 0.1 mL of H_2PdCl_4 (56.4 mmol L^{-1}) and 0.056 mL of HAuCl_4 (0.1 mol L^{-1}) was added to the mixture. Sequentially, 1 mL of AA (0.1 mol L^{-1}) were added into the above solution and react for 1 hours. After that, the product was collected by centrifugation and washed several times with water for further characterization and electrochemical measurements.

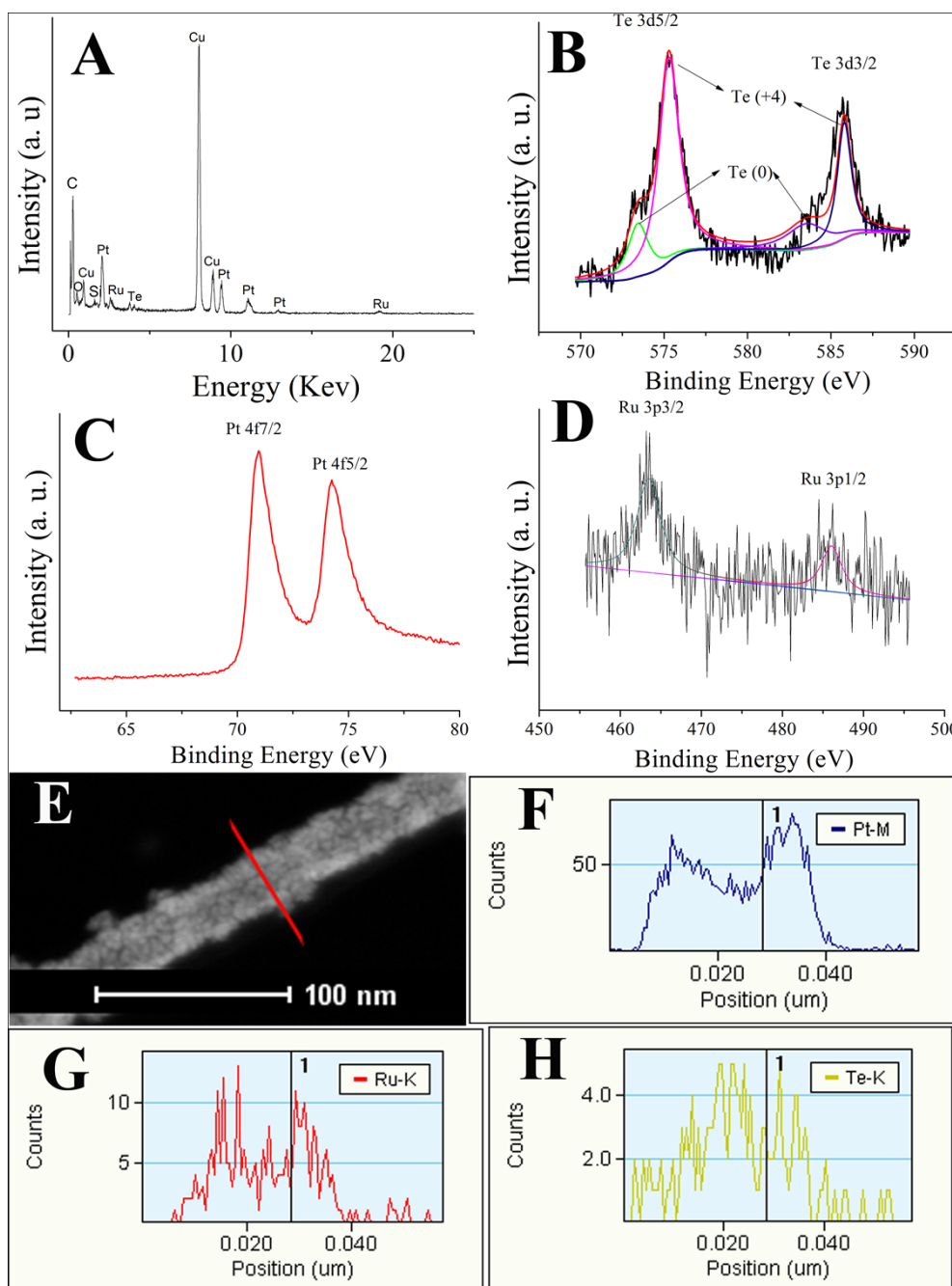


Fig. S1 (A) EDS of the as-prepared RuTe nanotubes. The peaks of Cu were originated from the carbon coated copper grid. XPS spectra of as-prepared RuTe/Pt nanotubes: Te 3d (B), Pt 4f (C) and Ru 3p (D). (E) HAADF-STEM images of RuTe/Pt nanotubes. The cross-sectional compositional line profiles of individual RuTe/Pt nanotubes: Pt-M (F), Ru-K (G) and Te-K (H).

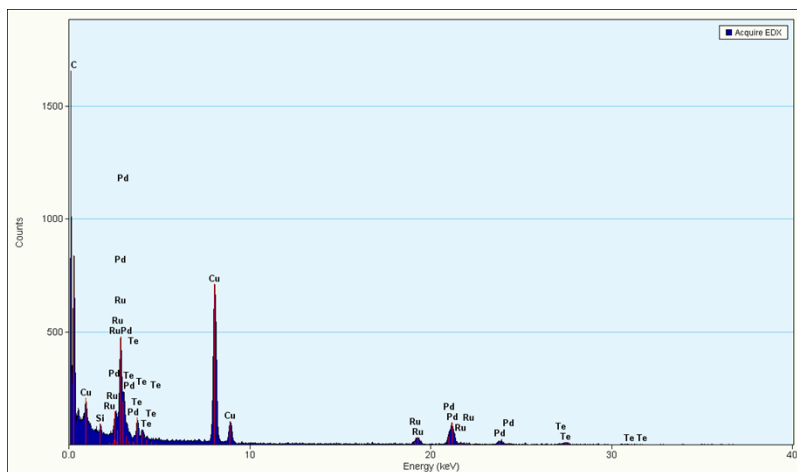


Fig. S2 (A) EDS of the as-prepared RuTe/Pd nanotubes. The peaks of Cu were originated from the carbon coated copper grid

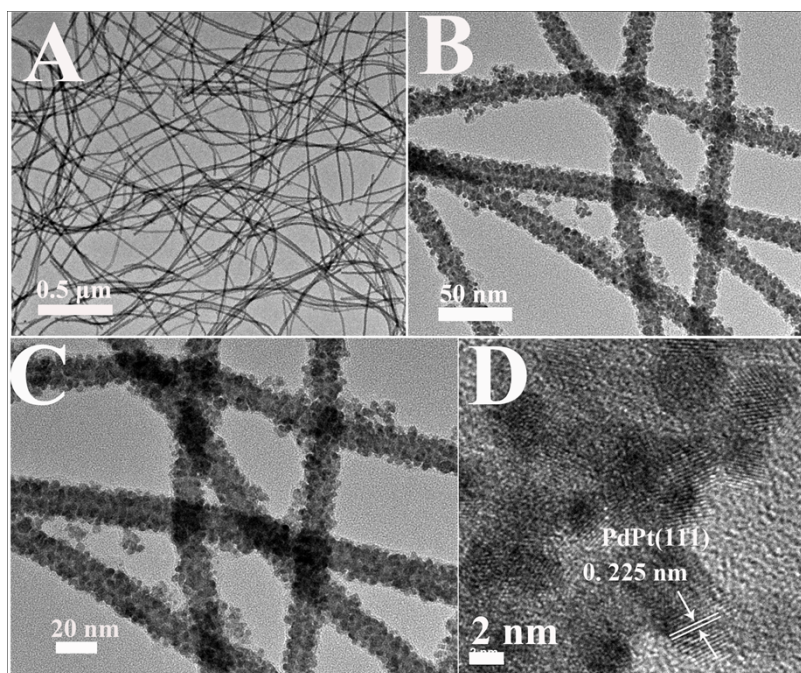


Fig. S3. (A, B, C) Typical TEM images, of the prepared RuTe/PdPt nanotubes with different magnifications. (D) High-resolution TEM images of the as-prepared RuTe/PdPt nanotubes.

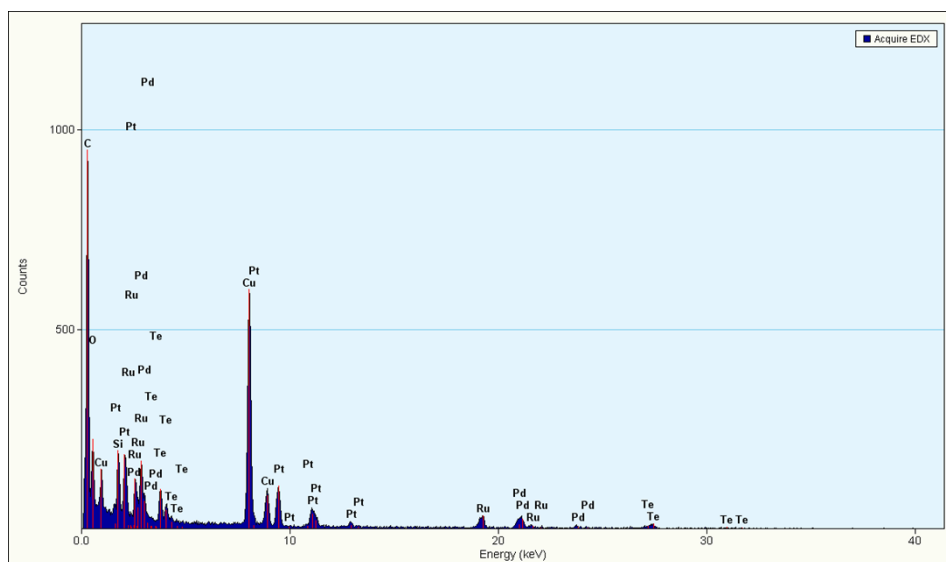


Fig. S4 EDS of the as-prepared RuTe/PdPt nanotubes. The peaks of Cu were originated from the carbon coated copper grid.

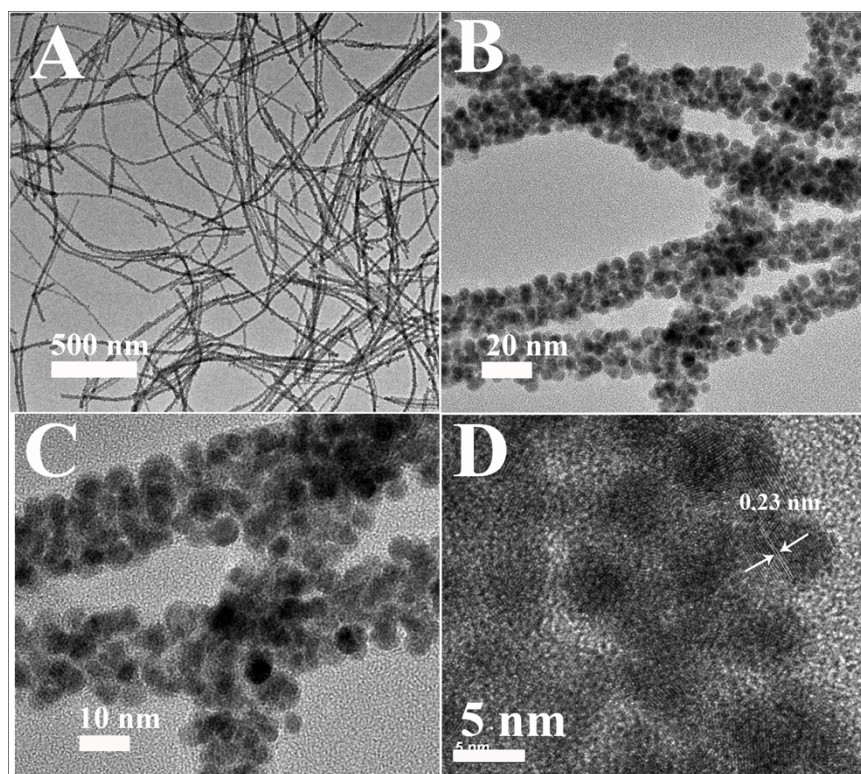


Fig. S5. (A, B, C) Typical TEM images of the as-prepared RuTe/PdPAu nanotubes with different magnifications. (D) High-resolution TEM images of the as-prepared RuTe/PdAu nanotubes.

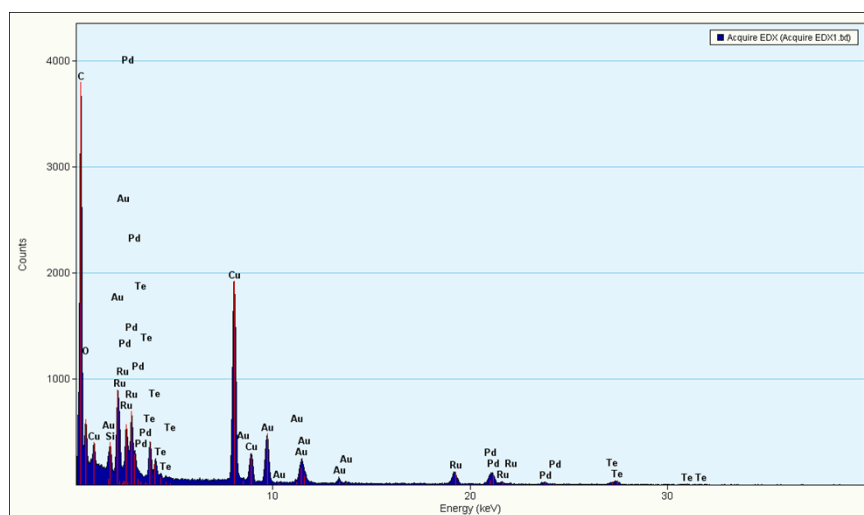


Fig. S6 EDS of the as-prepared RuTe/PdAu nanotubes. The peaks of Cu were originated from the carbon coated copper grid.

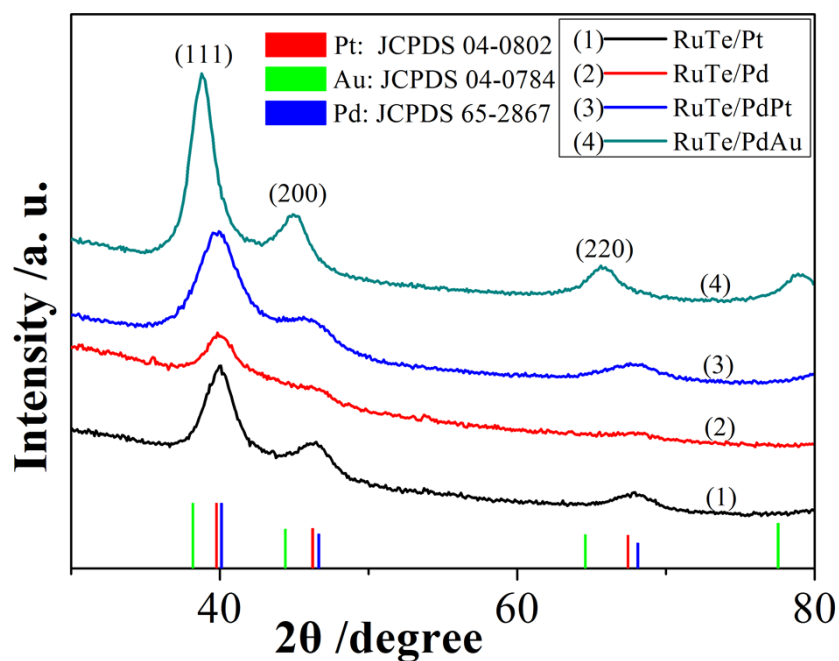


Fig. S7 XRD patterns of the as-synthesized nanotubes (1) RuTe/Pt, (2) RuTe/Pd, (3) RuTe/PdPt and (4) RuTe/PdAu. The intensity and position for Pt, Pd and Au references were taken from the JCPDS database.

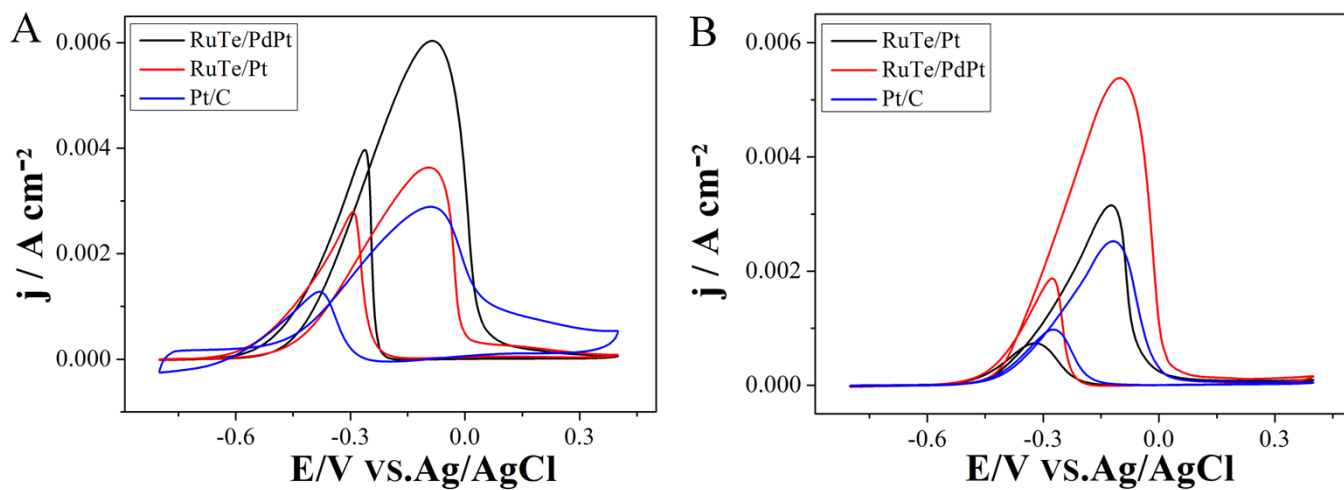


Fig. S8 Specific catalytic activity of RuTe/PdPt, RuTe/Pt NTs and Pt/C for (A) ethanol and (B) methanol electrooxidation, respectively. The current densities have been normalized by the ECSA.

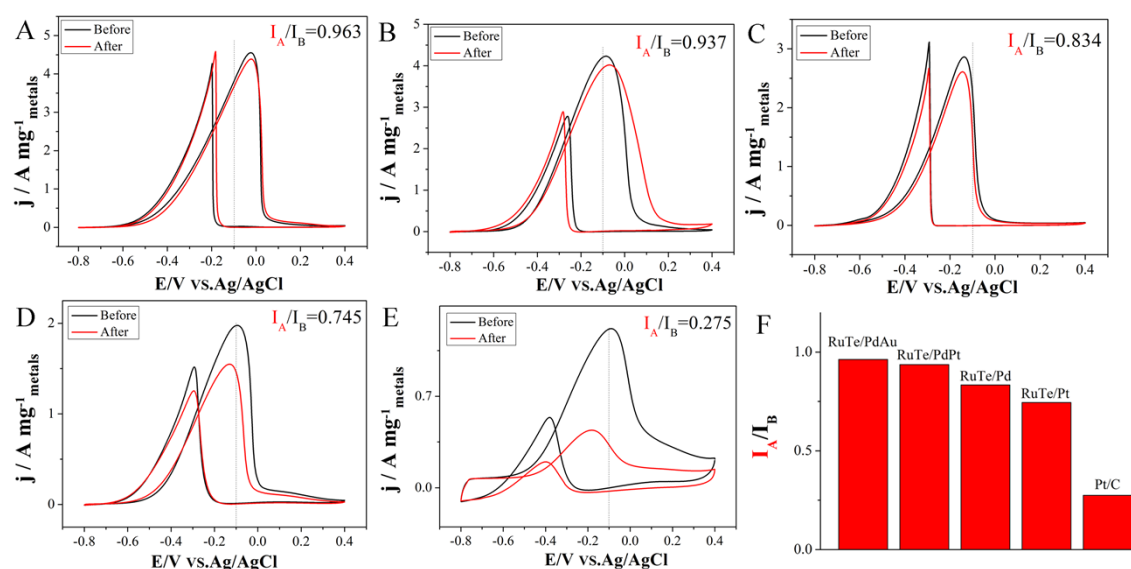


Fig. S9 Ethanol electrooxidation CV curves of before (black) and after i-t tsets (red) on various materials modified electrodes, (A) RuTe/PdAu NTs; (B) RuTe/PdPt NTs; (C) RuTe/Pd NTs; (D) RuTe/Pt NTs; (E) Pt/C. I_A is the current value recorded at -0.1 V after the i-t tests, I_B is the current value recorded at -0.1 V before the i-t tests. (F) The comparison of I_A/I_B value of various materials for ethanol electrooxidation.

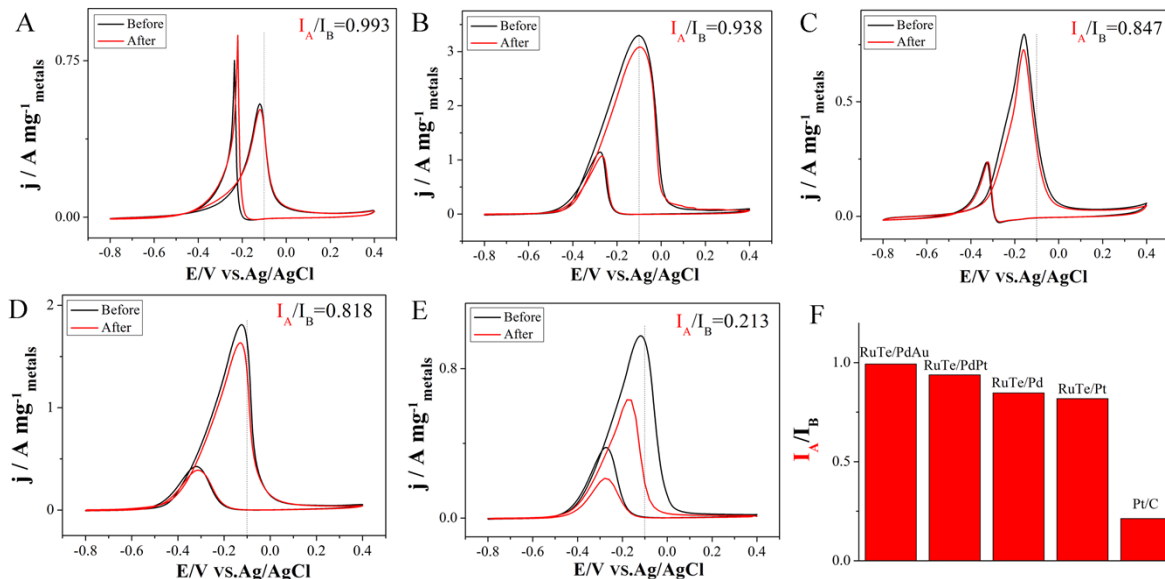


Fig. S10 Methanol electrooxidation CV curves of before (black) and after i-t tsets (red) on various materials modified electrodes, (A) RuTe/PdAu NTs; (B) RuTe/PdPt NTs; (C) RuTe/Pd NTs; (D) RuTe/Pt NTs; (E) Pt/C. I_A is the current value recorded at -0.1 V after the i-t tests, I_B is the current value recorded at -0.1 V before the i-t tests. (F) The comparison of I_A/I_B value of various materials for methanol electrooxidation.

Table S1

RuTe/Pt	RuTe/Pd	RuTe/PdPt	RuTe/PdAu
Ru ₈ Te ₁₁ /Pt ₈₂	Ru ₁₀ Te ₁₉ /Pd ₇₄	Ru ₁₀ Te ₁₉ /Pd ₂₃ Pt ₂₄	Ru ₉ Te ₁₇ /Pd ₃₃ Au ₃₇

Table S2. Cyclic voltammetric characteristics of ethanol electrooxidation in basic solution modified with various nanomaterials. The scan rate was 50 mV s⁻¹.

Electrode	Test Conditions	E _f (mV vs Ag/AgCl)	E _b (mV vs Ag/AgCl)	I _f (A mg ⁻¹ of metals)	I _b (A mg ⁻¹ of metals)
RuTe/PdAu NTs [this work]	0.5 M NaOH+1 M CH ₃ CH ₂ OH	-30	-210	4.6	4.3
RuTe/PdPt NTs [this work]	0.5 M NaOH+1 M CH ₃ CH ₂ OH	-90	-270	4.2	2.8
RuTe/Pd NTs [this work]	0.5 M NaOH+1 M CH ₃ CH ₂ OH	-140	-300	2.9	3.1
RuTe/Pt NTs [this work]	0.5 M NaOH+1 M CH ₃ CH ₂ OH	-91	-300	2.0	1.5
Pd ₄₅ Pt ₅₅ NWs ^[1]	0.5 M NaOH+1 M CH ₃ CH ₂ OH	~-50	~-210	0.9	1
Pt NTs ^[1]	0.5 M NaOH+1 M CH ₃ CH ₂ OH	~0	~-250	0.5	0.5
Pd ₆₇ Pt ₃₃ nanosponges ^[2]	0.5 M NaOH+1 M CH ₃ CH ₂ OH	~-100	~-200	1.6	1.8
Pd nanomembranes ^[2]	0.5 M NaOH+1 M CH ₃ CH ₂ OH	~-140	~-290	~0.58	0.9
Pt/Pd NTs ^[4]	0.5 M NaOH+1 M CH ₃ CH ₂ OH	0	~-230	1	0.75
Pd/rGO/CFP ^[5]	0.5 M NaOH+1 M CH ₃ CH ₂ OH	~-100	~-500	0.8	0.18
PdAu (Pd 65%) BHT ^[6]	1 M KOH+1 M CH ₃ CH ₂ OH	~-50	~-150	1.2	1.1
Pd/PANI/Pd ^[7]	1 M KOH+1 M CH ₃ CH ₂ OH	~-200	~-380	0.35	0.4
Pd _{0.5} Cu _{0.5} ^[8]	1 M KOH+1 M CH ₃ CH ₂ OH	~-200	~-400	1.6	-
PdCu/3DGS ^[9]	1 M KOH+1 M CH ₃ CH ₂ OH	~-100	~-400	1.2	0.6
Pt/PdCu/3DGF ^[10]	1 M KOH+1 M CH ₃ CH ₂ OH	~-50	~-250	3.0	2.4

Notes: NTs= nanotubes; NWs= nanowires; BHT= bimetallic nanoparticles heterostructure tubes; PANI= polyaniline; rGO= reduced graphene oxide; CFP= flexible carbon fiber paper; 3DGS=3D graphene sheets; 3DGF=3D graphene framework.

Table S3

(A) Cyclic voltammetric characteristics of Pt-based materials toward methanol electrooxidation in basic solution modified with various nanomaterials. The scan rate was 50 mV s⁻¹.

Electrode	Test Conditions	E _f (mV vs Ag/AgCl)	E _b (mV vs Ag/AgCl)	I _f (A mg ⁻¹ of metals)	I _b (A mg ⁻¹ of metals)
RuTe/PdPt NTs [this work]	1 M KOH+1 M CH ₃ OH	-100	-280	3.3	1.2
RuTe/Pt NTs [this work]	1 M KOH+1 M CH ₃ OH	-130	-320	1.8	0.45
Pd ₄₅ Pt ₅₅ NWS [1]	1 M KOH+1 M CH ₃ OH	~0	~-300	2	0.6
Pt/1-AP-rGO [11]	1 M KOH+1 M CH ₃ OH	~-200	~-300	0.8	0.25
Pt/rGO [11]	1 M KOH+1 M CH ₃ OH	~-200	~-300	0.4	0.15
N-Pt/RGO/CF [12]	1 M KOH+1 M CH ₃ OH	~-150	~-400	1.1	0.18
Pd ₅₀ Pt ₅₀ nanosponges [2]	1 M KOH+1 M CH ₃ OH	~-100	~-300	2.2	0.8

(B) Cyclic voltammetric characteristics of noble-Pt-based materials toward methanol electrooxidation in basic solution modified with various nanomaterials. The scan rate was 50 mV s⁻¹.

Electrode	Test Conditions	E _f (mV vs Ag/AgCl)	E _b (mV vs Ag/AgCl)	I _f (A mg ⁻¹ of metals)	I _b (A mg ⁻¹ of metals)
RuTe/PdAu NTs [this work]	1 M KOH+1 M CH ₃ OH	-120	-240	0.54	0.75
RuTe/Pd NTs [this work]	1 M KOH+1 M CH ₃ OH	-160	-330	0.8	0.25
Supported Pd ₃₀ Au ₇₀ nanoparticles [13]	1 M KOH+1 M CH ₃ OH	~0	~-150	~0.17	~0.24
G-AuPd@Pd [14]	1 M KOH+1 M CH ₃ OH	~200	~-350	0.65 (interms of Pd)	-
G-Pd [14]	1 M KOH+1 M CH ₃ OH	-150	-300	0.22	-

Notes: NTs=nanotubes; NWS=nanowires; Pt/1-AP-rGO=Pt nanoparticle-loaded 1-aminopyrene functionalized reduced graphene oxide composites; Pt/rGO=Pt nanoparticle-loaded reduced graphene oxide composites; N-Pt/RGO/CF=three-dimensional multilayered Pt/reduced graphene oxide modified carbon fiber electrode; G=graphene.

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