[Supporting Information]

Multi-Metallic Alloy Nanotubes with Nanoporous Framework

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Table S1. The ICP-AES-determined compositions of multi-metallic NTs prepared by controlling the relative amounts of metal precursors in growth solution.

Type of multi-metallic NTs	Molar ratio of metal precursors in growth solution	Composition of multi-metallic NTs
Pt-Pd	Pt : Pd = 2 : 1 Pt : Pd = 1 : 1 Pt : Pd = 1 : 2	Pt : Pd = 47 : 53 Pt : Pd = 31 : 69 Pt : Pd = 12 : 88
Pt-Ag	Pt : Ag = 4 : 1 Pt : Ag = 2 : 1	Pt : Ag = 84 : 16 Pt : Ag = 74 : 26
Pd-Ag	Pd : Ag = 4 : 1 Pd : Ag = 2 : 1	Pd : Ag = 96 : 4 Pd : Ag = 57 : 43
Pt-Pd-Ag	Pt : Pd : Ag = 3 : 2 : 1 Pt : Pd : Ag = 3 : 1 : 2 Pt : Pd : Ag = 2 : 3 : 1 Pt : Pd : Ag = 2 : 1 : 3 Pt : Pd : Ag = 1 : 1 : 1 Pt : Pd : Ag = 1 : 3 : 2 Pt : Pd : Ag = 1 : 2 : 3	Pt : Pd : Ag = 34 : 62 : 4 Pt : Pd : Ag = 54 : 28 : 18 Pt : Pd : Ag = 17 : 76 : 7 Pt : Pd : Ag = 56 : 26 : 18 Pt : Pd : Ag = 53 : 27 : 20 Pt : Pd : Ag = 6 : 93 : 1 Pt : Pd : Ag = 30 : 59 : 11

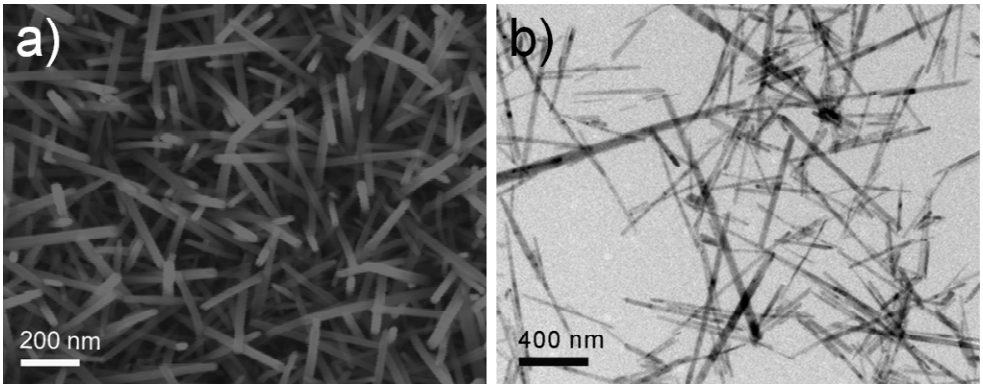

Figure S1. (a) SEM and (b) TEM images of the pristine ZnO NWs grown on Si wafer by hydrothermal synthesis method.

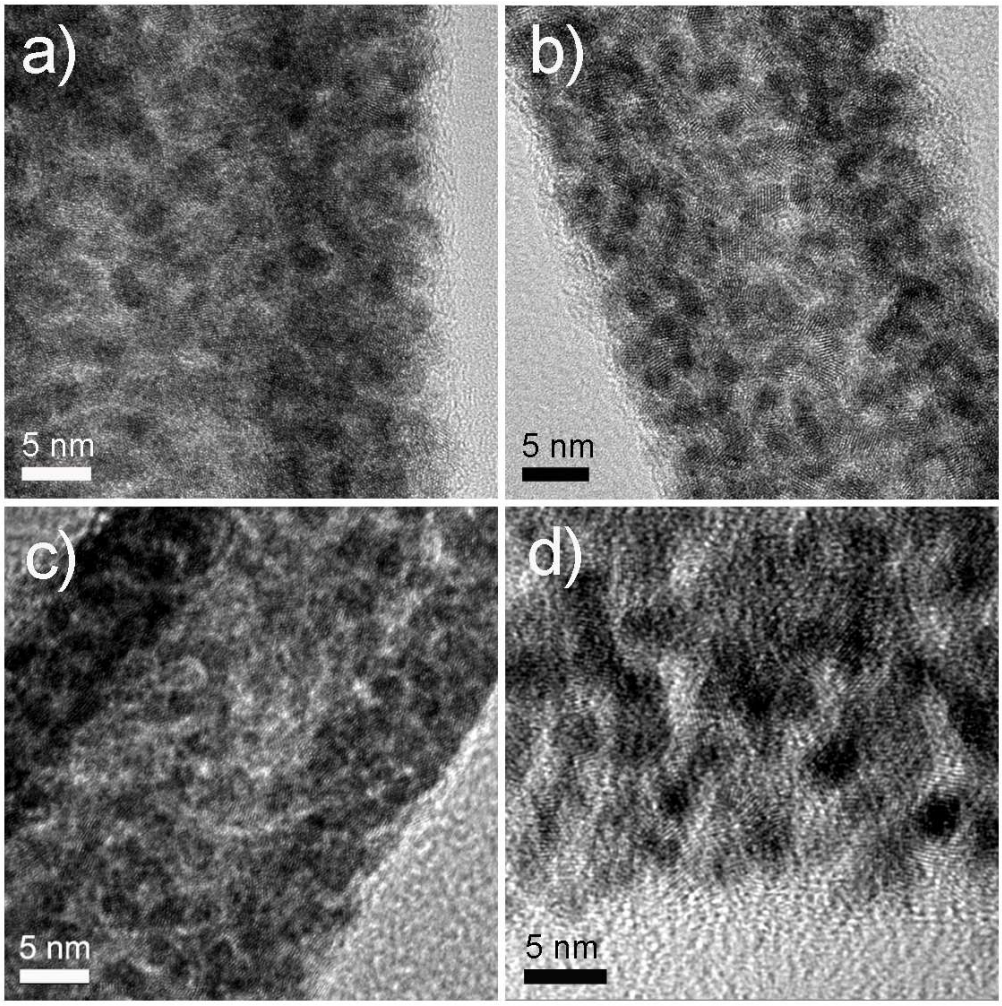

Figure S2. High-magnification TEM images of (a) Pt-Pd, (b) Pt-Ag, (c) Pd-Ag, and (d) Pt-Pd-Ag NTs, demonstrating that the three-dimensionally interconnected 2-3 nm sized nanoparticles result in the formation of porous walls of NTs.

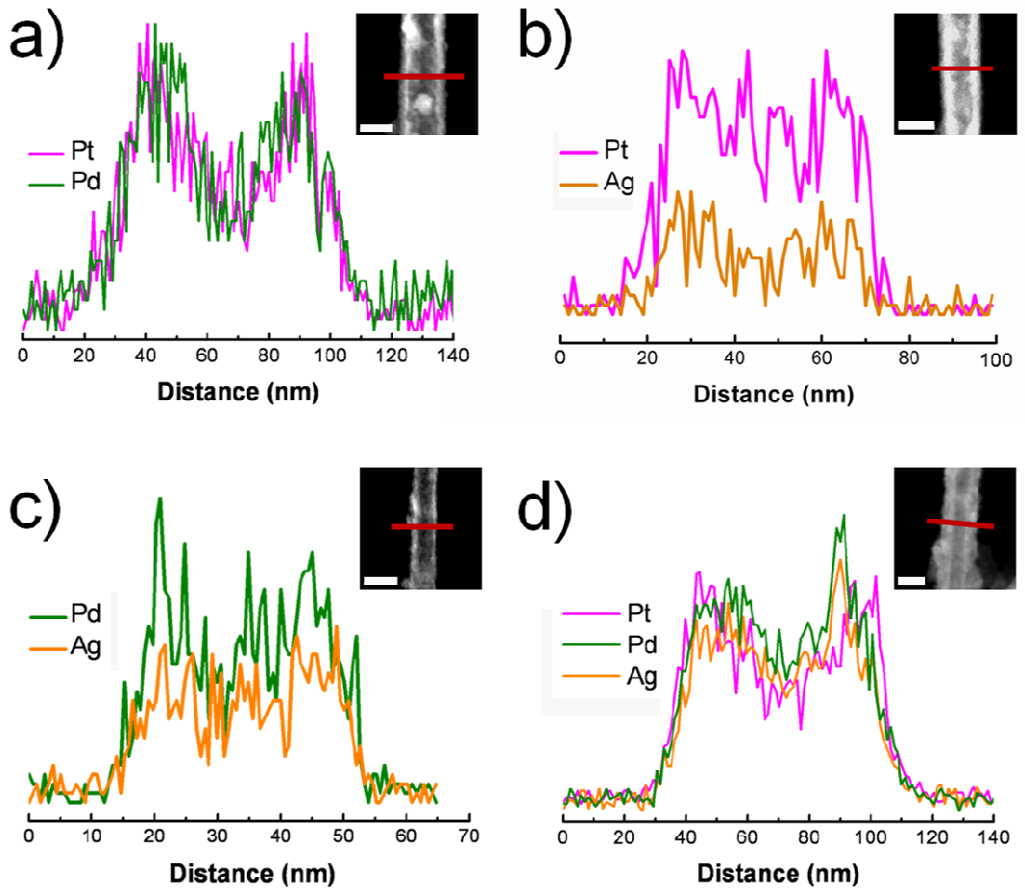

Figure S3. HAADF-STEM images and cross-sectional compositional line profiles of (a) Pt-Pd, (b) Pt-Ag, (c) Pd-Ag, and (d) Pt-Pd-Ag NTs. The scale bars indicate 50 nm.

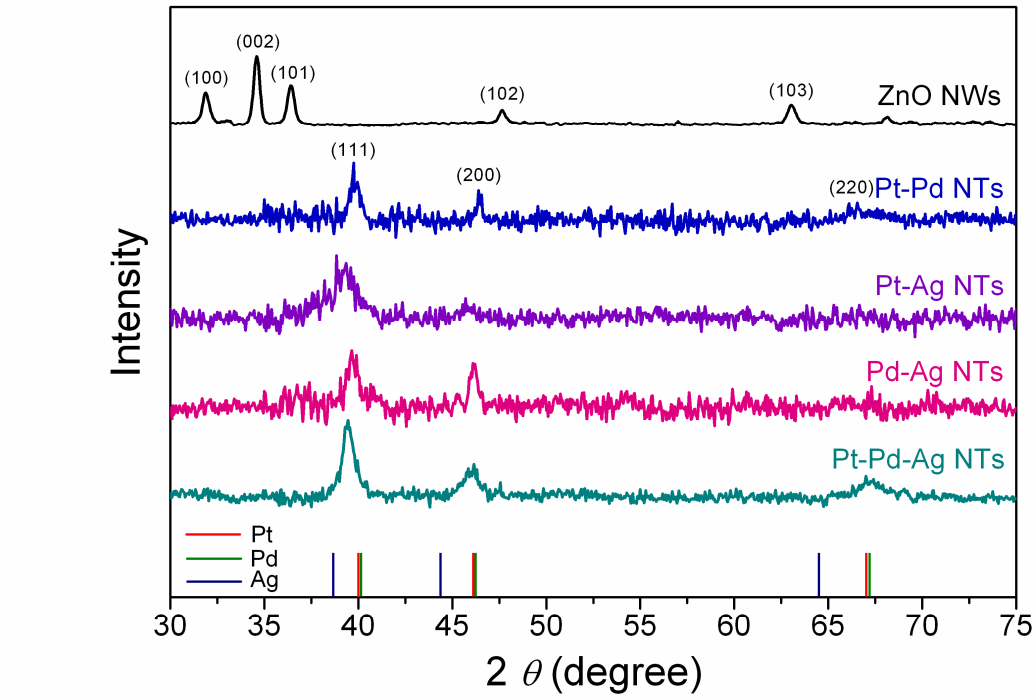

Figure S4. XRD patterns of the pristine ZnO NWs, Pt-Pd, Pt-Ag, Pd-Ag, and Pt-Pd-Ag NTs. The positions and intensities for pure Pt, Pd, and Ag references were taken from the JCPDS database (Pt: 04-0802, Pd: 65-6174, Ag: 04-0783). Observed three peaks for each NT can be indexed to the (111), (200), and (220) reflections of face-centered cubic (*fcc*) structure of metal, showing the pure crystalline nature of the prepared NTs.

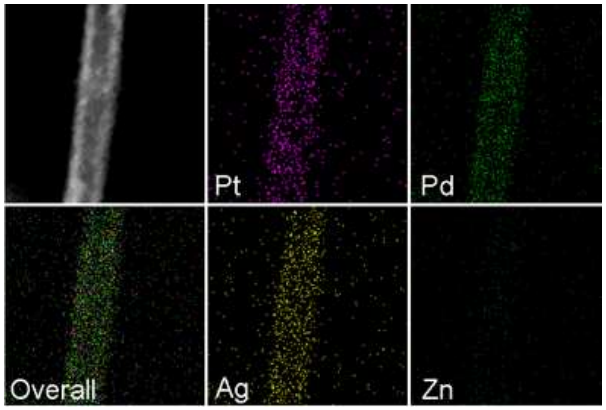

Figure S5. HAADF-STEM-EDS mapping images of the Pt-Pd-Ag NTs obtained after 1 h of reaction time.

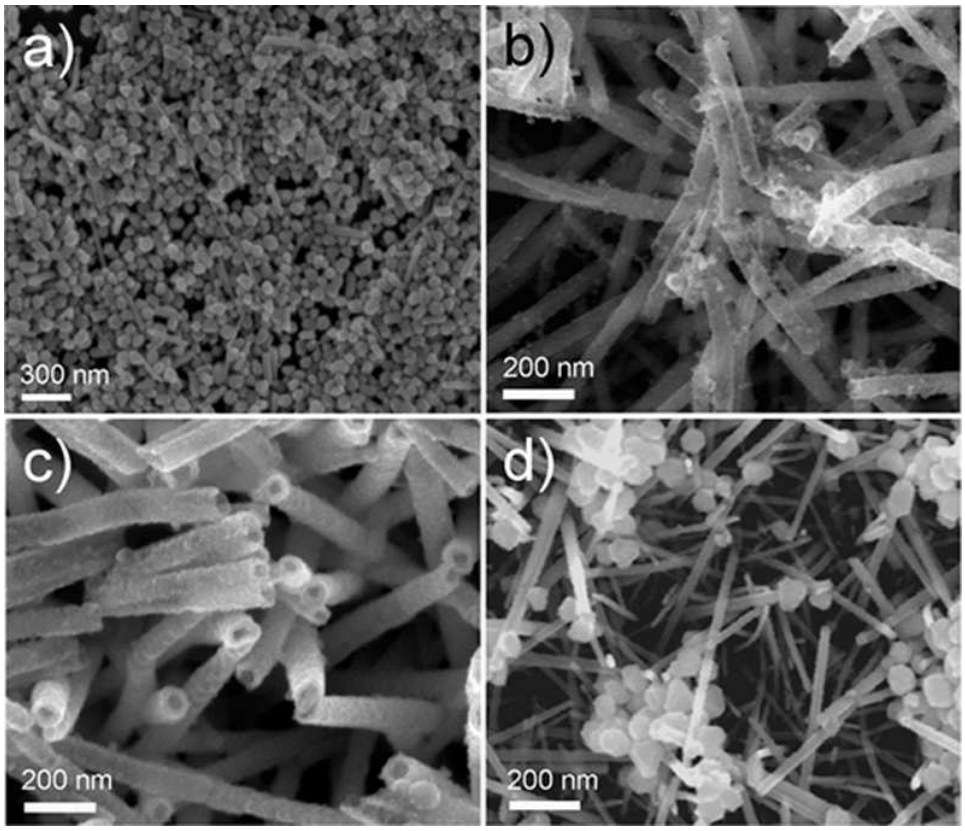

Figure S6. (a) SEM image Ag nanostructures prepared by the reduction of Ag^{+} with citrate in the absence of ZnO NWs. SEM images of nanostructures prepared by the reduction of (b) $PtCl_4^{2-}$, (c) $PdCl_4^{2-}$, and (d) Ag^{+} with citrate in the presence of ZnO NWs.

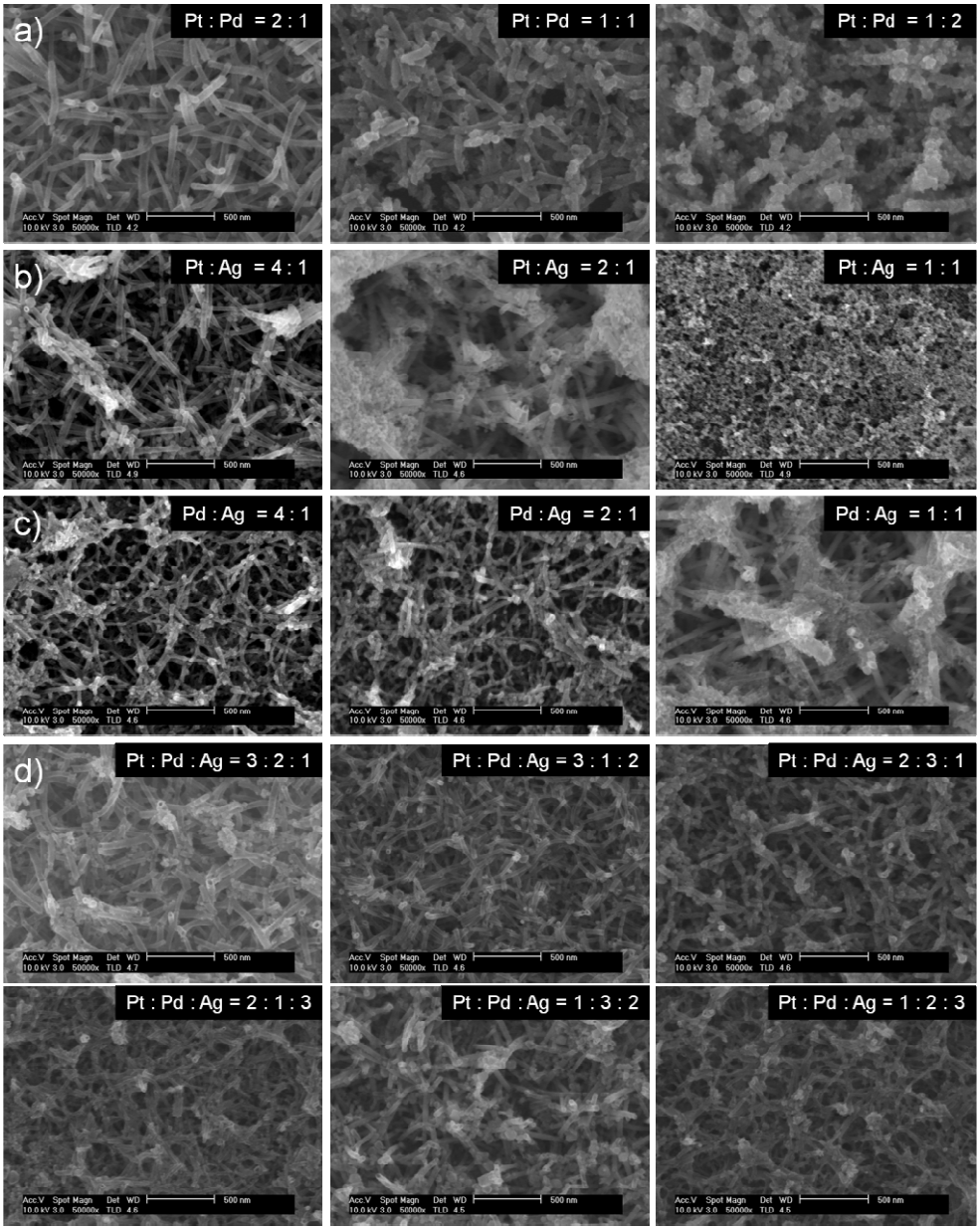

Figure S7. SEM images of (a) Pt-Pd, (b) Pt-Ag, (c) Pd-Ag, and (d) Pt-Pd-Ag nanostructures prepared by controlling the relative amounts of metal precursors in growth solution.

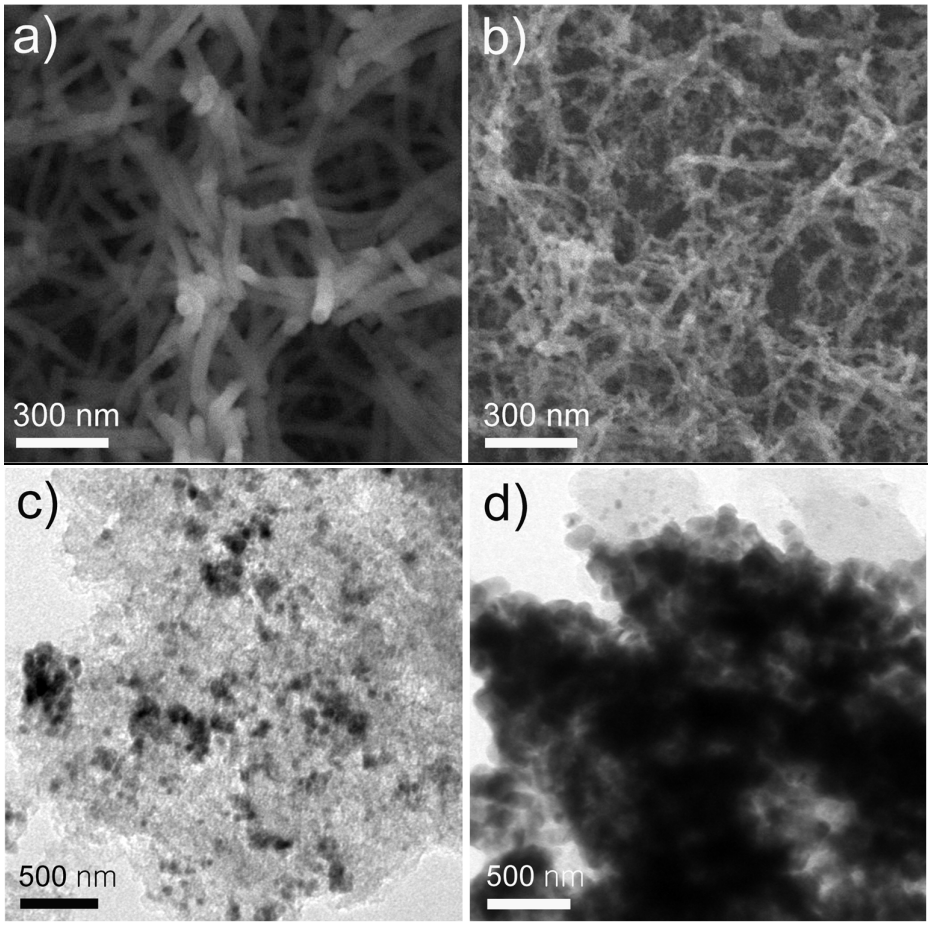

Figure S8. SEM images of the Pt-Pd NTs on ITO (a) before and (b) after the durability test. TEM images of the Pd/C (c) before and (d) after the durability test.

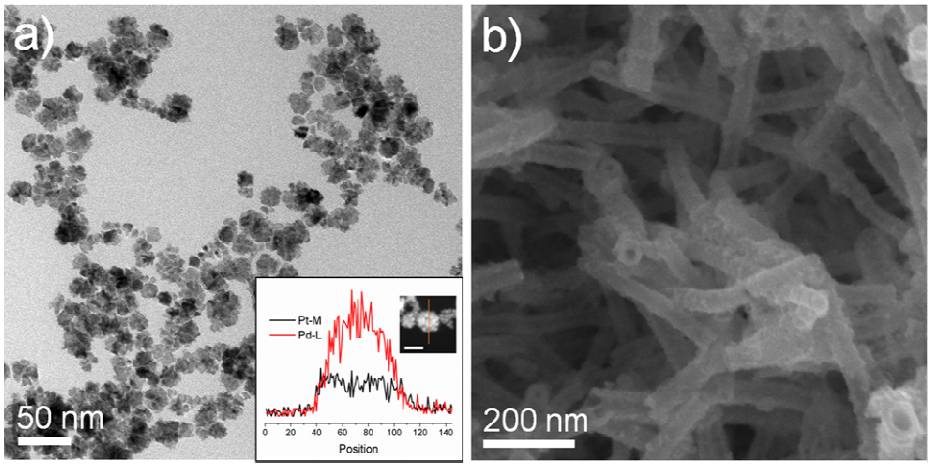

Figure S9. (a) TEM image of the dendritic Pt-Pd NPs. HAADF-STEM image and cross-sectional compositional line profiles of Pt-Pd NPs shown in inset clearly demonstrate that the prepared NPs are Pt-Pd alloys. The scale bar in the inset indicates 30 nm. (b) SEM image of the Pd NTs on ITO.

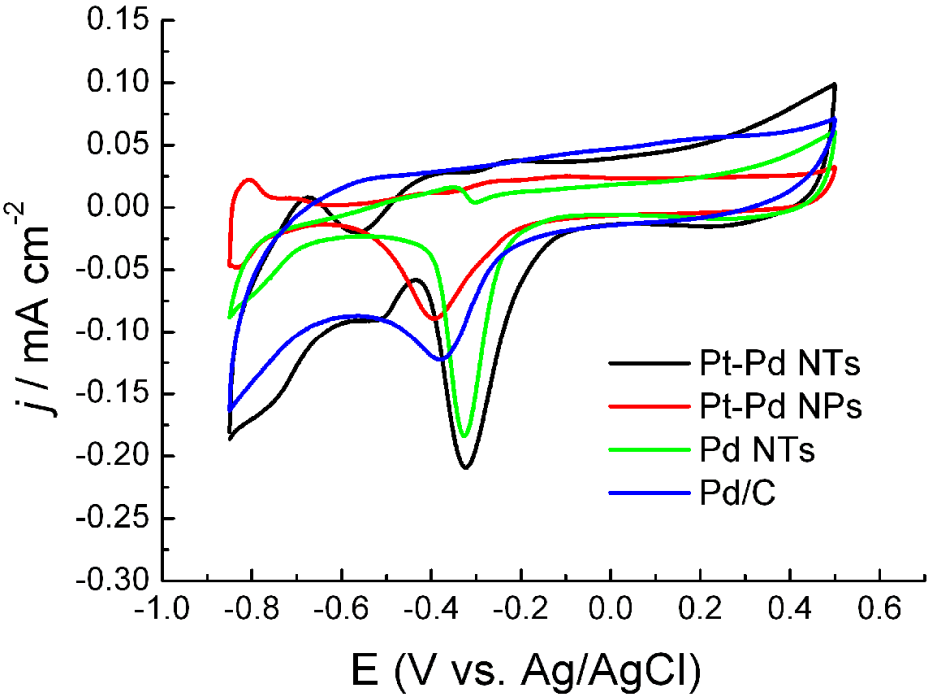

Figure S10. CVs in 0.1 M KOH for the Pt-Pd NTs, Pt-Pd NPs, Pd NTs, and Pd/C on ITO electrodes. Scan rate: 50 mV s^{-1}. The current values were normalized with respect to the electrochemically active surface areas (ECSA), which were calculated by measuring the coulombic charges for oxygen desorption to avoid the interference of hydrogen absorption in Pd. The ECSA was estimated by the following equation; ECSA = Q_o/q_o, where Q_o is the surface charge that can be obtained from the area under the CV trace of oxygen desorption and q_o is the charge required for desorption of monolayer of oxygen (422.46, 422.16, and 424 $\mu C/cm^2$ for the Pt-Pd NTs, Pt-Pd NPs, and Pd nanostructures, respectively. Ref.: R. Woods, in *Electroanalytical Chemistry: A Series of Advances*, Vol. 9 (Ed. A. J. Bard), Marcel Dekker, New York, **1974**, pp 1-162.).

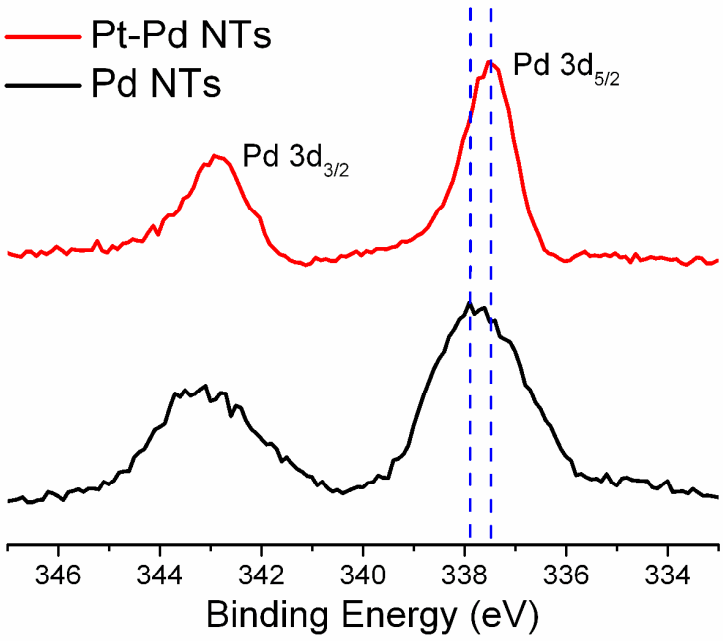

Figure S11. XPS spectra for the Pd 3d core levels of the Pt-Pd and Pd NTs.

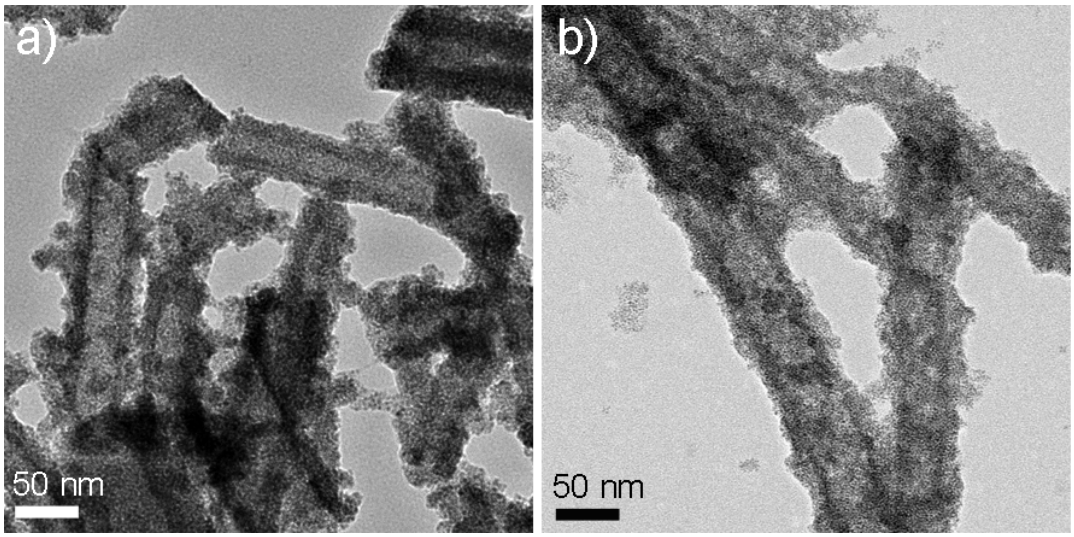

Figure S12. TEM images of the Pt-Pd NTs (a) before and (b) after the 30 sec of CA measurement.